PUNCTURE RESISTANCE OF GEOTEXTILES AND EVALUATION OF THE G-RATING CLASSIFICATION SYSTEM

by

Paul Angelo Maisano B. Eng. (Civil) (Hons)

A thesis submitted to the Department of Civil and Building Engineering, Victoria University of Technology, for the degree of Master of Engineering.

Department of Civil and Building Engineering
Victoria University of Technology
Victoria, Australia

March 1995

TO MY WIFE:

Cathy

DECLARATION

This thesis contains no material which has previously been submitted for an award or degree at any University. To my knowledge the work reported in this thesis is original and contains no material published by other investigations, except where appropriate reference has been given to the source of the material.

[redacted]

P. A. Maisano

SYNOPSIS

The puncture resistance of geotextiles in Australia is measured in terms of the G-Rating, which is the product of CBR and drop cone puncture test results.

CBR and drop cone puncture tests were conducted on 24 geotextiles to provide up-to-date results, and to evaluate the G-Rating. CBR puncture tests using modified plungers were also conducted to assess the accuracy of shape factors quoted in the literature- 3.0 for angular aggregate and 0.8 for rounded aggregate. Wide strip tensile tests were also conducted to compare with CBR puncture test results.

The results of the testing program show no relationship between wide strip tensile test results and CBR puncture test results. The modified plunger CBR puncture test results show that shape factors are not only shape dependent, but are fabric dependent as well, with the results somewhat different from those commonly quoted. The exponent used to calculate the G-Rating varies for the same fabric tested at different drop heights in the drop cone puncture test. Also, the restriction of elongation in CBR puncture tests to 80 per cent by the G-Rating classification system, was found unnecessary for all the geotextiles tested, as elongation at failure in all cases did not exceed 80 per cent.

A Rupture Index classification is proposed, being the product of failure load and vertical plunger displacement at failure in a CBR puncture test. It is considered to be simpler than the G-Rating as it relies on the results of only one test. The Rupture Index calculated for a given fabric will not vary by more than the inherent variability of the specimens tested. However, G-Rating values were shown to vary considerably for the same fabric tested at different drop heights in the drop cone puncture test.

ACKNOWLEDGMENTS

The author is grateful to many people and organisations for their assistance during the term of the project. Many thanks are extended especially to the following:

Mr D. O. Jordan, Senior Lecturer, Department of Civil and Building Engineering, for his invaluable advice, guidance and patience as my principal supervisor. His assistance and friendship throughout this period is greatly appreciated.

Mr R. G. Brown, Senior Geotechnical Engineer, VicRoads, for his helpful advice and input, particularly his help in conceptualising much of the project in the initial stages.

Technical staff of the Department of Civil and Building Engineering (Mr J. Sibly, Mr N. Welgus and Mr L. Martin) for the fabrication of various pieces of testing equipment used in the testing program.

Victoria University of Technology for the provision of a VUT - Postgraduate Research Award.

Geofabrics Australasia Pty Ltd for their provision of geotextile samples. In particular, Mr R. McKenna for his invaluable advice, discussion and critique of various aspects of the project, and Mr T. Loffel for many discussions and for use of the Geofabrics Australasia library.

Soil Filters Australia for their provision of geotextile samples. In particular Mr J. Day for many worthwhile discussions and advice on many aspects of the project.

Polyfelt Geosynthetics Pty Ltd for their provision of geotextile samples. In particular Mr M. Sadlier (formerly of Polyfelt Geosynthetics) for several discussions about the project.

Rheem Australia Ltd for their provision of geotextile samples. In particular Ms L. Fern for several discussions about the project.

Nylex Corporation Ltd for their provision of geotextile samples. In particular Mr G. Burdeu for several discussions about the project.

Sarlon Industries Pty Ltd for their provision of geotextile samples, in particular Mr M. Kandilas.

Geosynthetic Testing Services for permission to use their testing laboratory for the entire testing program. In particular Mr R. Kang for his advice and Ms B. Grant for many hours of assistance and patience throughout the testing period. Special thanks are extended to all the staff of Geofabrics Australasia Pty Ltd and Geosynthetic Testing Services for making my stays at Albury pleasant ones.

My research colleagues Anthony, Simon, Soheil, Stuart and Brian for their friendship, assistance and support in many general discussions, and for providing a pleasant working atmosphere.

Finally, I would like to thank my wife Cathy for her patience, encouragement and support throughout the project, and also my family for their support throughout the course of my studies.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 4

CHAPTER 5

LIST OF TABLES

LIST OF ABBREVIATIONS

AS	Australian Standard
ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California bearing ratio
DIN	Deutsches Institut für Normung (German Standard)
EOS	Equivalent opening size
FHWA	Federal Highway Administration
NATA	National Association of Testing Authorities
NRRL	Norwegian Road Research Laboratory
NSW	New South Wales
QMRD	Queensland Main Roads Department
SNRA	Swedish National Road Administration

NOTATION

a = Horizontal distance between inside of clamping rings and outside of plunger

A = Rupture resistance

Gradient of line of best fit

A_c = Surface area of the frustum of a cone for a flat CBR plunger

A_F = Surface area of frustum of cone (for hemispherical plunger)

A_S = Surface area of segment of sphere

B = Intercept of line of best fit with D_{500} axis

Intercept of line of best fit with F_{cal} axis

d = Nominal aggregate diameter

Diameter of CBR plunger

d_c = Average diameter of contact area

d_1 = Diameter of hole corresponding to h_1

d_2 = Diameter of hole corresponding to h_2

d_{50} = Nominal aggregate size at 50 per cent passing

d_{125} = Diameter of hole for a drop height of 125mm

d_{250} = Diameter of hole for a drop height of 250mm

d_{500} = Diameter of hole for a drop height of 500mm

d_{750} = Diameter of hole for a drop height of 750mm

d_{1000} = Diameter of hole for a drop height of 1000mm

d_{1500} = Diameter of hole for a drop height of 1500mm

d_{2000} = Diameter of hole for a drop height of 2000mm

D_{500} = Predicted d_{500} value

F_{cal} = Predicted CBR puncture test failure load

F_{mod} = CBR puncture test failure load using a modified plunger

F_{net} = Net puncture force

F_p = CBR puncture test failure load using a flat plunger

F_{req} = Required puncture resistance

G = Geotextile strength rating

h_1 = First drop height

h_2 = Second drop height

h_{50} = Drop height required to produce a 50mm diameter hole

p = Average normal stress on the geotextile

q_R = Subgrade reaction stress

r = Radius of CBR plunger

R = Radius of the geotextile specimen

RI = Rupture Index

S = Shape factor for plungers

S_f = Shape factor for aggregate

T = Tensile force per unit width

x = Distance between inside of clamping rings and outside of plunger at failure

x_p = Fabric length between inside of clamping rings and tip of pyramid-tipped plunger at failure

x_R = Distance between inside of clamping rings and centre of tip of hemispherical plunger at failure

Greek Symbols

α = Half of angle subtended by the fabric in contact with the plunger

β = Angle between test specimen and vertical edge of the plunger

δ = Vertical plunger displacement at failure load

ε = Fabric elongation

μ = Mass per unit area

CHAPTER 1

1.O INTRODUCTION

1.1 General:

Puncture resistance is an important property for geotextiles used in separation applications. It enables them to withstand the stresses of installation with little or no damage. The installation phase is well recognised as the most critical for geotextile survivability.

There have been many tests developed to measure puncture resistance, including the CBR puncture test and the drop cone puncture test. These tests have been used in some parts of Europe for over 15 years, and have been used in Australia for over ten years. They were standardised in Australia in 1990. In Australia the results of the CBR and drop cone tests are used to classify geotextiles by the G-Rating classification system.

VicRoads is a very large user of geotextiles in Victoria, mainly as a separation layer under sealed roads. Their current specifications are written in terms of the G-Rating, which was developed from tests conducted in the early 1980s (Brown, 1991).

1.2 Aim and scope of research:

The aim of this research was to provide up-to-date results from CBR and drop cone puncture tests, and to evaluate the G-Rating classification system. Some existing drop cone test results have shown that the exponent used to calculate the equivalent drop height was considerably in error for some fabrics. A user survey was made of all Victorian municipalities, VicRoads divisions, and some major contractors, to see whether the G-Rating is commonly used for selection purposes.

The G-Rating does not include a direct measure of tensile strength. The CBR puncture test was originally called the 'Tensile Strength Test', and a comparison between the results of this test and the wide strip tensile test was performed, with a view to adding a measure of tensile strength into the G-Rating classification system if necessary.

To show the effect of various shapes on fabric behaviour, CBR puncture tests were performed with plunger tips more nearly resembling real aggregate shapes than the flat CBR plunger. The results of these tests were used to validate the values currently quoted for shape factors in the literature.

This research is specifically related to geotextiles generally used as separators in road applications.

1.3 Layout of thesis:

Chapter Two is a review of the current literature with respect to puncture resistance and tensile strength, geotextile field performance and exhumation of geotextiles. The history of geotextile use in Australia since the mid 1970s is summarised, together with the current system of geotextile classification in Australia.

Chapter Three contains a description of the geotextiles tested and a discussion of the tests conducted and the reasons for choosing them. The test methods used and the environments in which the tests were conducted are described. Alternative methods of calculation for geotextile elongation are discussed and the reasons for the choice of the preferred method are given.

Chapter Four contains the results of the testing program. Detailed descriptions of fabric behaviour are given and CBR puncture test results are compared with wide strip tensile test results. A Rupture Index classification is proposed and a relationship is developed between mass per unit area and mechanical properties.

Chapter Five contains a discussion of a survey of geotextile users. The results are presented, together with comments from respondents regarding material selection and fabric damage.

Chapter Six contains an evaluation of the G-Rating classification system based on the results of the testing program and the user survey. Modifications to the G-Rating as currently used are proposed.

Chapter Seven summarises the conclusions reached in Chapters Three, Four, Five and Six. Further work is recommended based on logical extensions of the testing program. Work in areas not investigated, but seen as relevant to the separation function, is also recommended.

CHAPTER 2

2.O LITERATURE REVIEW:

2.1 Introduction:

This literature review summarises the advances made in geotextile testing in the past two decades, specifically related to the puncture resistance of geotextiles used for separation. It also summarises the current state of testing and specification for geotextiles in Australia. The exhumation of geotextiles is reported on and the outcomes of such studies with respect to puncture resistance and strength loss in general are included.

The references used were taken mainly from the four international geotextiles conferences, namely the International Conference on the Use of Fabrics in Geotecnics (Paris, France, 1977), the Second International Conference on Geotextiles (Las Vegas, U.S.A., 1982), the Third International Conference on Geotextiles (Vienna, Austria, 1986) and the Fourth International Conference on Geotextiles, Geomembranes and Related Products (The Hague, Netherlands, 1990). United States Federal Highway Administration (FHWA) publications on geotextile engineering and design and Standards from Europe, the United States and Australia were also sources of information.

The review is limited to geotextile testing, specification and field performance. No detailed description is given of fabric structure and manufacture as this has been adequately covered by other publications, for example, Koerner (1990).

2.2 Geotextile definitions:

2.2.1 General:

When geotextiles began to be used in the 1950s, they were referred to in the same terms as textile fabrics. This was partly due to the early names given to geotextiles which included filter fabric, engineering fabric, geofabrics and civil engineering fabric (Christopher and Holtz, 1985). The definition of Alfheim and Sorlie (1977) is: "...a synthetic material produced like a cloth with a structure of plastic fibres or filaments. The fibres being either directionally oriented (woven) or randomly oriented (non-woven). The fibres are held together by physical, mechanical, thermic or chemical bonding, or a combination of these methods." (sic).

As geotextiles were initially used either as construction expedients or in temporary constructions, a clear definition of geotextiles or, indeed, detailed information on geotextile properties, was not required. The use of geotextiles has since become more specialised and the need for a clear definition has arisen. The definition used in this thesis is that of ASTM D4439 (1987): "Any permeable textile material used with foundation, soil, rock, earth, or any other geotechnical engineering-related material, as an integral part of a man-made project, structure or system."

All woven geotextiles are manufactured in three sequential steps: extrusion, beaming and weaving. On the other hand, non-wovens are produced by different methods including needle punching, heat bonding and resin bonding, and, due to their method of manufacture, possess properties different from woven fabrics, including lower modulus, a higher elongation at break and higher flexibility and deformability (Raumann, 1982). Composite geotextiles usually consist of a non-woven which is needle punched onto a woven base, or one or more alternating layers of woven and/or non-woven fabrics.

2.2.2 Geotextile properties:

The properties of geotextiles are related to the functions they serve. The five categories of geotextile properties indicated by Koerner (1990), are physical, mechanical, hydraulic, endurance and degradation properties. Those related to the separation function include mechanical properties such as puncture resistance, tear resistance and tensile strength, and hydraulic properties such as equivalent opening size (EOS) and soil retention characteristics. Physical properties, such as mass per unit area and thickness, are indirectly related to separation as they affect the robustness of materials and also, to some extent, mechanical properties.

Mechanical properties are usually measured on geotextiles in isolation. The results obtained may therefore be conservative, as values of mechanical properties tend to be higher when the geotextiles are tested inside a soil mass (Christopher and Holtz, 1985).

The properties considered in this thesis include puncture resistance and tensile strength. Puncture resistance is required to resist perforation of the fabric by aggregate, tree stumps or rough ground during installation, and to resist forces caused by soil or aggregate under stress pushing the geotextile into voids within the fill (Koerner, 1990). Tensile strength is necessary for the separation function, as differential movement horizontally or vertically between materials above and/or below the geotextile may lead to a tensile stress in the geotextile.

2.2.3 Geotextile functions:

To date, there have been approximately fifteen functions of geotextiles quoted in the literature. However, some of these functions are very specialised and fall outside the scope of this thesis, which is concentrated on geotextile puncture resistance related to the separation function. The four major functions quoted in the literature are separation, filtration, drainage and reinforcement (Christopher and Holtz, 1985; Koerner, 1990; Lasalle et al., 1982; Giroud, 1979; Koerner, 1984; Brorsson and Eriksson, 1986; De Groot et al., 1986; Nijhof et al., 1986; Austroads, 1990). A fifth major function, that of a moisture barrier, is quoted in some literature, but fabrics modified for use as a moisture barrier fall outside the definition of geotextiles given in ASTM D4439 (1987).

The filtration and drainage functions of geotextiles are only indirectly related to mechanical strength. Provided a geotextile has adequate mechanical strength or robustness to resist damage such as holes or tears, the filtration and cross-fabric drainage functions will depend upon its characteristic opening size. However, this may change as tensile stress is applied to the geotextile and the openings within it are altered in size and shape.

2.2.3.1 The separation function:

The main function dealt with in this thesis is separation, which seems to be the most widely reported. It is the function of keeping apart two dissimilar materials which would otherwise interpenetrate each other. Separation is related to mechanical properties although it, too, is affected by the opening size of the fabric.

A concise definition of geotextile separation is given by Koerner (1990) as: "The introduction of a flexible synthetic barrier placed between dissimilar materials so that the integrity and functioning of both materials can remain intact or be improved." The effect of adding a flexible synthetic barrier, or geotextile, is often synergistic because geotextiles can complement the strength of a soil/aggregate system. This can be illustrated by analogy with reinforced concrete, which uses steel, having excellent tensile characteristics, to complement concrete which, although strong in compression, is weak in tension. Similarly, with geotextiles placed in soil/aggregate systems, the geotextile, which is good in tension, is used to complement the soil, which is good in compression but poor in tension (Fluet, 1988).

The stability of an aggregate system consisting of discrete particles depends on the friction generated between the particles to remain intact. The addition of a geotextile has a confining effect, thus adding stability in most cases, as well as acting as a barrier to the intrusion of fine grained soil particles. The mixing of fine grained soils and aggregate can lead to failure by pumping, commonly seen in railway track bases, where fine soil particles are 'pumped' up between aggregate particles. This causes lubrication of the aggregate, reducing inter-particle friction, and adversely affecting the drainage capacity of the granular material as the fine particles fill the voids within the aggregate. At the same time, the aggregate sinks into the fine grained subgrade (Koerner, 1990). This will also cause a loss in aggregate strength which, in the case of a road, can lead to rutting, cracking, potholes and, eventually, total pavement failure. The function of separation is shown schematically in Figure 2.1 with pumping and aggregate sinking shown separately for clarity.

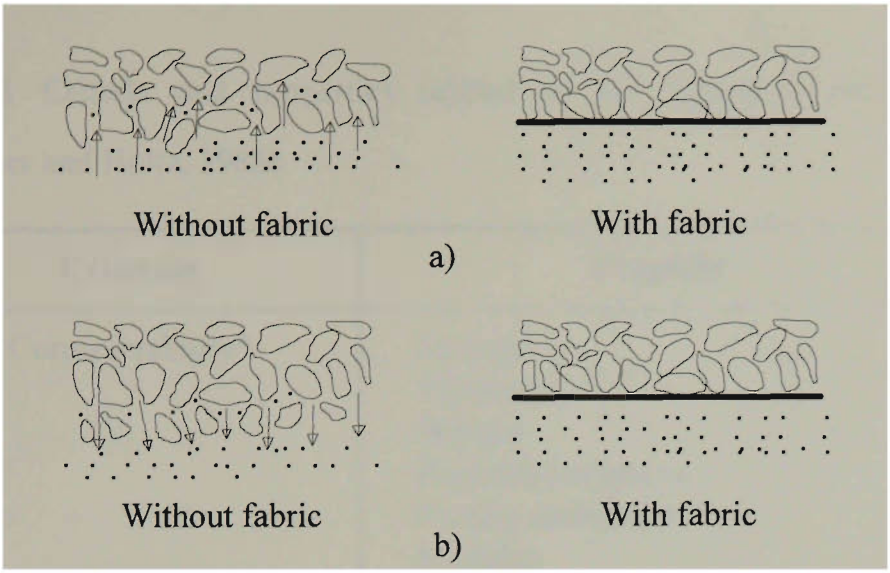

Figure 2.1 Failure mechanisms associated with the use of geotextiles involved in the separation function a) pumping and prevention using geotextiles and, b) stone sinking into subgrade and prevention using geotextiles (after Koerner, 1990).

To perform the separation function, a geotextile must be robust enough to survive the installation process. Robustness during installation directly depends on the mechanical properties of the geotextile. Some of the mechanical properties relevant to the separation function include tensile strength, puncture resistance, tear resistance and impact resistance (Christopher and Holtz, 1985; Koerner, 1990; De Groot et al., 1986). A more complete, though not all-inclusive, list can be seen in Table 2.1.

As the separation function requires the fabric structure to remain intact, the relevant mechanical properties must be those that will provide stability, thus ensuring continuity of the geotextile. The geotextile should be able to resist puncturing during installation and in service (Lasalle et al., 1982). However, should the geotextile become punctured, this defect must not be able to propagate through the fabric. Hence, tear resistance is also important to maintain continuity should a minor rupture or puncture occur.

Table 2.1 Criteria and properties related to the separation function (after Christopher and Holtz, 1985)

Criterion	Property
Constructability*	Strength Thickness Weight Puncture resistance Cutting resistance Modulus Flexibility Tear resistance
Durability	Chemical resistance Wet and dry stability Abrasion resistance
Mechanical	Tensile strength Fatigue Burst strength Puncture resistance Tear strength

* This is assumed to refer to the ability to survive the construction process.

2.2.3.2 Applications requiring separation:

In the areas of subgrade stabilisation and coastal/river bank protection, the separation function dominates. In other applications, such as drainage, use under embankments and as a pipe wrap, separation is a secondary function (Christopher and Holtz, 1985). It is safe to say that, if the separation function is lost, even if it is not the primary function, other functions will not be fulfilled adequately or, in some cases, at all. A geotextile that cannot perform its separation function adequately (due to some form of damage), cannot provide drainage or filtration to the required standard. Ingold (1988) states that, for the filtration function, reference is never made to mechanical properties such as puncture and tear strength. However, he also states that, if a geotextile is ruptured during installation, its proper functioning as a filter can be severely hampered.

In order to illustrate the functions required for different applications, Table 2.2 is provided which lists some applications of geotextiles indicating which of the four major functions dominates, the applications involving secondary functions and those relevant to each application.

Table 2.2 Applications and controlling functions of geotextiles (after Christopher and Holtz, 1985)

Primary Function	Application	Secondary Function(s)
Separation	Unpaved roads (temporary & permanent)	Filter, drain, reinforcement
	Paved roads (primary & secondary)	Filter, drain
	Construction access roads	Filter, drain, reinforcement
	Working platforms	Filter, drain, reinforcement
	Railroads (new construction)	Filter, drain, reinforcement
	Railroads (rehabilitation)	Filter, drain, reinforcement
	Pre-loading (stabilisation)	Reinforcement, drain
	Paved and unpaved parking facilities	Filter, drain, reinforcement
	Coastal and river protection	Filter, drain, reinforcement
Drainage	Retaining walls	Separation, filter
	Vertical drains	Separation, filter
Reinforcement	Sub-base reinforcement in roadways	Filter
	Load redistribution	Separation
	Bridging non-uniform soft soil areas	Separation
Filter	Trench drains	Separation, drain
	Pipe wrapping	Separation, drain
	Base course drains	Separation, drain
	Structural drains	Separation, drain
	Reverse filters for erosion control	Separation, drain

2.3 Geotextile test methods:

2.3.1 Introduction:

The textile industry has been producing and testing fabrics for many years. The tests developed over these years have been those which indicate the strength of fabrics in terms relevant to the textile industry. It was soon discovered that textile testing was not strictly relevant to the functions of geotextiles and geotextile test methods were required which would measure properties relevant to the end uses of the geotextiles.

2.3.2 The use of existing textile test methods:

Some textile tests have been incorporated into the geotextile testing spectrum. The diaphragm burst test - ASTM D3786 (1987), and the grab tensile test - ASTM D1682 (1964), are two examples. While these tests can be useful in providing strength properties, they do have some fundamental disadvantages.

The diaphragm burst test is conducted over a test area which is 31mm in diameter. The specimen is rigidly clamped and a rubber membrane against the specimen is expanded under pressure until the geotextile bursts. A test specimen of this small size can give artificially high results for the burst strength of staple fibre fabrics where the length of fibres is 50mm or greater (Christopher, 1992). In this case, the strength of individual fibres is being tested, which is generally greater than the inter-fibre friction holding them together. This could be misleading for designers who might assume the results of such a test on these fabrics to be an accurate reflection of the geotextile's large-scale burst resistance.

A similar problem associated with specimen size is encountered when testing using the ball burst test described in ASTM D3787 (1980). In the test a 25mm diameter ball is pushed through a fabric specimen 45mm in diameter which is clamped along its outer edge (Koerner, 1990). The ball is a good choice for simulating rounded aggregate but not so good for simulating angular aggregate. A test similar to this has been carried out with an 8mm diameter blunt-ended steel piston on the same size specimen (Koerner et al., 1986). It is possible for a piston as small as this to slip between yarns in woven fabrics, especially those of the slit film type, thus giving misleading results.

The grab tensile test is widely used by geotextile manufacturers, mainly for quality control purposes, and is quoted in many geotextile specifications. The specimen is 100 x 150mm in size, but the jaws are only 25mm wide and the specimen is placed so that the jaw is located in the centre of the 100mm edges. When gripped in this manner, fabrics have a tendency to exhibit a Poisson's ratio effect where the fabric "ropes-up" over the middle portion of the test specimen (Koerner, 1990). This leads to a higher failure load than for specimens gripped across their entire width, as the overhanging fabric inhibits necking and increases the amount of fibres available to resist the applied load (Curiskis, 1994).

2.3.3 New test methods for geotextiles:

Since the mid to late 1970s, many tests have been developed for geotextiles, with the purpose of quantifying engineering properties. As a result, a variety of tests have become available to geotextile designers/users. Initially, this was a good thing as manufacturers, suppliers, designers and users could choose the tests which would yield results relevant to the intended application. However, this situation has since deteriorated to the point where it is possible for manufacturers to quote results from tests that are better suited to their particular type of product. Thus, for example, a staple fibre fabric manufacturer may quote puncture resistance after testing 45mm diameter specimens and compare this to test results for a woven fabric on 150mm diameter specimens. This would result in a biased comparison.

Although sample size plays an important role, so too do testing conditions and strain rate. Geotextiles, being visco-elastic materials, are known to give higher strength values when tested at higher strain rates (Warwick, 1991). The stress resistance mechanism in a geotextile consists of both fibre stress and inter-fibre friction. Tests at a slow rate of strain rely on the inter-fibre friction and tests at a fast strain rate rely on fibre strength (Anjiang et al., 1990). At a slow strain rate, fibres re-align themselves and the area over the which the friction acts is increased, but this does not lead to higher strength values because the friction between the fibres does not reach as high a level as the stress within the fibres. At a fast strain rate fibre re-alignment does not have time to occur, and resistance to failure is governed by fibre strength.

The first tests designed specifically with geotextile functions in mind were the CBR puncture test and the drop cone puncture test. Both tests are described in some detail in sections 2.3.3.1 and 2.3.3.2 respectively.

2.3.3.1 The CBR puncture test:

The need for tests relevant to the applications of geotextiles led to the development of the CBR puncture test at the Norwegian Road Research Laboratory (NRRL) as reported by Alfheim and Sorlie (1977), although they referred to it as a tensile strength test. This early description recognised the tensile behaviour of the geotextile in the test, where essentially two-dimensional stress is induced within its plane.

The CBR puncture test utilises a standard CBR mould and 50mm diameter plunger. The geotextile is clamped between two rings which sit on top of the mould and the plunger is pushed into the specimen at a constant rate. Figure 2.2 shows a schematic cross-section of the CBR puncture test setup.

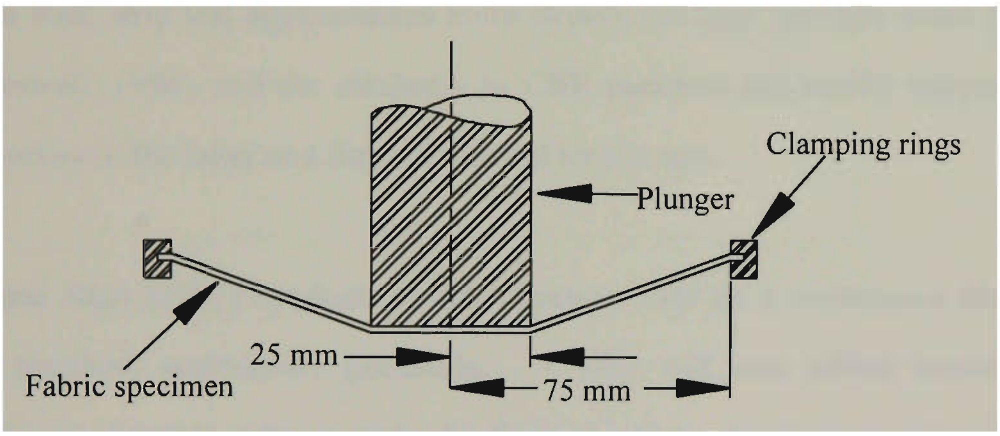

Figure 2.2 Schematic cross-section of the CBR puncture test (after Mc Gown et al., 1981)

Warwick (year unknown) concluded that the results of CBR puncture tests could only be used to compare different fabrics, and are not representative of field strength. This is in part consistent with other investigations, especially the work of Murphy and Koerner (1988), who found that the CBR puncture test could be used to compare the strength of all types of geotextiles such as wovens, non-wovens and composites, and also geomembranes, geocomposites and geonets.

Over the years since its development, this test has been referred to as either a burst or puncture test but, as Murphy and Koerner (1988) put it, the CBR puncture test

"...is an axi-symmetric strength test and should be considered as such." Koerner (1990) states that the CBR puncture test should be considered as a form of bi-axial tensile test, because the fabric between the outer edge of the plunger and the inner edge of the CBR mould is theoretically in a pure state of axi-symmetric tension.

Cazzuffi et al. (1986) conducted a series of tests on non-woven geotextiles, and found that the CBR load at failure multiplied by 2π yielded values very similar to the strength per unit width measured in 500mm wide strip tensile tests. At this width, a wide strip test approximates more closely the 'true' strength value (Myles and Carswell, 1986), and the similarity to CBR puncture test results indicates the effectiveness of the latter as a form of bi-axial tensile test.

Lhote and Rigo (1987) conducted CBR puncture tests on a continuous filament, needle punched, non-woven geotextile. A silty soil was added beneath the geotextile to simulate more closely the field situation. Its bearing capacity was varied from 12 to 67 kPa by altering its water content. Specimen diameters of 150mm and 120mm were used to determine the effect of a smaller test area. The inclusion of the silt produced a higher CBR load at failure, more so for the larger diameter specimens. It is not stated whether they considered that the higher failure loads recorded were due to the bearing capacity of the soil alone, or to what extent soil/geotextile interaction was a factor.

Tests which attempt to model geotextile interaction with aggregates cannot model each shape and size of aggregate used. A shape factor is used to account for the difference in shape between a flat CBR plunger and various aggregate or rock shapes. Werner defines it as

$$S_f \geq \frac{F_{req}}{F_p} \tag{2.1}$$

Where:

F_{req} = Required puncture resistance (N).

F_p = CBR puncture test failure load using a flat plunger (N).

S_f = Shape factor for aggregate.

Werner (1986) and Lhote and Rigo (1987) quote shape factors of 0.8 for round, blunted stones and 3.0 for sharp, very angular stones. Both papers cite "Designing with geosynthetics" course notes (Bell and Koerner, 1984) as the source of shape factor values. Attempts were made to obtain these course notes from the second author, but they are not available. According to Werner, interpolation between the two extremes is possible but requires judgement and experience. He reports crushed rock as having a shape factor of between 2.0 and 3.0, depending on the angularity of the particles. No test results are given to substantiate the values of shape factor quoted.

The implication of a value of 0.8 for rounded stone is that it requires a greater force to push a plunger with a hemispherical tip through a fabric than a flat-ended plunger. As the value of 2.0 to 3.0 for angular stone implies a penetration force under a pyramid-tipped plunger of only one-half to two-thirds that of a flat-ended plunger, it is hard to see why a value greater than one should not also apply for a hemispherical plunger.

Another way to account for the different shapes of aggregate is to use plungers that model these shapes. The most obvious plungers to better simulate the shapes of aggregates would be those with rounded or pointed tips. Very little mention has been made of plungers with hemispherical tips in the literature apart from their existence (Warwick, 1991).

Lhote and Rigo (1987) state that the results for a pyramid-tipped and a flat CBR plunger are very different, but give no supporting data. When testing with a flat plunger and a modified plunger, a shape factor is given by Equation 2.2, where F_{mod} is the failure load from a CBR puncture test using a modified plunger.

$$S = \frac{F_p}{F_{mod}} \tag{2.2}$$

Where:

S = Shape factor for plungers.

Most of a geotextile sample is assumed to be in axi-symmetric tension in a flat plunger CBR puncture test (Koerner, 1990). However, the base of a CBR plunger is flat and may not be representative of real aggregates. Therefore, the behaviour of a geotextile on contact with aggregate (or an angular plunger) would be expected to differ from that under a flat plunger. Lhote and Rigo (1987) proposed that the bearing effect at the base of a flat CBR plunger gives way to a more local effect at the tip of a pyramid-tipped plunger.

Werner (1986) conducted CBR puncture tests on 150mm diameter specimens using a 50mm diameter plunger with a three-sided pyramidal tip, which resulted in large reductions in CBR failure load compared with tests using a flat plunger. Shape factors calculated using Equation 2.2 for stiffer fabrics such as wovens and heat bonded non-wovens differ considerably from the value of 3.0 commonly quoted for angular aggregate (see Table 2.3).

Table 2.3 shows that a shape factor of 2.0 to 3.0 would be valid for angular aggregate when using a pyramid-tipped plunger on a needle punched non-woven fabric. However, on the basis of this data, this value for the shape factor would be invalid for other types of geotextiles. Hence, it appears that shape factors not only depend on the shape of the aggregate, but are fabric dependent as well.

Table 2.3 Calculated shape factors for pyramid-tipped plunger tests (after Werner, 1986)

Geotextile type	Percentage loss in strength	Corresponding shape factor
Needle punched, non-woven	50 - 66	2.0 - 2.9
Heat bonded non-woven	70 - 75	3.3 - 4.0
Slit film woven	85	6.7

The use of a 25mm diameter plunger with a four-sided pyramidal tip, in puncture tests on two needle punched fabrics and one heat bonded fabric, is described by Foch (1990). The specimens tested with this plunger were 80mm in diameter. He found that the failure load under the pyramid-tipped plunger, compared with that for a flat CBR plunger on 150mm diameter specimens, was significantly less. The reduction in failure load for a needle punched fabric was 78 per cent, and 88 per cent for the heat bonded fabric. These strength losses correspond to shape factors of approximately 4.5 for the needle punched fabrics and approximately 8.3 for the heat bonded fabric. This indicates that heat bonded fabrics may offer much less resistance to penetration by a pointed plunger than by a flat plunger. Only one of the geotextiles is specified in sufficient detail in the paper to enable the manufacturer to be identified. This geotextile exhibited a smaller reduction in failure load than the other fabrics. As the company for which the author of the paper was a representative also produced this geotextile, it may have been named for commercial reasons.

In a CBR puncture test, elongation at failure (as %) may be calculated by Equation 2.3, taken from DIN 54.307 (1982), with the variables defined in Figure 2.3.

$$\varepsilon = \left(\frac{x-a}{a}\right) \times 100 \qquad (2.3)$$

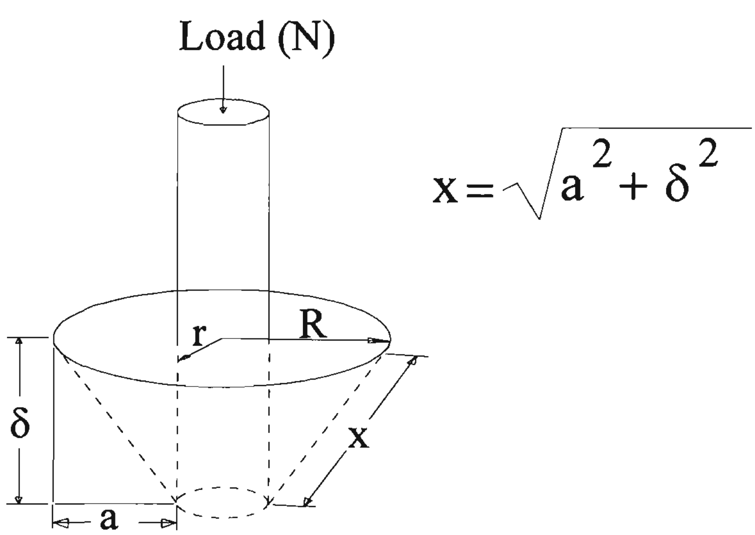

Figure 2.3 Variables for CBR puncture test elongation calculations (after Murphy and Koerner, 1988)

Where:

R = Radius of the geotextile specimen (mm).

r = Radius of CBR plunger (mm).

δ = Vertical plunger displacement at failure load (mm).

a = Horizontal distance between inside of clamping rings and outside of plunger (mm).

x = Distance between inside of clamping rings and outside of plunger at failure (mm).

Cazzuffi et al. (1986) calculated elongation differently, using the change in area of the geotextile sample. Their relationship is given in Equation 2.4. In their tests this method gave values for elongation at failure which were very similar to the elongation at failure measured in 500mm wide strip tensile tests on the same materials.

$$\varepsilon = \left[\frac{\pi\,(R+r)x + \pi r^2 - \pi R^2}{\pi R^2}\right] \times 100 \qquad (2.4)$$

Equation 2.3 does not take into account any deformation of the fabric in contact with the base of the plunger, whereas Equation 2.4 does. Therefore, it seems that Equation 2.3 is not going to adequately represent actual elongation behaviour. This is because actual elongation behaviour is three-dimensional and would be better represented by a three-dimensional expression such as Equation 2.4, than by a two-dimensional expression such as Equation 2.3.

2.3.3.2 The drop cone puncture test:

The drop cone puncture test uses the normal CBR mould and a 1 kg cone dropped from a height of 500mm. The apex angle of the cone is 45° and the tip can be machined to a small radius (1 or 2mm) or left unmachined (AS 3706.5, 1990). The 150mm diameter geotextile specimen is gripped between two rings which sit on top of the mould. The diameter of the hole thus formed is measured. Figure 2.4 shows a schematic layout of the drop cone test.

The drop cone puncture test was developed at the NRRL because early experience showed that some types of geotextiles had a greater tendency than others to puncture when aggregate was dumped on them (Alfheim and Sorlie, 1977). This form of dynamic puncture could not be related to tensile strength, so it was necessary to develop a dynamic test to simulate this condition. The original name given to this test was the cone penetration test. According to Alfheim and Sorlie, the results of the drop cone test should not be taken as a measure of the field performance of geotextiles, but should only be used to compare the penetration resistance of geotextiles in the laboratory for classification purposes.

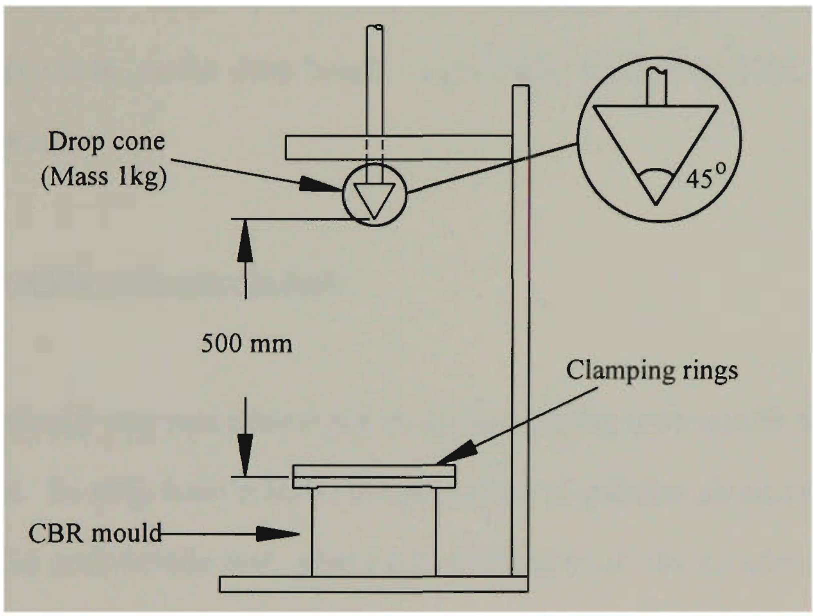

Figure 2.4 Schematic view of the drop cone test

In this test, puncture resistance is measured in terms of the diameter of the failure hole. The larger the diameter of the hole, the lower the puncture resistance of the specimen, and vice-versa. In Australia, the actual hole diameter under a standard drop height is used in a simple formula to calculate the drop height (h_{50}) required to cause a 50mm diameter hole (Waters, 1984).

Lawson (1982) observed geotextiles in the field to determine the effect of rock drop height on geotextile puncture resistance, and found that puncture damage was approximately proportional to the square root of the drop height. He stated that the drop cone test appeared ideally suited to "depicting" the dynamic puncture resistance of geotextiles. The dynamic nature of this test makes it a much better indicator of the likely behaviour of geotextiles when rock is dropped onto them, compared with a CBR puncture test or wide strip tensile test. However, Lawson looked at rip-rap in erosion control structures, where the size of the rocks is much larger than the aggregates used in road making. Therefore, his approximate relationship, based on large rocks, may not translate to geotextiles used for separation under roads, as the drop height is generally smaller and the size of rock used is much smaller.

2.3.3.3 The wide strip tensile test:

The wide strip tensile test was developed from the simpler strip tensile tests used on ordinary fabrics. In strip tensile tests, the specimen is gripped along its full width, as opposed to the grab tensile test, where it is gripped over one quarter of its width. The narrowest strip in common usage is 50mm but, at this width, edge effects dominate behaviour, and the stress-strain conditions imposed on the geotextiles are not representative of those to which they are exposed in the field. In most cases in the field, the geotextile is loaded under plane strain conditions where lateral contraction is restricted by friction between the geotextile and the surrounding soil, compared with strip tensile tests where lateral contraction can occur. This lateral contraction, which is relatively constant in magnitude, is a higher percentage of specimen width for narrow specimens, thereby having a greater effect on these specimens.

The effect of sample width on the uni-axial strength of geotextiles was studied by Myles and Carswell (1986). Tensile tests were performed on geotextile samples ranging in width from 50mm to one metre, with the full specimen width gripped in the jaws. They found that, as sample width approached one metre, the strength per unit width converged to a constant value, which they called the true strength value. This is shown in Figure 2.5.

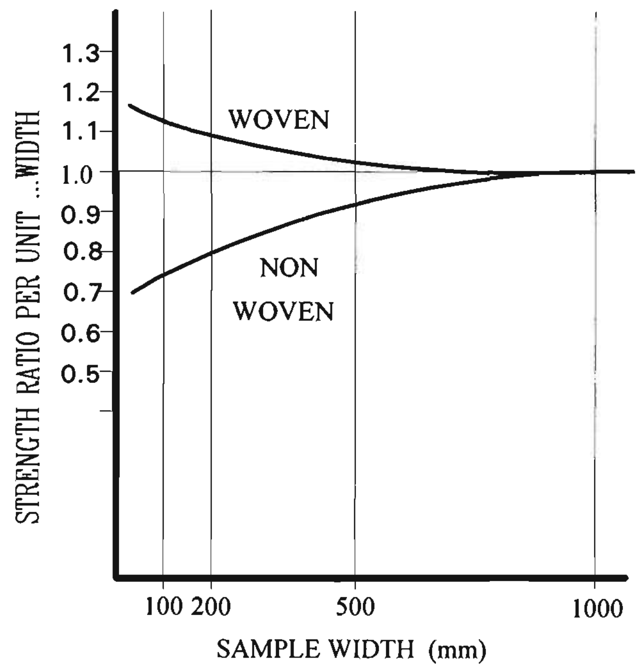

Figure 2.5 Influence of sample width on strength (after Myles and Carswell, 1986)

To perform tests on one metre wide samples requires specialised clamping mechanisms in order to avoid sample slippage, and relatively sophisticated testing equipment. It takes considerably longer to prepare a test specimen of this size than for a 50mm wide specimen. This test is not a relatively quick and inexpensive means of testing geotextiles and is really a performance indicating test, as opposed to an index test.

The majority of authors is generally in favour of the use of 200mm wide specimens for tensile testing. Myles and Carswell (1986) and Anjiang et al. (1990) found that testing on 200mm wide samples gave a closer approximation to the true strength of the geotextile being tested than narrower strip tests. Myles and Carswell found that, at this width, test results overestimated the failure load of a high strength woven by approximately 10 per cent, and underestimated that of a lightweight non-woven by approximately 20 per cent. (see Figure 2.5)

Shrestha and Bell (1982) compared 200mm wide samples tested under unrestricted conditions, and 200mm wide samples tested under plane strain conditions. Their conclusion was that, at 200mm, the strength of normally tested samples was less than ten per cent lower than for samples tested under plane strain conditions. Their results indicate that the difference between the true strength and the strength at 200mm, is much smaller than that given by Myles and Carswell (1986). Shrestha and Bell simulated plane strain conditions by using wooden brackets and pins to restrict necking. The effect of these pins on strength values and material behaviour was not commented on. The tests by Myles and Carswell may be a better approximation of plane strain conditions as they tested very wide specimens, where the effects of necking were inhibited by the width of the specimen, thereby probably approximating field behaviour more closely than Shrestha and Bell.

2.4 Puncture resistance of geotextiles:

The definition of puncture resistance which is used in this thesis is: *resistance to the intrusion of aggregate, soil or other material into the geotextile which would cause perforation of the geotextile*. A perforation is considered to be a hole, tear or rip in the geotextile.

The resistance of geotextiles to puncturing stresses is an important element of geotextile strength. Many geotextile functions rely on the geotextile remaining intact - referred to as continuity by Giroud (1987). He points out that, as granular materials are made up of discrete particles, they can be dispersed but, due to their structure, geotextiles cannot be dispersed. This is important as any punctures or tears will lead to a loss of continuity which can allow the undesirable dispersion of soil particles.

Investigations of puncture resistance have been reported by many authors, some of whom have derived, either theoretically or empirically, expressions for the puncture resistance of geotextiles, usually as a function of the applied pressure (usually tyre pressure or surcharge) and aggregate size. Other factors include variables such as subgrade bearing stress, aggregate shape (sphericity), initial void diameter and thickness of aggregate layer.

Geotextile puncture resistance has been taken by most authors as being proportional to the square of the diameter of the aggregate. Most relationships for puncture resistance are expressed in terms of aggregate diameter and assume the surcharge acts on a spherical aggregate particle of diameter 'd'. These relationships are generally of the form shown in Equation 2.5 (John, 1987). Some may use different variable names or break up variables differently, but they all generally give similar values (Lhote and Rigo, 1987; Werner, 1986; Koerner, 1990).

$$F_{req} = \frac{p\left(\pi d^2\right)}{4} \qquad (2.5)$$

Where:

F_{req} = Required puncture resistance (N).

p = Average normal stress on the geotextile (Pa).

d = Nominal aggregate diameter (m).

John (1987) also adds to this expression a term which takes subgrade bearing stress (q_R) into account, as shown in Equation 2.6. This situation is illustrated in Figure 2.6. If no subgrade reaction is assumed, then this relationship is identical to Equation 2.5.

$$F_{net} = \frac{\pi}{4}\left(pd^2 - q_R d_c^{\,2}\right) \qquad (2.6)$$

Where:

F_{net} = Net puncture force (N).

p = Average normal stress on the geotextile (Pa).

d = Nominal aggregate diameter (m).

q_R = Subgrade reaction stress (Pa).

d_c = Average diameter of contact area (m).

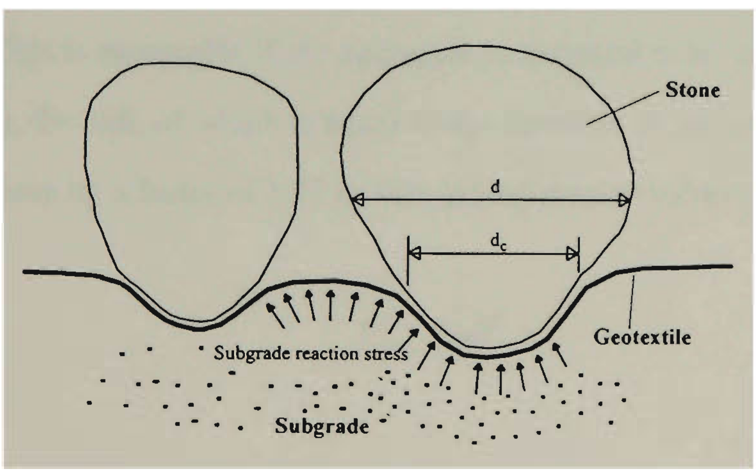

Figure 2.6 Geotextile puncture analysis showing subgrade reaction (after John, 1987)

Exact values for d_c are not given in John (1987), neither does he give a method for calculating values of d_c. However, two estimates of d_c are given, being 0.5d for rounded aggregate and 0.25d for angular aggregate. These variables assume spherical particles but, as real aggregates are non-spherical, dimensions d and d_c represent average dimensions. John uses d_c values as he assumes that the net puncture force is resisted by a radial tension around the contact area perimeter (πd_c). When using Equation 2.6 to obtain an equivalent CBR plunger load, d_c must be 50mm. The value of d_c depends on the size and shape of the aggregate and, as this is not necessarily 50mm, he proposed an approximate conversion factor for required puncture strength in terms of puncture force and the ratio of contact area diameters. This relationship is given in Equation 2.7 where the value of 0.05 is the diameter of the CBR plunger in metres.

$$F_{req} \approx \frac{0.05\, F_{net}}{d_c} \tag{2.7}$$

Giroud (1979) proposed an approximate relationship for puncture resistance which is given as Equation 2.8. It is almost identical to Equation 2.5, the only difference being that the pressure is applied to the geotextile through a square area instead of a round one. This is acceptable if the aggregate is assumed to be arranged cubically. A square area, the side of which is equal to the diameter of a round area, is greater than a round area by a factor of 1.27 ie. $4/\pi$, giving greater values of F_{req}.

$$F_{req} = pd^2 \tag{2.8}$$

2.5 Geotextile survivability:

In Christopher and Holtz (1985) the term 'survivability' for geotextiles is defined as "...resistance to damage during construction and initial operation." The installation/construction process is frequently mentioned in the literature as the source of the greatest stress on geotextiles performing a separation function.

Christopher and Holtz (1985) developed a ranking system for geotextile installation survivability based on the severity of construction conditions. Survivability is ranked in five categories - low, moderate, high, very high and not recommended. The 'not recommended' ranking indicates a situation where the use of a geotextile is not recommended because of possible overstressing, whereas the 'low' ranking indicates less severe installation conditions, where a fabric requires only low survivability to be deemed acceptable for use. Table 2.5 is reproduced from Christopher and Holtz and shows the survivability rankings for all fabric types, based on ground pressure from construction equipment and type of subgrade preparation.

Table 2.4 Fabric survivability requirement (after Christopher and Holtz, 1985)

	Construction equipment		
Subgrade Preparation Conditions	Low ground pressure equipment (<27 kPa)	Medium ground pressure equipment (>27<55 kPa)	High ground pressure equipment (>55 kPa)
Subgrade is smooth and level.	Low	Moderate	High
Subgrade has been cleared of large obstacles.	Moderate	High	Very high
Minimal site preparation is provided.	High	Very high	Not recommended

* NOTE: Initial lift thickness of cover material 150-300mm.

When considering the results of tests on geotextiles in the laboratory, it must be borne in mind that they will not have been adversely affected by in-situ conditions such as exposure to moisture, excessive exposure to ultraviolet light and physical damage during installation or in service. If a geotextile cannot survive the process of installation, then its long term durability becomes unimportant as a design consideration.

Nowatzki and Pageau (1984) investigated the effect of holes on geotextile tensile strength by conducting tests on 50 x 250mm specimens in which round holes, ranging in diameter from zero (ie. no hole) to 12.5mm, were cut in the centre of the specimens. Their results showed that, for woven fabrics, the loss of tensile strength was between two and 40 per cent for a hole diameter to specimen width ratio of less than ten per cent, for loads applied in the machine direction. For loads applied in the cross-machine direction, the loss of tensile strength was between 24 and 45 per cent. They found that a hole diameter to specimen width ratio of less than ten per cent had very little effect on tensile strength for the non-woven geotextile tested. The mode of failure for the materials with holes was similar for both wovens and non-wovens. The hole gradually stretched until it became oval-shaped, continuing until strands at the edge of the hole broke. This type of failure follows basic mechanics theory which treats holes as stress concentrators. Tests were also conducted on specimens in which slit cuts perpendicular to the direction of loading were made in the specimen. The results of these tests were said to compare favourably with the round hole tests, but no supporting data was given. The governing factor for tensile strength reduction was said to be the percent reduction in width and not the shape of the cut.

2.5.1 Field testing of geotextiles:

Three types of field test were carried out by Dixon and Osborn (1990) on a staple fibre non-woven, a continuous filament non-woven and a high strength woven. The first test involved dropping a two tonne angular granite block from one metre onto a geotextile placed on a layer of sandy gravel. The second test involved placing a geotextile onto a layer of levelled rock (d_{50}=125mm), covering it with 150mm of sand, and trafficking it with a 67 tonne excavator (number of passes not given). The third test involved the use of 7.5 tonne rocks as a base, with smaller rocks and gravel in the voids. A geotextile was placed on top of this and covered with 200mm of sand. This was then trafficked with a tracked mobile crane (number of passes and mass of crane not given).

The staple fibre fabric showed less damage than the other fabrics in all three tests (refer to Table 2.4). The high strength woven exhibited severe damage, including splitting and lacerations. The comparatively little damage to the staple fibre fabric was attributed to the localisation of damage, because the smaller fibre lengths allow higher local elongation in the immediate vicinity of the damaged area. This is consistent with the results of Wehr (1986). Wehr reported on field trials of geotextiles in test pits under railway ballast over a ten year period. He found that damage in needle punched geotextiles exhumed after ten years of service was never in zones of greatest elongation.

Table 2.5 Geotextile damage from field tests (after Dixon and Osborn, 1990)

Geotextile	Dropped block trial 1	Trafficking trials 1 & 2
Staple fibre non-woven	Small localised hole	Small pitted holes
Continuous filament non-woven	Large hole with some shredding	Large holes
High strength woven	Very large hole Extensive splitting	Extensively lacerated

2.5.2 Exhuming of geotextiles:

In general, exhuming of geotextiles has shown that in-service stresses have not hindered satisfactory performance. Rathmayer (1982) stated that, although the properties of some fabrics had changed, samples exhumed from 22 sites throughout Finland appeared to have performed satisfactorily as both separators and filters. He also stated that, for fabrics used as part of permanent structures, the working stresses do not affect design criteria. Strength requirements must, therefore, be related to the installation procedure.

In 1973, the Swedish National Road Administration (SNRA) initiated a field test to measure the performance of nine geotextiles used as separators, including woven and non-woven (needle punched and heat bonded) fabrics. Samples of these geotextiles were tested prior to installation and the strength measured in these tests is the initial strength. Further samples were exhumed five and then ten years after installation. The strength measured in these tests is the residual strength, usually expressed as a percentage of initial strength. Visual examination of these geotextiles after ten years showed no signs of migration of fines. Strip tensile tests (50mm wide) showed that a high strength woven lost approximately 50 per cent of its initial strength, and for the non-woven geotextiles exhumed, the change in strength was between a 10 per cent loss and a 14 per cent gain. The conclusion of this research was that measured strength loss did not appear to have affected the proper functioning of any of the geotextiles examined (Brorsson and Eriksson, 1986).

Hausmann et al. (1990) conducted laboratory abrasion tests on geotextiles using a modified Deval attrition test (BS 812, 1951). The hole diameters found in drop cone tests gave a good qualitative indication of strength loss due to abrasion, as hole diameters increased with increasing abrasion. In the same investigation, geotextiles were exhumed from 15 sites in New South Wales (NSW) and tested in narrow strip tensile tests, where the observed loss of initial strength was between 15 and 73 per cent. Heavier non-wovens exhibited less damage than lighter ones, but composite geotextiles exhibited the least damage of all fabrics tested. This is consistent with the findings of Ruddock (1977) who stated that, "A considerable reduction in the loss of strength...is achieved by the addition of a light needled layer to a woven fabric."

Sprague and Cicoff (1989) reported on the installation of a woven and a non-woven geotextile beneath a road pavement in Greenville County, South Carolina. Geotextile samples were exhumed from beneath the pavement after compaction, but prior to the completion of the road. Most of the samples exhibited puncture damage to a minor extent. The Mullens Burst tests and puncture tests carried out on these samples were set up to avoid these puncture holes. As would be expected, the loss in strength was small, although there were still some puncture holes in almost every test specimen. From this work, it was concluded that slit film woven and needle punched non-woven geotextiles show the same degree of installation survivability, under similar conditions. However, these conclusions seem dubious as the major puncture areas were purposely avoided for testing, hence producing biased results.

Bonaparte et al. (1988) exhumed samples of two different heat bonded fabrics from seven existing unpaved roads. The age of the materials ranged from 1 to 12 years. Testing found the residual strength was between 50 and 90 per cent of initial strength, varying with the severity of installation conditions. Tests were also performed to determine the cause of the measured loss in strength. Differential scanning calorimetry and Fourier transform infrared spectroscopy analyses showed very little polymer degradation. Scanning electron photomicrographs indicated the primary cause of strength loss to be mechanical damage to the macroscopic structure of the geotextile. At some sites, the geotextiles sustained considerable installation damage. However, as the overlying road conditions at all sites had not deteriorated since construction it was assumed that they still performed adequately as separators. The traditional view of survivability, where geotextiles are said to have survived if they sustain only minor damage, was questioned. Their observations were that these fabrics had functioned as good separators even though they had sustained considerable installation damage.

The most extensive survey of geotextile survivability available at the time of writing is that of Koerner and Koerner (1990). Sixty-six geotextiles, including woven slit film, woven monofilament, non-woven heat bonded and non-woven needle punched fabrics, were exhumed from 48 sites and wide strip tensile, grab tensile, puncture, trapezoidal tear and Mullens Burst tests were conducted on all geotextile samples. The exhuming was carried out as soon as possible, but always within one week of installation. The number of holes greater than 6mm was recorded for each sample. A plot of strength retained against the number of holes per square metre, reproduced here as Figure 2.7, shows the data points divided into three arbitrary groups. For samples with 0 to 6 holes per square metre (A), the strength retained was between 100 and 67 per cent. The next group was samples with 6 to 30 holes per square metre (B), for which the strength retained was between 85 and 45 per cent. The third group (C) was deemed unacceptable as there were more than 50 holes per square metre and the strength retained was between 60 and 15 per cent.

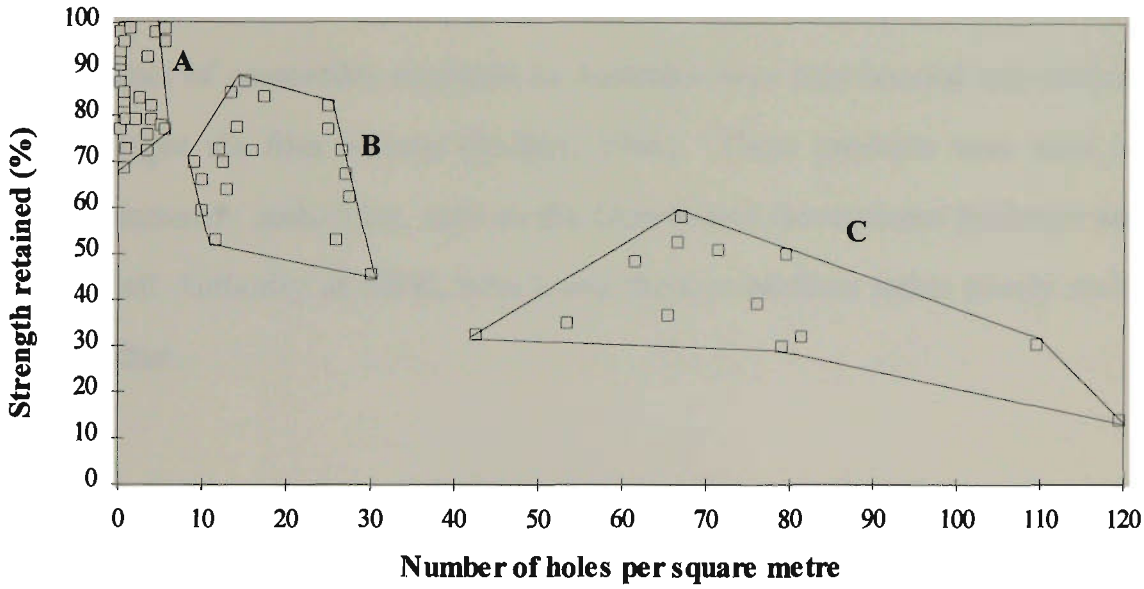

Figure 2.7 Number of holes per square metre versus strength retained (after Koerner and Koerner, 1990).

It is desirable to compare the results of Koerner and Koerner to those of Nowatzki and Pageau (1984) (see page 29). However, one hole in a 50mm by 250mm would correspond to 80 holes per square metre. The results of Koerner and Koerner show a residual strength of less than 40 per cent for this number of holes, whereas the minimum residual strength quoted by Nowatzki and Pageau is 55 per cent. The size of the holes made by Nowatzki and Pageau ranged in diameter up to 12.5mm, whereas Koerner and Koerner only recorded holes greater than 6mm.

In the published work mentioned in sections 2.5.1 and 2.5.2, there are no results given which would enable specific geotextiles to be allotted survivability rankings to Christopher and Holtz (1985). A specific research program would be required for this purpose.

2.6 Geotextiles in Australia:

2.6.1 Introduction:

The first types of geotextiles available in Australia were heat bonded non-wovens and lightweight slit film wovens (Sadlier, 1988). These products were used by several government authorities, such as the Queensland Government Railways and the State Rail Authority of NSW, who found them to perform rather poorly under railroad ballast.

In the mid 1970s, needle punched non-wovens were introduced into Australia. Both the NSW and Queensland railway authorities conducted full scale tests on a variety of geotextiles, and produced reports to aid in geotextile selection for applications such as ballast separation, drainage and erosion control. These reports were important as, at the time, there were no standardised methods for geotextile testing in Australia. Hence, anything that could aid in geotextile selection, especially if it was based on the results of field trials, was readily accepted and used (Finn and Sadlier, 1986).

As reported by Sadlier (1988), a survey by the Commonwealth Department of Housing and Construction in 1980, found that a number of state road authorities were using geotextiles. These included the Queensland Main Roads Department

(QMRD), the NSW Roads and Traffic Authority and the Victorian Country Roads Board (now part of VicRoads). The main use of geotextiles by these bodies was for subgrade separation under road pavements .

2.6.2 Major Australian geotextile publications:

The first major Australian geotextile publication was the QMRD report 'Evaluation of Geotextiles' (Waters et al., 1983). This report initiated much of the research into geotextiles which has since been undertaken in Australia. It was also the basis, along with some American Standards, for the draft geotextile Standard issued in 1987.

The second major Australian geotextile publication was the Austroads 'Guide to Geotextiles' developed in January, 1990. Austroads is an association of road authorities from the six states and two territories of Australia, and a federal government department (Austroads, 1990). This publication included references to the draft Standard. In October, 1990, the geotextile Standard AS 3706 was published. This was followed by the design manual by Warwick (1991). The manual summarises the major filter criteria from the leading geotextile authorities worldwide. It also mentions various test methods and the use of modified plungers in CBR puncture tests. It is the most extensive geotextile reference written in Australia.

2.6.3 Geotextile classification:

The 1983 QMRD report 'Evaluation of Geotextiles' proposed a new classification system for geotextiles in Australia called the G-Rating. The G-Rating is given by:

$$G = \sqrt{F_p \times h_{50}} \tag{2.9}$$

Where:

G = Geotextile strength rating $(N.mm)^{½}$.

F_p = CBR puncture test failure load using a flat plunger (N).

h_{50} = Drop height required to produce a 50mm diameter hole (mm).

When the results of the CBR puncture and drop cone puncture tests were evaluated, it was found that some fabrics performed well in only one of the two tests. It was considered reasonable at the time to take the geometric mean of the two tests (Waters et al., 1983).

The CBR puncture test and drop cone puncture tests have since been published as Australian Standards AS 3706.4 (1990) and AS 3706.5 (1990) respectively.

In AS 3706.4, the rate of strain is 20mm/minute and the load at failure (F_p) is recorded. In AS 3706.5, a formula is given to calculate a drop height that would cause a 50mm diameter hole (h_{50}) from the measured hole diameter. It is given in two forms as shown in Equation 2.10.

$$d_2 = d_1\left(\frac{h_2}{h_1}\right)^{0.68} \quad \textbf{OR} \quad h_2 = h_1\left(\frac{d_2}{d_1}\right)^{1.47} \tag{2.10}$$

Where:

h_1 = First drop height (mm).

h_2 = Second drop height (mm).

d_1 = Diameter of hole corresponding to h_1 (mm).

d_2 = Diameter of hole corresponding to h_2 (mm).

Six robustness classification groups were nominated and allotted ranges of G values as shown in Table 2.6. For most fabrics, G values fell into reasonably well-defined groups and the numerical boundaries were chosen from the limits of these groups (Litwinowicz, 1993).

Table 2.6 Classification of fabrics in terms of the G-Rating (after Waters et al., 1983)

Classification	G-Rating
Weak	<600
Slightly Robust	600-900
Moderately Robust	900-1350
Robust	1350-2000
Very Robust	2000-3000
Extremely Robust	>3000

In situations where geotextiles are used for separation purposes, selection is recommended in terms of robustness categories and soil properties. This is shown in Table 2.7. Other factors, such as the presence of vegetation and the weight of construction plant, are mentioned as further considerations, but their effect is not quantified.

Table 2.7 G-Rating categories for varying subgrade strengths (after Waters et al., 1983)

Soil Properties			Fabric Category
Description	**Undrained Cohesion (kPa)**	**CBR (%)**	
Firm	25-50	2.5-5.0	Moderately Robust
Soft	10-25	1.0-2.5	Robust
Very soft	<10	<1.0	Very Robust

The G-Rating classification requires that, if elongation at failure in the CBR puncture test exceeds 80 per cent, the load at 80 per cent elongation shall be used to calculate the G-Rating (Austroads, 1990). It is not possible to say whether the 80 per cent rule is valid or not as this needs to be verified by in-situ testing. However, it can be said that the elongation of the geotextile should not be so great that it would lead to rutting beyond acceptable levels.

The second area of uncertainty regarding the G-Rating concerns the formula used for calculating h_{50} (see Equation 2.10). A single exponent value is given in AS 3706.5 (1990) for all fabrics, regardless of material type or method of manufacture. A note in AS 3706.5 states that the exponent was generally found to be between 0.55 and 0.7, with 0.68 chosen as the best approximation. As different geotextiles may produce exponents outside this range, it is possible that the exponent may need to be varied for particular fabrics. However, this also needs to be verified with testing.

2.7 Conclusion:

Of the 35 fabrics tested as part of the Queensland study (Waters et al., 1983) only about 25 are still available, and many have changed in their composition. For this reason, there appears to be a lack of knowledge of the behaviour of present-day geotextiles.

A lack of published field data inhibits any correlations between the G-Rating classification system and geotextiles in practice. The relationships between drop height and hole diameter in AS 3706.5 (5) should be reviewed for currently available geotextiles.

Modified plungers should be used in CBR puncture tests to better model geotextile/aggregate interaction, and with a view to possibly incorporating such results into a classification system. At the same time, if possible, the results of these tests should be used to validate the values of shape factors for rounded and angular aggregate currently in use.

Wide strip tensile tests must also be conducted to compare previously defined relationships between CBR and wide strip tensile tests with current test results.

As a result of this literature review, and the conclusions outlined above, it was decided to investigate the behaviour of geotextiles in CBR and drop cone puncture tests, and to use the results to evaluate the G-Rating classification system. The results of the CBR puncture tests were also compared with wide strip tensile test results. It was also decided to investigate the behaviour of geotextiles under pyramid-tipped and hemispherical plungers to validate the shape factor values currently quoted in the literature.

CHAPTER 3

3.O TESTING PROCEDURES AND CALCULATION METHODS

3.1 Introduction:

A testing program was undertaken which included as many of the geotextiles currently available in Australia, that could be obtained at the time. It was felt that this research was of sufficient importance to warrant such a wide spectrum of fabrics being tested.

This chapter summarises the geotextiles tested, their composition and method of manufacture. It also contains a description of the test methods and equipment used as part of the research program. In total, 1,475 tests were carried out on 24 geotextiles. These included CBR puncture tests using flat, pyramid-tipped and hemispherical plungers, drop cone puncture tests at various drop heights and wide strip tensile tests.

Also included is a description of the different methods for calculating elongation in CBR puncture tests using a flat plunger. For CBR puncture tests using a pyramid-tipped plunger, the formula for elongation is given, and for tests using the hemispherical plunger, the formulae for elongation based on two and three-dimensional analyses, are also given.

3.2 Materials tested:

The geotextiles included in the testing program were non-woven fabrics of either needle punched or heat bonded construction, woven fabrics and a composite woven/non-woven fabric. The non-woven geotextiles consisted of continuous filaments, except for two which were made of staple fibres. Table 3.1 lists the brand names of the materials tested, their composition and method of manufacture.

Table 3.1 Summary of geotextiles tested.

Manufacturer	**Product**	**Name**	**Weight (g/m^2)**	**Material**	**Type of fabric**
Geofabrics	Bidim	A 12 A 14 A 24 A 29 A 34 A 44	120 140 180 215 260 310	Polyester	Non-woven needle punched continuous filament
Polyfelt	Polyfelt	TS 420 TS 500 TS 550 TS 600 TS 650 TS 700 TS 750	130 140 180 200 235 280 350	Polypropylene	Non-woven needle punched continuous filament
Soil Filters	Terrafix	310 R 360 R	310 375	Polyester	Non-woven needle punched staple fibre
Rheem	Polytrac	155 C	155 345	-Polypropylene -Polypropylene/ Polyester	-Plain woven tape fabric -Composite woven/non-woven fabric
CSR Humes	Propex	2002	155	Polypropylene	Plain woven tape fabric
Nylex	Terram	700 SUV 1000 SUV 3000 SUV	110 140 280	Polypropylene	Non-woven thermally bonded continuous filament
Sarlon	Polyweave	F R HR	102 180 150	Polypropylene	Plain woven fabric

3.2.1 Sampling procedure:

The materials were obtained directly from manufacturers and/or suppliers and stored indoors, away from direct sunlight, and samples were not taken until the commencement of the testing program. At this time, two days were set aside to prepare all the test specimens. The minimum length of geotextile sampled was two metres and the minimum number of specimens taken from each sample was ten.

The test specimens were taken so as to avoid areas within two metres of the end of a production roll, and within 100mm of any edge. Areas which were obviously soiled were also avoided. All rectangular specimens were cut so that the edges were either parallel or perpendicular to the warp (machine) or weft (cross-machine) yarns for wovens, and parallel or perpendicular to the machine direction for non-wovens. For woven materials, specimens were taken so that no two contained the same warp or weft yarns. The sampling procedure complied with the requirements of AS 3706.1 (1990).

3.3 Testing equipment and procedures:

The laboratory at which the tests were conducted is National Association of Testing Authorities (NATA) registered for the tests carried out. All temperature, humidity, and distance measurements were also carried out using NATA registered equipment. All the tests were performed in a standard atmosphere, as defined by Section 5.2 of AS 3706.1 (1990), in which the temperature was 23 ± 5°Celsius and the relative humidity was 65 ± 5 per cent. Temperature and humidity were monitored using a hygrothermograph, which was calibrated several times during the testing program to ensure accuracy. All specimens were subjected to atmospheric conditioning by placing on a wire shelf for at least two hours in the standard atmosphere.

The flat and modified plunger CBR puncture tests and the wide strip tensile tests were carried out on an Instron 4302 testing machine. The load cell used for the CBR tests was a UK 877, 10 kN static load cell. The data was collected and analysed to AS 3706.4 (1990) for the CBR puncture tests and AS 3706.2 (1990) for the wide strip tensile tests, by Instron series IX Automated Materials Testing System, version 2.51M.

The drop cone puncture tests were carried out on a drop cone test apparatus constructed to meet the requirements of AS 3706.5 (1990).

All CBR and drop cone puncture test specimens were weighed on an A & D FX-200 electronic balance, reading to 0.01 grams.

3.3.1 CBR puncture tests:

The procedure for the CBR puncture tests followed that given in AS 3706.4 (1990). Specimens 195mm in diameter were taken and labelled with a water-based felt-tip pen. They were then placed between two clamping rings and the rings tightened. The grooves in the rings caused the fabric to be partially stretched which took out some of the slack in the specimen.

The clamped fabric was placed onto a CBR mould in the testing machine and the 50mm diameter plunger was pushed through it at a rate of 20mm/minute. The force-displacement curve was displayed on a computer screen and the failure load and vertical plunger displacement at failure recorded on a hardcopy printout. Tests were done on ten specimens from each sample. For the composite fabric, ten specimens were tested with the woven face up and ten specimens with the woven face down. The coefficient of variation was calculated for all fabrics and found to be not greater than the 20 per cent limit specified in AS 3706.4 (1990).

The testing procedure followed when using the pyramid-tipped plunger was the same as the flat plunger CBR puncture tests, except for the shape of plunger tip and the number of specimens tested, which was five for the pyramid-tipped plunger. For the composite fabric, five specimens were tested for each face. The pyramid was four-sided with an apex angle of 45 degrees, with the apex machined to a 2mm radius and all other edges machined to a 1mm radius as shown in Figure 3.1.

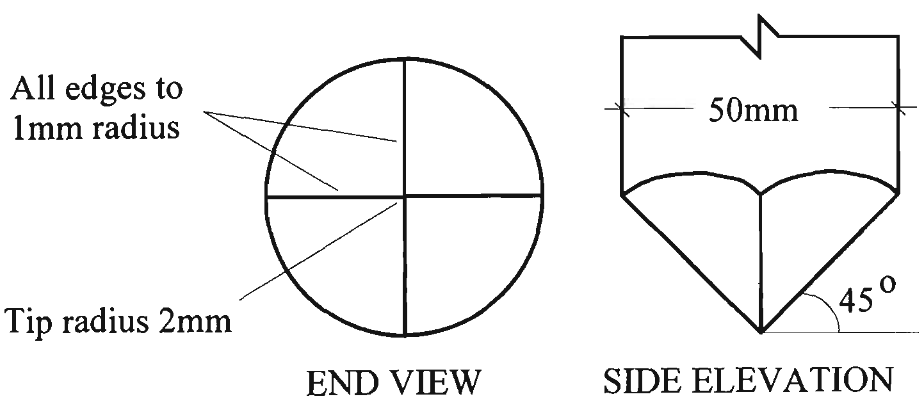

Figure 3.1 Dimensions of the pyramid-tipped CBR plunger.

The testing procedure followed with the hemispherical plunger was also the same as the flat plunger CBR puncture tests, except for the shape of the plunger tip, which was rounded to a 25mm radius as shown in Figure 3.2. The number of specimens tested was five for each fabric. For the composite fabric, five specimens were tested for each face.

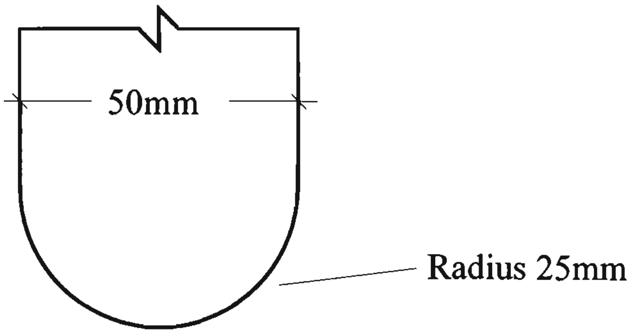

Figure 3.2 Dimensions of the hemispherical CBR plunger.

3.3.2 Drop cone puncture tests:

The drop cone puncture tests were carried out according to AS 3706.5 (1990). Before any tests were actually performed on the specimens, 5 pieces of paper were cut to shape and placed between the clamping rings. A circle of radius 5mm was drawn at the centre each piece of paper and the cone was allowed to fall on them one at a time. After removal of the cone, it was found that it had initially punctured the paper within 2mm of the centre of the circle for each piece of paper, which is within the 5mm tolerance given by AS 3706.5 (1990).

Specimens 195mm in diameter were cut and labelled with a felt-tip marking pen. The fabric was placed between two clamping rings and the latter were tightened. The clamps together with the fabric were placed onto a CBR mould. With the fabric and the drop cone in position, the vertical distance between them was measured every fifty tests and found to be 500mm ± 1mm.

The drop cone was held in position by a pin placed through the rod to which it was attached. For each specimen, the pin was removed, allowing the cone to fall freely onto the fabric. Upon coming to rest, the cone was returned to its original position and pinned. A graduated measuring cone was then placed into the hole in the fabric and allowed to rest under its own weight. The point of contact between the fabric and the cone was found using the thumbnail. This method follows that outlined by Waters et al. (1983). It gave hole diameters identical to those found by marking the cone with a chinagraph pencil. The diameter of each hole was measured to the nearest 0.25mm, although AS 3706.5 (1990) only requires the measurement of hole diameters to the nearest 1mm. However, it was felt that the scatter of plotted points would be reduced by measuring the holes more accurately.

The hole diameter (d_{500}) and drop height were recorded for ten specimens of each fabric tested at 500mm. For the composite fabric, ten specimens were tested with the woven face up and ten with the woven face down. The coefficient of variation was calculated for all fabrics and found to be less than 20 per cent.

Tests were conducted at 500mm drop height for all but the Terram 700 SUV and both Terrafix fabrics. For the Terram fabric, the cone totally penetrated the specimen when dropped from 500mm, therefore, the drop height was reduced to 250mm. For the Terrafix fabrics, the holes produced by the cone dropped from 500mm were very small and awkward to measure. Hence, the drop height for these fabrics was increased to 750mm.

In order to determine the form of the relationship between hole diameter and drop height for each fabric, tests were also conducted at 250mm and 750mm for all fabrics except the Terram 700 SUV and both Terrafix fabrics. For the Terram fabric, the alternative drop heights were 125mm and 375mm respectively, and for the Terrafix fabrics they were 875mm and 1000mm. Both alternative drop heights for the Terrafix fabrics were greater than 750mm in order to obtain holes large enough to measure accurately.

The values chosen for the alternative drop heights enabled comparisons between failure hole diameters for a drop height ratio of two. AS 3706.5 (1990) requires an exponent of 0.68 to be applied to the drop height ratio in order to obtain the drop height which would give a hole diameter of 50mm (see Equation 2.8). Applying this exponent to a drop height ratio of two gives a value of 1.60 for the ratio of failure hole diameters. For most fabrics, the diameter of the hole obtained with a 500mm drop height was compared with that obtained using a 250mm drop height. For the Terram 700 SUV fabric, the values obtained with drop heights of 250mm and 125mm were compared. For the Terrafix range, additional drop cone tests were conducted at 1500mm so that the results could be compared with those at 750mm.

For the tests at 500mm, the measured hole diameter was greater than 10mm for all but the Polyweave HR fabric. At 250mm, seven fabrics gave hole diameters of 10mm or less. AS 3706.5 (1990) states that drop heights should be chosen to "...achieve a puncture diameter preferably greater than 10mm." In order to obtain this, drop cone tests at 1000mm were conducted on all fabrics except the Bidim A 12 and the Terram 700 SUV and 1000 SUV fabrics, as the cone totally pierced these fabrics when tests were attempted at this drop height. The results from these tests were compared with those at 500mm, to calculate the ratio of failure hole diameters, and the exponents, for a drop height ratio of two. This allowed a comparison between the exponents found for the d_{500}/d_{250} and d_{1000}/d_{500} results.

3.3.3 Wide strip tensile tests:

The wide strip tensile tests were conducted according to AS 3706.2 (1990). For the non-woven samples, ten specimens of dimensions 200 x 250mm were cut so that five had their longer edge parallel to the machine direction, and five perpendicular to the machine direction. For the woven samples, ten specimens were cut with dimensions of 220 x 400mm. Five specimens had their longer edge parallel to the warp direction, and five parallel to the weft direction.

For the woven specimens, the 220mm width was reduced by alternately ravelling yarns from each side of the specimen until the width was 200mm, or until the removal of another yarn would have caused the width to fall below 200mm. The length of 400mm was required to allow the specimen to be folded around rods in order to prevent specimen slippage between the jaws during testing, as wovens are much thinner and smoother than non-wovens. The rods used were 5mm steel rods of length 220mm. The composite specimens were cut as though they were non-wovens, as ravelling of outer threads proved extremely difficult, and there was no allowance made for composite fabrics in AS 3706.2 (1990). Each jaw face was covered with a coarse sand and coated with an epoxy resin to provide more friction between the jaw face and the test specimen.

Once the test specimen was in position, the jaws were tightened. The gauge length was measured periodically throughout the testing period and found to be 100mm ± 1mm. The upper jaw was then raised at a rate of 20mm/minute until the specimen failed. The following properties were measured and recorded for each specimen - yield tensile strength, elongation at yield strength, ultimate tensile strength and elongation at ultimate strength.

3.4 Calculation methods:

3.4.1 Fabric elongation:

The definition of elongation when referring to geotextile deformation is different from that normally recognised by engineers. Elongation is normally used in engineering to describe the change in length of materials. However, for geotextiles, elongation refers to a change in length or area compared with the initial length or area. This is commonly referred to as strain in engineering, but in geotextile literature these terms are used interchangeably.

3.4.1.1 CBR puncture tests using a flat plunger:

The method of calculation of elongation values required by AS 3706.4 (1990), uses the change in the distance between the plunger edge and the inside of the clamping rings (see Figure 3.3). The West German Standard DIN 54.307 (1982) gives a formula for elongation which is reproduced as Equation 3.1 (and Equation 2.3). It also gives a graph of vertical plunger displacement versus fabric elongation, based on this formula. This graph is given in AS 3706.4 (without the formula) and is reproduced here as Figure 3.4.

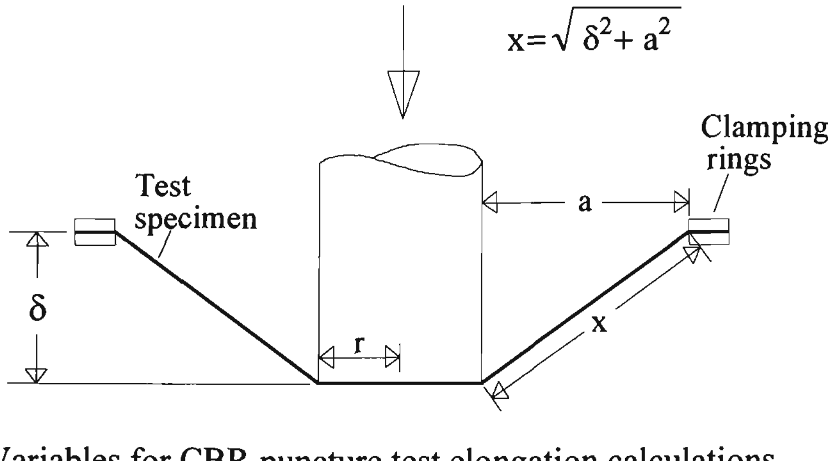

Figure 3.3 Variables for CBR puncture test elongation calculations

$$\varepsilon = \left(\frac{x - a}{a} \right) \times 100 \qquad (3.1)$$

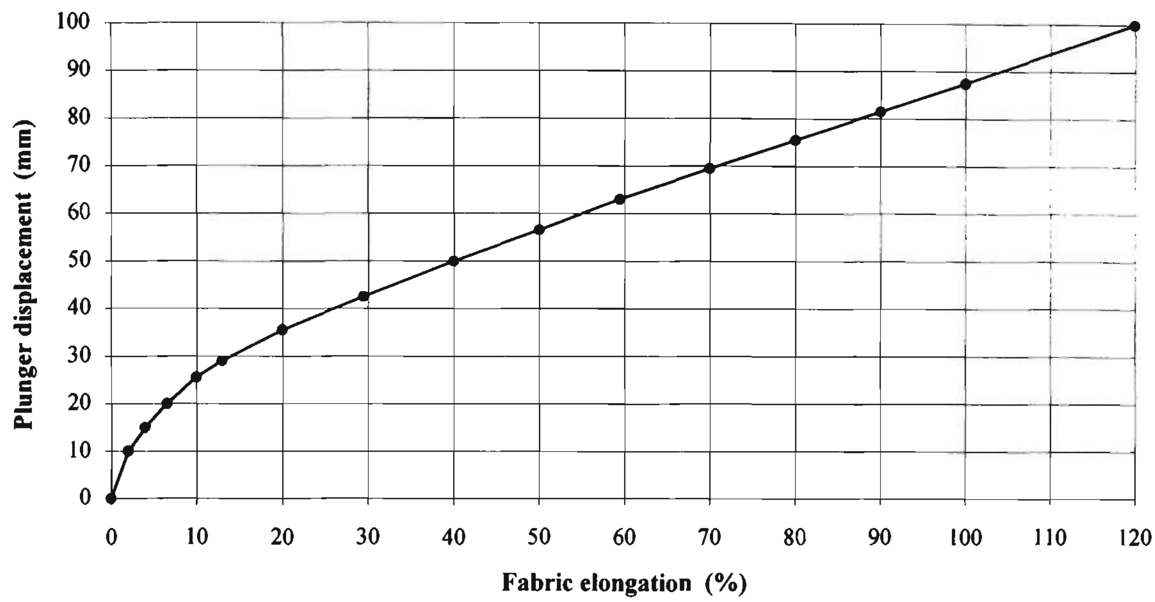

Figure 3.4 Fabric elongation calculated from plunger displacement (after AS 3706.4)

Both the Australian and West German Standards calculate elongation in a vertical plane through the plunger axis. The use of 'x' and 'a' values alone does not take any deformation across the base of the plunger into account. As fabrics were observed to deform across the plunger base during testing, this method of elongation calculation does not accurately represent the geotextile's behaviour. If relative movement across the base of the plunger occurs, the elongation calculated using Equation 3.1 will be greater than the actual percentage change in distance between the plunger edge and the clamping rings. This is because a portion of the distance 'x' is made up of fabric that was initially in contact with the plunger base. A denominator of 'a' alone does not include any reference to this portion of fabric.

A method of calculation which would overcome this problem would be to determine the change in distance between the clamping rings and the centre of the plunger. Using the variables defined in Figure 3.3, the elongation is as shown in Equation 3.2. This formula better reflects the behaviour of the test specimens as it includes the radius of the plunger in the denominator. The term 'a+r' is equal to the radius of the specimen (R), but is given in this form to allow comparison of Equations 3.1 and 3.2. The numerator in both equations is the same, but the latter has a larger denominator, giving smaller elongation values.

$$\varepsilon = \left(\frac{x - a}{a + r}\right) \times 100 \qquad (3.2)$$

Equation 3.1 assumes that all deformation occurs between points B and C in Figure 3.5 i.e. that the fabric between points A and B does not stretch and remains in full contact with the base of the plunger. Equation 3.2 assumes that the stretching occurs over the full distance between points A and C.

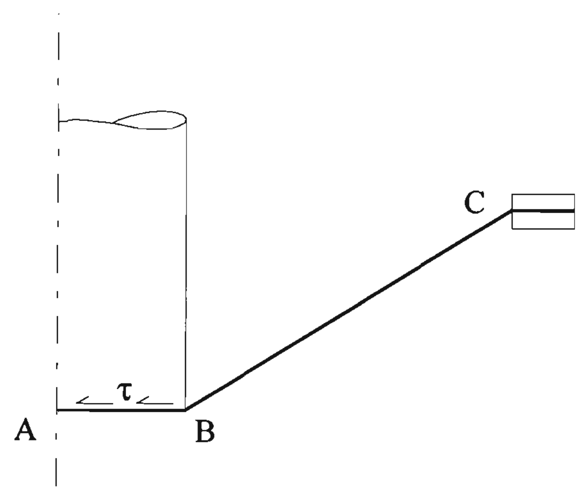

Figure 3.5 Visualisation of shear stresses at interface of plunger and fabric

The shear stress τ must reduce the amount of deformation of fabric in contact with the plunger along A-B. Therefore, neither Equation 3.1 or 3.2 accurately represents the actual elongation behaviour of CBR puncture test specimens. However, it is observed that some sliding of the fabric occurs across the plunger base and, therefore, it is thought that Equation 3.2 better represents the true elongation.

Figure 3.6 shows, schematically, a three-dimensional view of a geotextile specimen undergoing a CBR puncture test, and also the variables required to determine three-dimensional fabric elongation (ie. change in specimen area). This method of elongation calculation was first proposed by Cazzuffi et al. (1986), as they observed the deformed shape of the specimen to approximate a frustum of a cone. They also observed deformations along the base of the plunger, and recognised the inadequacy of Equation 3.1 in reflecting elongation behaviour when this occurs.

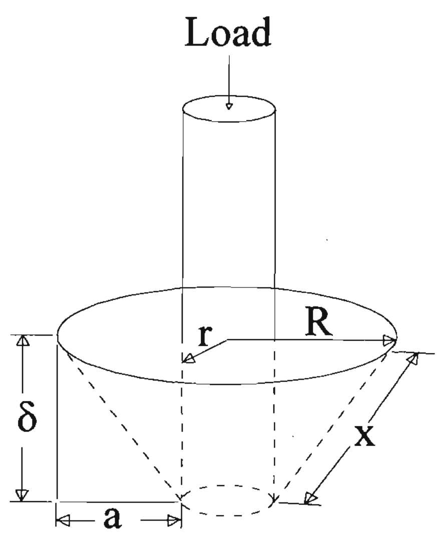

Figure 3.6 Variables for CBR puncture test failure elongation calculations (after Cazzuffi et al., 1986)

Their formula for elongation is reproduced here as Equation 3.4. This equation is arrived at by assuming the shape of the deformed specimen to be that of a frustum of a cone. The surface area of the frustum, given by Equation 3.3, plus the area of geotextile in contact with the plunger base (πr^2) gives the total surface area of a geotextile specimen during a CBR puncture test. The elongation, or change in specimen area, is found by subtracting from this the initial area of the flat specimen (πR^2), and dividing by the same to obtain a percentage difference.

$$A_c = \pi(R + r)x \tag{3.3}$$

$$\varepsilon = \left[\frac{\pi(R + r)x + \pi r^2 - \pi R^2}{\pi R^2}\right] \times 100 \tag{3.4}$$

Where:

A_c = Surface area of the frustum of a cone for a flat CBR plunger.

For x values between 50 and 100, the calculated elongations are as shown in Table 3.2.

Table 3.2 Comparison of elongation values from different equations

x value (mm)	**Elongation by Eq. 3.1 (%)**	**Elongation by Eq. 3.2 (%)**	**Elongation by Eq. 3.4 (%)**
50	0	0	0
60	20	13.3	17.8
70	40	26.7	35.6
80	60	40	53.3
90	80	53.3	71.1
100	100	66.7	88.9

The actual elongation of the specimen will not be the same for that part of the specimen in contact with the plunger and that part which is stretching freely between the plunger and the clamping rings. However, although the amount of restriction on deformation which the base friction causes is unknown, it is thought to be relatively small, and Equation 3.4 is considered to give an adequate representation of actual behaviour.

The actual shape of the test specimens was observed to be not quite that of a frustum of a cone as assumed by Equation 3.4, particularly at larger plunger displacements. The specimen shape actually observed was a three-dimensionally curved surface, similar in cross-section to that shown in Figure 3.7, with β, the angle between the test specimen and the vertical edge of the plunger, increasing with increasing radial distance. The curvature of the specimen is exaggerated for clarity.

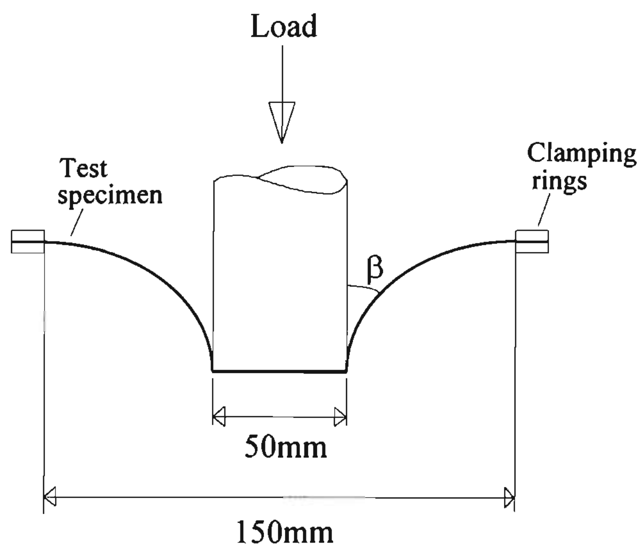

Figure 3.7 Schematic view of actual specimen shape during CBR puncture test

As Equation 3.4 is the closest approximation to actual geotextile behaviour in a CBR puncture test, it should be the preferred method of elongation calculation.

3.4.1.2 Pyramid-tipped plunger CBR puncture tests:

The calculation of elongation for a pyramid-tipped plunger follows the same basic procedure as for the flat plunger. Figure 3.8 shows the variables required to calculate elongation using Equation 3.5 (from Pühringer, 1990). The angle between the edges of the pyramid and the horizontal plane varies from 45 to 55 degrees depending on the orientation of the section through the plunger (see A-A and B-B).

This does not affect elongation calculations as Equation 3.5 assumes that the fabric does not conform to the shape of the pyramid tip.

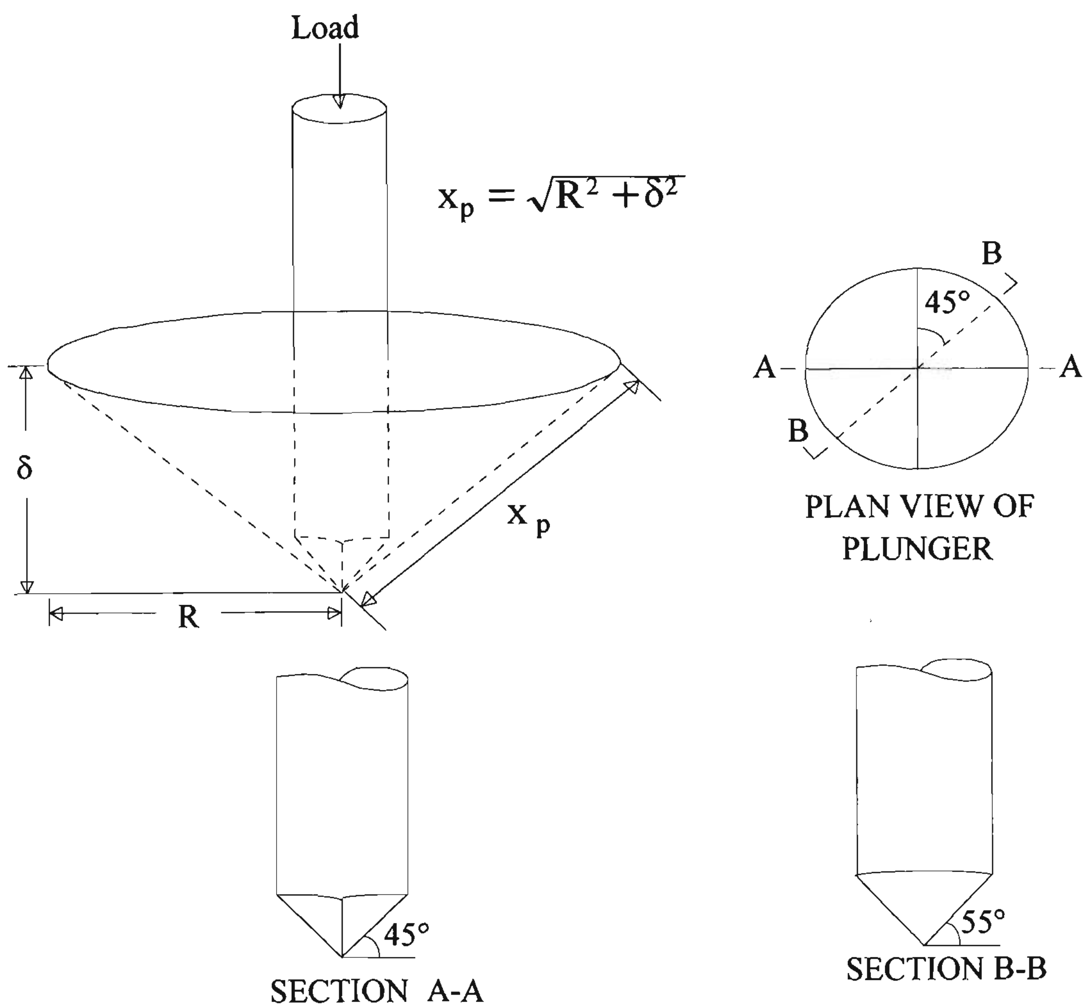

Figure 3.8 Variables for calculating fabric elongation for a pyramid-tipped plunger.

$$\varepsilon = \left(\frac{x_p - R}{R} \right) \times 100 \tag{3.5}$$

Where:

x_p = Fabric length between inside of clamping rings and tip of pyramid-tipped plunger at failure (mm).

This is a two-dimensional analysis equation. For a three-dimensional analysis the shape of the deformed specimen is an inverted cone, for which the surface area is given in Equation 3.6.

$$\text{Surface area of cone} = \pi R x_p \tag{3.6}$$

The three-dimensional elongation is given by Equation 3.7.

$$\varepsilon = \left[\frac{\left(\pi R x_p\right) - \pi R^2}{\pi R^2} \right] \times 100 \tag{3.7}$$

If Equation 3.7 is expanded, it simplifies to Equation 3.5 as shown below.

$$\varepsilon = \left[\frac{\left(\pi R x_p\right) - \pi R^2}{\pi R^2} \right] \times 100$$

$$= \left[\frac{\pi R\left(x_p - R\right)}{\pi R^2} \right] \times 100$$

$$= \left(\frac{x_p - R}{R} \right) \times 100$$

As the plunger cut through most of the specimens tested, Equation 3.7 is not correct after this occurs. After initial rupture, fabrics are cut by the edges of the plunger tip, and the amount of travel of the plunger tip, and of the centre of the specimen, are no longer the same. Equation 3.5 can be used for elongation calculation with this plunger but it only applies for pre-rupture conditions. As the plunger penetrates further through some fabrics than others, it cannot be used to calculate elongation at failure load for the purpose of comparison between fabrics.

3.4.1.3 Hemispherical plunger CBR puncture tests:

The calculation of elongation values for the hemispherical plunger is somewhat different from the standard plunger. Figure 3.9 shows the variables needed to calculate elongation with a hemispherical plunger.

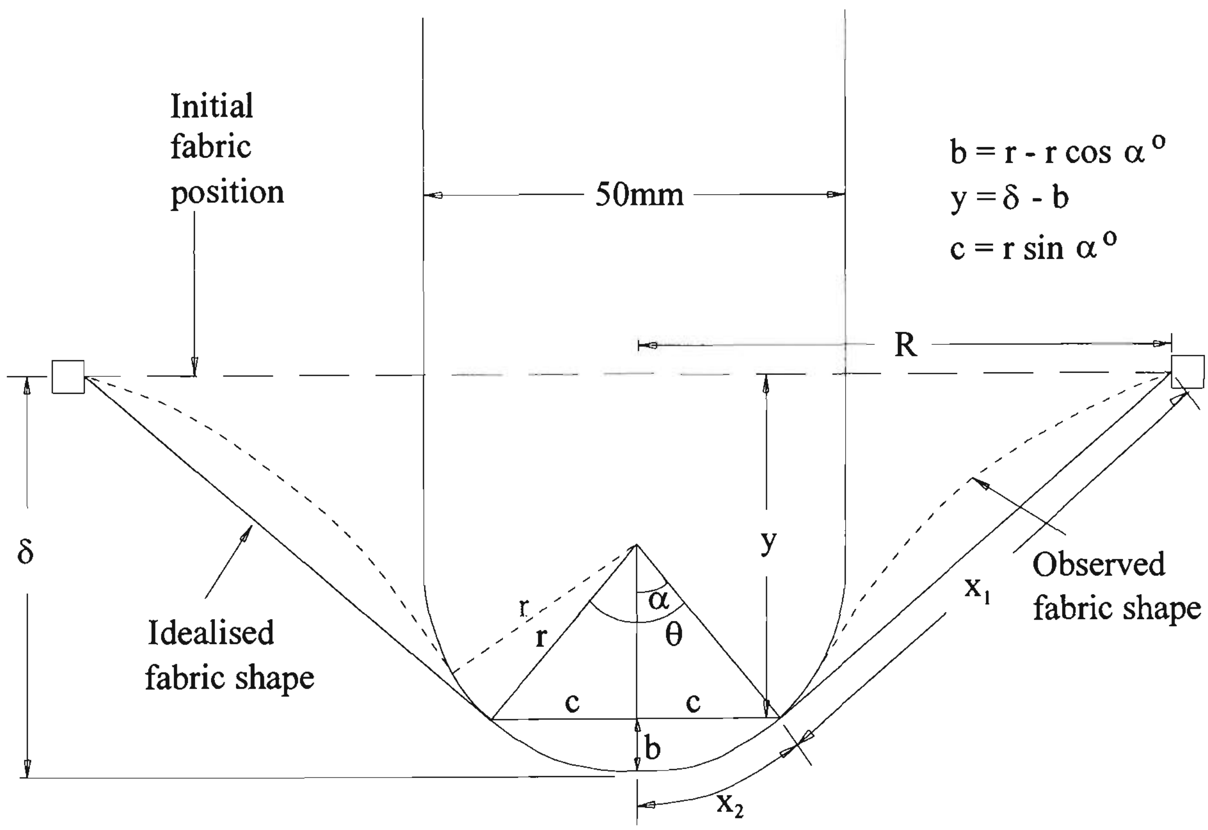

Figure 3.9 Variables for calculating fabric elongation for a hemispherical plunger.

Equation 3.8 calculates the length of fabric not in contact with the plunger, while Equation 3.9 uses the angle α (in radians), to calculate the (arc) length of geotextile in contact with the plunger. Equation 3.11 uses a two-dimensional representation of the test set-up to determine fabric elongation.

$$x_1 = \sqrt{(R-c)^2 + y^2} \qquad (3.8)$$

$$x_2 = r\alpha^c \qquad (3.9)$$

$$x_R = x_1 + x_2 \qquad (3.10)$$

$$\varepsilon = \left(\frac{x_R - R}{R}\right) \times 100 \qquad (3.11)$$

Where:

α = Half of angle subtended by the fabric in contact with the plunger.

x_R = Distance between inside of clamping rings and centre of tip of hemispherical plunger at failure (mm).

Figure 3.9 represents the idealised elastic fabric shape with no friction between the fabric and the plunger. Some fabrics stretched somewhat in contact with the plunger, resulting in an increased α value, and a curvature of the fabric between the plunger and the clamping rings. The staple fibre fabrics were observed to have higher values of α than other types of fabric. The woven fabrics, particularly the Polyweave HR fabric, and the heat bonded Terram 3000 SUV fabric, were observed to have much smaller α values, closer to the idealised material. The length of geotextile in contact with the plunger depends on α and, in turn, the length x_R will change as α changes.

Three-dimensional elongations for the hemispherical plunger are also affected by the value of α, with higher values leading to a larger area of geotextile in direct contact with the plunger. In order to determine three-dimensional elongations, the areas of two parts of the test specimen must be determined - a segment of a sphere, which is in direct contact with the plunger, and a frustum of a cone, between the segment of the sphere and the clamping rings. Figure 3.10 shows this schematically.

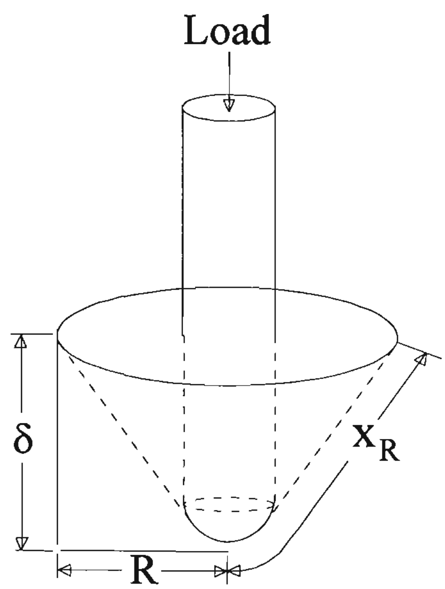

Figure 3.10 Schematic three-dimensional view of hemispherical plunger test.

The surface area of the sphere segment is given by Equation 3.12 and the area of the frustum is given by Equation 3.13. The fabric elongation is given by Equation 3.14.

$$A_S = 2\pi rb \tag{3.12}$$

$$A_F = \pi(R + c)x_1 \tag{3.13}$$

$$\varepsilon = \left[\frac{A_S + A_F - \pi R^2}{\pi R^2}\right] \times 100 \tag{3.14}$$

Where:

A_S = Surface area of segment of sphere.

A_F = Surface area of frustum of cone (for hemispherical plunger).

The value of α depends not only on the plunger displacement but also on the non-linear behaviour of the specimen. As the amount of fabric in contact with the plunger varies between different fabric types (because of a plastic component of deformation), the prediction of α is not possible. However, for the idealised specimen shape, the relationship between δ and α is given by Equation 3.15, for which the derivation is given in Appendix A.

$$\delta = \frac{75\sin\alpha\cos\alpha + 25\left(1 - \cos\alpha - \sin^2\alpha\right)}{\cos^2\alpha} \qquad (3.15)$$

A value of α is required for the calculation of b, c, x_1 and x_2 (see Figure 3.9) and, for a given δ, Equation 3.15 can be solved for α on a programmable calculator or simple spreadsheet. Alternatively, Figure 3.11 can be used to determine α directly from δ values between zero and 100mm. Measured δ values at failure load for this plunger ranged from 33mm to 81mm.

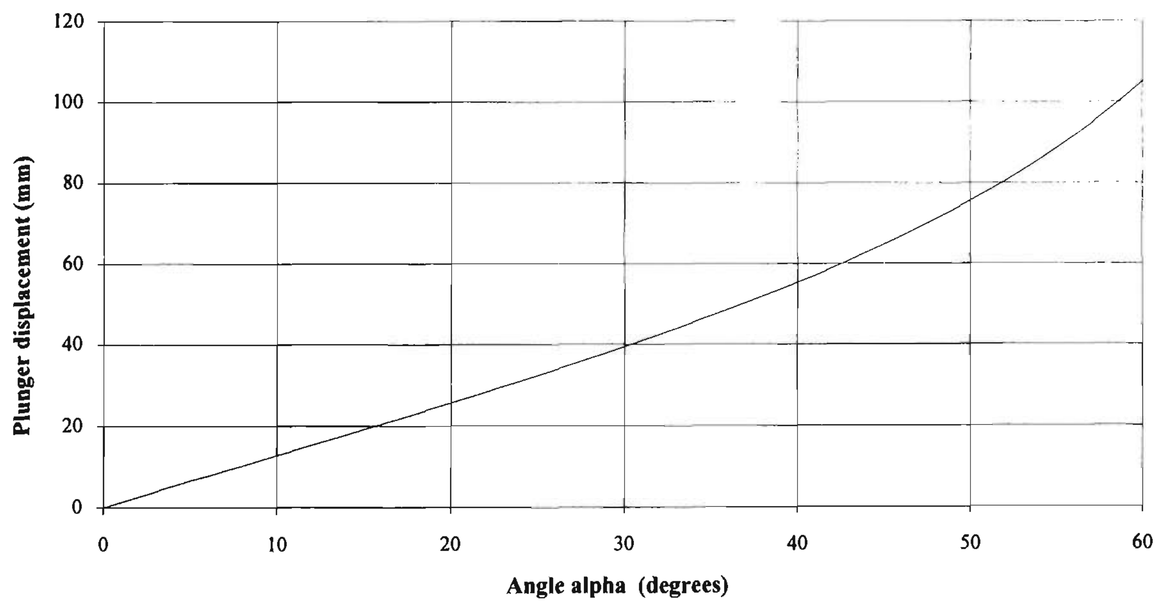

Figure 3.11 Vertical plunger displacement (δ) as a function of α.

As with the flat plunger, Equation 3.14 ignores the effect of friction between fabric and plunger, and assumes an idealised shape for the stretched fabric. However, it is considered to give a good approximation to actual elongation and is recommended for general use.

CHAPTER 4

4.O RESULTS OF TESTING PROGRAM

4.1 Introduction:

This chapter discusses the results of CBR puncture tests using a flat plunger, comparing them with wide strip tensile test results. The use of modified plungers in CBR puncture tests is also discussed, including the change in specimen behaviour under these plungers compared with the flat plunger.

Drop cone puncture test results at a range of drop heights are discussed and the relationship between drop height and hole diameter in AS 3706.5 (1990) is also reviewed.

The mass per unit area of the CBR and drop cone test specimens is given, together with relationships between mass per unit area and failure load for the CBR test specimens, and between mass per unit area and d_{500} (hole diameter for 500mm drop height) for drop cone test specimens.

4.2 CBR puncture tests:

4.2.1 Tests using a flat CBR plunger:

CBR puncture tests using a flat CBR plunger were performed for two reasons, the first being to determine the CBR puncture resistance of all the geotextiles in the testing program, without the need to rely on values quoted by manufacturers and the second to obtain data for calculation of G-Rating values.

The measured CBR failure load was greater than the value quoted by the manufacturer for 16 of the 24 fabrics tested, and both sets of values are given in Table 4.1. It is obvious from the table that the composite fabric has changed as, compared with the value quoted by the manufacturer, the measured failure load showed an increase of over 100 per cent.

The mode of failure observed for all specimens was symmetrical straining between the plunger and the clamping rings, to just before maximum load. At this point, specimens began to tear around the perimeter of the plunger with maximum load occurring soon after. This was expected as the maximum stress in a CBR puncture test specimen occurs at the edge of the plunger (Waters et al., 1983).

Table 4.1 Comparison of measured and manufacturer quoted CBR failure load.

Fabric Name	Measured CBR failure load (N)	Manufacturer quoted CBR failure load (N)	Difference (%)
Bidim			
A 12	1575	1390	13.3
A 14	1869	1800	3.8
A 24	2654	2390	11.1
A 29	3125	2690	16.2
A 34	3792	3400	11.5
A 44	4520	4100	10.2
Polyfelt			
TS 420	1639	1350	21.4
TS 500	1843	1550	18.9
TS 550	1903	1950	-2.4
TS 600	2523	2150	17.4
TS 650	2729	2500	9.2
TS 700	3451	3250	6.2
TS 750	4635	3700	25.3
Polytrac			
155	3621	3050	18.7
C (woven up)	1465	700	109.3
C (woven down)	1520	700	117.1
Polyweave			
R	1866	1967	-5.1
F	2764	3184	-13.2
HR	4651	4026	15.5
Propex			
2002	3506	3900	-10.1
Terrafix			
310 R	1363	1429	-4.6
360 R	1871	2350	-20.4
Terram			
700 SUV	934	900	3.8
1000 SUV	1182	1200	-1.5
3000 SUV	2547	2900	-12.2

4.2.1.1 Comparison of CBR tensile strength and wide strip tensile strength:

The CBR puncture test is related to the wide strip tensile test because tension is mobilised in the geotextile in both tests. In a CBR puncture test, the plunger load is resisted by tension in the plane of the geotextile specimen, with a component parallel to the direction of the applied load. The horizontal component acts as a shear stress between the plunger base and the geotextile in contact with the plunger. As plunger displacement increases, the vertical component of this tension increases resulting in an increased shear stress as it is the product of normal stress on the plunger base and coefficient of friction (constant for any given plunger and geotextile combination). However, in a wide strip tensile test, specimen behaviour is different as the applied load and the resisting tension are parallel, with no shear stress present.

Murphy and Koerner (1988) stated that the CBR puncture test is not actually a puncture test, but rather an axi-symmetric strength test, and should be thus considered. The fabric between the plunger and the clamping rings is theoretically in a pure state of axi-symmetric tension. In a CBR puncture test, there is total restraint along the edge of the entire specimen. In a plane strain tensile test necking is restricted, so the stress state in such a test would be not too dissimilar to that in a CBR puncture test.

As the maximum stress in a CBR test sample occurs at the perimeter of the plunger, the strength per unit width is calculated by dividing tensile force at failure in the plane of the fabric by the circumference of the plunger, as described by Waters et al. (1983), and as shown in Equation 4.1. Cos β is taken as 1.0 by Waters et al. as they assume β to be zero at the perimeter of the plunger tip i.e. the fabric just outside the plunger edge is vertical. As β varies with increasing radial distance, and many specimens were observed during testing to come into contact with the sides of the plunger adjacent to the tip, a value of zero at the perimeter of the tip is realistic.

$$T = \frac{F_p}{\pi \, d \, \text{Cos}\beta} \tag{4.1}$$

Where:

T = Tensile force per unit width (kN/m).

F_p = CBR puncture test failure load using a flat plunger (kN).

d = Diameter of CBR plunger (m).

β = Angle between the plunger and the fabric (Degrees).

With cos β equal to 1.0 and d equal to 50mm, Equation 4.1 becomes, approximately, Equation 4.2 (Cazzuffi et al., 1986).

$$T = 2\pi \cdot F_p \tag{4.2}$$

Equation 4.1 (with cos β = 1.0) was used to calculate the strength per unit width of all the specimens tested and these values are given in Table 4.2 together with results of wide strip tensile tests. The difference varies from -0.9 per cent to 39.7 per cent.

Table 4.2 Comparison of measured and calculated strength per unit width in kN.m.

Fabric Name	Strength per unit width (Wide strip test)	Strength per unit width (Eq. 4.1)	Percentage Difference
Bidim			
A 12	7.55	10.0	32.5
A 14	9.03	11.9	31.8
A 24	12.1	16.9	39.7
A 29	15.9	19.9	25.2
A 34	19.5	24.1	23.6
A 44	21.9	28.8	31.5
Polyfelt			
TS 420	9.34	10.4	11.4
TS 500	10.6	11.7	10.4
TS 550	11.1	12.1	9.0
TS 600	13.0	16.1	23.9
TS 650	15.2	17.4	14.5
TS 700	19.6	22.0	12.2
TS 750	24.8	29.5	19.0
Polytrac			
155	25.3	23.1	-8.7
C (woven up)	13.5	9.33	-30.9
C (woven down)	13.5	9.68	-28.3
Polyweave			
R	13.6	11.9	-12.5
F	25.1	17.6	-29.9
HR	32.6	29.6	-9.2
Propex			
2002	22.5	22.3	-0.9
Terrafix			
310 R	7.76	8.68	11.9
360 R	10.6	11.9	12.3
Terram			
700 SUV	N/A	5.95	N/A
1000 SUV	8.03	7.52	-6.4
3000 SUV	19.2	16.2	-15.6

For the needle punched fabrics, which showed considerable necking in wide strip tensile tests, the strength per unit width was less than that calculated using the CBR puncture test results. Conversely for the woven, composite and heat bonded fabrics, all of which exhibited negligible necking, the strength per unit width in wide strip tests was higher than the calculated CBR strength per unit width. This indicates that the degree of necking in wide strip tensile tests affects tensile strength, with larger values of necking leading to smaller values of strength. Giroud (1992) compared bi-axial and uni-axial properties of geotextiles, and found that the percentage increase in measured strength from uni-axial to bi-axial tensile tests, was equal in magnitude to the percentage decrease in elongation. This increase in strength was 15 per cent for the non-wovens and 5 per cent for the wovens.

Myles and Carswell (1986) found that, at 200mm, the wide strip tensile test overestimated the true strength of wovens (no necking) by about ten per cent, and underestimated the true strength of non-wovens (necking) by about 20 per cent. If the strength values given in Table 4.2 for the CBR tests were changed by ten and 20 per cent in accordance with fabric type, the wide strip test results would be more closely approximated. Cazzuffi et al. (1986) showed that the strength calculated from CBR puncture tests was very similar to strength determined from wide strip tests on 500mm wide samples. At this width, the plane strain condition is more closely approximated by the laterally unrestrained sample. Therefore, the strength per unit width in such a case would correspond more closely to that calculated from a CBR puncture test, than an unrestrained 200mm wide strip test.

4.2.1.2 Fabric elongation:

In the field, a geotextile is usually restricted in lateral deformation by confinement within the fill and in a CBR puncture test the specimen is clamped along its entire edge, but in a wide strip tensile test there is no restraint on lateral contraction. Lateral contraction in a wide strip tensile test is due to Poisson's ratio effects which are not representative of those in the field, where lateral contraction is restricted. Because lateral contraction is prevented in a CBR puncture test, Poisson's ratio effects in the field are better modelled.

Giroud (1992) gives probable values for Poisson's ratio of 0.10-0.15 for wovens and 0.35 for non-wovens based on elastic theory. This is consistent with the observations of specimens in wide strip tensile tests, where wovens were seen to contract very little laterally, compared with non-wovens. Table 4.3 shows elongation values using Equation 3.4 (p. 55) compared with the average of elongation values for wide strip tensile tests to AS 3706.2 (1990) in the machine and cross-machine directions. The difference in values was much greater for the non-woven fabrics, which is directly attributable to lateral contractions in the wide strip tests for all but the Terram fabrics, for which only a small degree of necking was observed.

Table 4.3 Elongation values from CBR puncture and wide strip tensile tests.

Fabric Name	Elongation by Equation 3.4 (%)	Elongation to AS 3706.2 (%)	Percentage increase in elongation
Bidim			
A 12	25.0	46.7	87
A 14	26.8	47.7	78
A 24	27.9	46.3	66
A 29	31.8	50.1	58
A 34	31.4	52.6	66
A 44	32.0	55.1	72
Polyfelt			
TS 420	25.2	54.7	117
TS 500	27.9	53.4	91
TS 550	31.8	57.1	80
TS 600	31.6	53.3	69
TS 650	30.4	61.0	100
TS 700	30.8	63.9	107
TS 750	32.0	68.9	115
Polytrac			
155	16.4	20.3	24
C (woven up)	8.4	9.9	18
C (woven down)	9.6	9.9	3
Polyweave			
R	17.7	22.8	29
F	20.7	35.6	72
HR	22.5	25.8	15
Propex			
2002	22.3	27.7	24
Terrafix			
310 R	68.7	140.0	104
360 R	68.2	144.5	112
Terram			
700 SUV	37.1	N/A	N/A
1000 SUV	39.6	60.7	53
3000 SUV	38.4	75.8	97

Comparison of elongation values in Table 4.3 shows behaviour consistent with the observations of Cazzuffi et al. (1986), who found that the elongation in 500mm wide strip test specimens, with lateral contraction accounted for in the calculation method, was close to that calculated for CBR puncture tests using Equation 3.5. They also found that the elongation of 200mm wide strip specimens, for which lateral contraction was not accounted for in the calculations, was much greater than that of the 500mm wide specimens. According to Myles and Carswell (1986), a 500mm wide strip tensile test more closely represents the true behaviour of geotextiles than at 200mm width. The elongation in a CBR puncture test calculated using the three-dimensional formula is then a better approximation to elongation in the field than a 200mm laterally unrestricted wide strip tensile test.

4.2.2 Tests using modified plungers:

The distribution of stress in a geotextile specimen is different when using a flat plunger compared with a pointed or rounded penetrating element. The latter two result in a concentration of stress at the centre of the plunger rather than around the perimeter of the plunger. CBR puncture tests using plungers with pyramidal and hemispherical tips were conducted in order to determine the difference in behaviour compared with flat plunger tests.

4.2.2.1 Pyramid-tipped plunger CBR puncture test:

Critical geotextile applications usually involve angular aggregate. The larger and more angular the particles, the more damage they can cause to the geotextile. The drop cone test is a dynamic test and more related to the installation procedure than to the quasi-static penetration mode experienced by geotextiles in service. A CBR puncture test, whether it is performed using a flat or modified plunger, loads a specimen gradually, thereby more closely simulating the application of load in normal service.

The results of tests using a pyramid-tipped plunger showed a significant decrease in failure load compared with the flat plunger, for all but staple fibre fabrics. As shown in Table 4.4, the decrease was 47-68 per cent for needle punched fabrics, 49-60 per cent for heat bonded fabrics and 63-78 per cent for woven fabrics. The composite fabric exhibited an average decrease in failure load of 60 per cent, putting it in the same range as the continuous filament non-wovens. Assuming the pyramid-tipped plunger used is an adequate model of angular aggregate, CBR puncture tests using a flat plunger overestimate the puncture resistance of all but staple fibre fabrics.

The small gain in failure load of 1-3 per cent for the staple fibre fabrics is due to the localisation of the load to fibres in the immediate vicinity of the tip of the pyramid. Under the pyramid-tipped plunger, the filaments in continuous filament fabrics are stretched until they are cut by the edges of the plunger. In staple fibre fabrics, the fibres are stretched but failure is not by cutting of fibres, rather, it was seen to be mainly due to large-scale slipping of fibres in the vicinity of the plunger with very little cutting. This failure mechanism is similar to that of staple fibre fabrics under a flat plunger, hence the closeness of failure load values for the two plungers (see Table 4.4). Lhote and Rigo (1987) explained this by proposing that a bearing-type failure occurs across the base of a flat CBR plunger, which gives way to a more local failure at the tip of the pyramid-tipped plunger. This agrees well with observations of test specimens under a pyramid-tipped plunger, but for the flat plunger, failure was observed to be at the perimeter and not across the base.

Table 4.4 Comparison of flat and pyramid-tipped plunger CBR failure loads.

Fabric Name	**Flat CBR plunger load (N)**	**Pyramid-tipped CBR plunger load (N)**	**Percentage change in strength**
Bidim			
A 12	1575	834	-47.1
A 14	1869	774	-58.6
A 24	2654	1113	-58.1
A 29	3125	1193	-61.8
A 34	3792	1570	-58.6
A 44	4520	1815	-59.9
Polyfelt			
TS 420	1639	635	-61.3
TS 500	1843	727	-60.6
TS 550	1903	618	-67.5
TS 600	2523	845	-66.5
TS 650	2729	865	-68.3
TS 700	3451	1166	-66.2
TS 750	4635	1568	-66.2
Polytrac			
155	3621	807	-77.7
C (woven up)	1465	542	-63.0
C (woven down)	1520	647	-57.4
Polyweave			
R	1866	635	-66.0
F	2764	1023	-63.0
HR	4651	1188	-74.5
Propex			
2002	3506	935	-73.3
Terrafix			
310 R	1363	1403	2.9
360 R	1871	1894	1.2
Terram			
700 SUV	934	403	-56.9
1000 SUV	1182	601	-49.2
3000 SUV	2547	1022	-59.9

The results for the needle punched fabrics compare favourably with those of Werner (1986) who reported a reduction in failure load of 50-66 per cent for these fabrics. However, for heat bonded (70-75 %) and woven (85 %) fabrics, his values are higher than those given in Table 4.4, especially for the heat bonded fabrics.

4.2.2.2 Hemispherical plunger CBR puncture test:

Not all geotextile applications involve angular aggregate. The effect of rounded puncturing elements is not discussed in literature available at the time of writing. Spherical aggregate affects a geotextile less severely than angular aggregate.

The results of tests using a hemispherical plunger showed a moderate decrease in failure load compared with the flat plunger, for all but staple fibre fabrics. As shown in Table 4.5, the decrease was 2-22 per cent for the needle punched fabrics, 2-12 per cent for the heat bonded fabrics and 23-35 per cent for the woven fabrics. The average decrease in failure load for the composite fabric was 32 per cent, putting it in the range of the woven fabrics. Under the pyramid-tipped plunger, this fabric showed a decrease in failure load in the range of the needle punched fabrics.

The staple fibre fabrics showed an increase in failure load, compared with the flat plunger, of 13 and 21 per cent for the 310 R and 360 R fabrics respectively. This increase in failure load is due to the localisation of stress at the centre of the hemispherical tip, as was the case with the pyramid-tipped plunger. However, unlike the pyramid-tipped plunger, there was no cutting of fibres by the plunger and the failure load is therefore greater. For the other fabrics the absence of cutting of fibres led to much smaller decreases in failure load under the hemispherical plunger, than under the pyramid-tipped plunger.

Table 4.5 Comparison of flat and hemispherical plunger CBR failure loads.

Fabric Name	Flat CBR plunger load (N)	Hemispherical CBR plunger load (N)	Percentage change in strength
Bidim			
A 12	1575	1499	-4.9
A 14	1869	1729	-7.5
A 24	2654	2317	-12.7
A 29	3125	2890	-7.5
A 34	3792	3687	-2.8
A 44	4520	4443	-1.7
Polyfelt			
TS 420	1639	1441	-12.1
TS 500	1843	1442	-21.8
TS 550	1903	1530	-19.6
TS 600	2523	2152	-14.7
TS 650	2729	2417	-11.4
TS 700	2451	2969	-14.0
TS 750	4635	4085	-11.9
Polytrac			
155	3621	2361	-34.8
C (woven up)	1465	1032	-29.6
C (woven down)	1520	1008	-33.7
Polyweave			
R	1866	1371	-26.5
F	2764	2094	-24.2
HR	4651	3486	-25.1
Propex			
2002	3506	2693	-23.2
Terrafix			
310 R	1363	1540	13.0
360 R	1871	2267	21.2
Terram			
700 SUV	934	820	-12.2
1000 SUV	1182	1094	-7.5
3000 SUV	2547	2495	-2.0

4.2.2.3 Relationship between failure load under flat and modified plungers:

In order to relate the failure load in a modified plunger test to that in the flat plunger CBR puncture test, a shape factor S may be defined as shown in Equation 4.3 (and Equation 2.2).

$$S = \frac{F_p}{F_{mod}} \qquad (4.3)$$

Where:

F_p = CBR puncture test failure load using a flat plunger (N).

F_{mod} = CBR puncture test failure load using a modified plunger (N).

Shape factor values for the pyramid-tipped plunger are given in Table 4.6. For the Bidim fabrics, the average shape factor is 2.4 if the lightest weight fabric is excluded. For the Polyfelt fabrics, excluding the two lightest fabrics, the average value is 3.0. For the non-woven heat bonded Terram fabrics, the average is 2.3 and for the composite fabric (Polytrac C), the average is 2.6.

Shape factor values for the woven geotextiles differ greatly from each other, with the Polyweave fabrics having an average shape factor of 3.2, the Propex fabric 3.8 and the Polytrac fabric 4.5, with the weighted average shape factor for all wovens being 3.6. For the staple fibre fabrics, the shape factor is 1.0 as failure load under both plungers was about the same.

Table 4.6 Failure load and shape factor values for a pyramid-tipped plunger.

Fabric Name	Flat CBR plunger load (N)	Pyramid-tipped plunger load (N)	Shape Factor	Average Shape Factor
Bidim				
A 12	1575	834	1.9	2.3
A 14	1869	774	2.4	
A 24	2654	1113	2.2	
A 29	3125	1193	2.6	
A 34	3792	1570	2.4	
A 44	4520	1815	2.5	
Polyfelt				
TS 420	1639	635	2.6	2.9
TS 500	1843	727	2.5	
TS 550	1903	618	3.1	
TS 600	2523	845	3.0	
TS 650	2729	865	3.2	
TS 700	3451	1166	3.0	
TS 750	4635	1568	3.0	
Polytrac				
155	3621	807	4.5	4.5
C (woven up)	1465	542	2.7	2.6
C (woven down)	1520	647	2.4	
Polyweave				
R	1866	635	2.9	3.2
F	2764	1023	2.7	
HR	4651	1188	3.9	
Propex				
2002	3506	935	3.8	3.8
Terrafix				
310 R	1363	1403	1.0	1.0
360 R	1871	1894	1.0	
Terram				
700 SUV	934	403	2.3	2.3
1000 SUV	1182	601	2.0	
3000 SUV	2547	1022	2.5	

Using a hemispherical plunger, the shape factor for all but staple fibre fabrics is greater than one. The test results summarised in Table 4.7 indicate a shape factor of 1.1-1.2 for continuous filament non-wovens, and 1.3-1.5 for wovens. The average value for the composite fabric is 1.5. The variation between fabric types, and between weights for a given fabric, is much smaller than for the pyramid-tipped plunger. The shape factor for staple fibre fabrics is 0.9, as failure load increased by an average of 17 per cent under the hemispherical plunger compared with the flat plunger.

Table 4.7 Failure load and shape factor values for a hemispherical plunger.

Fabric Name	Flat CBR plunger load (N)	Hemispherical CBR plunger load (N)	Shape Factor	Average Shape Factor
Bidim				
A 12	1575	1499	1.1	
A 14	1869	1729	1.1	
A 24	2654	2317	1.2	1.1
A 29	3125	2890	1.1	
A 34	3792	3687	1.0	
A 44	4520	4443	1.0	
Polyfelt				
TS 420	1639	1441	1.1	
TS 500	1843	1442	1.3	
TS 550	1903	1530	1.2	
TS 600	2523	2152	1.3	1.2
TS 650	2729	2417	1.1	
TS 700	3451	2969	1.2	
TS 750	4635	4085	1.1	
Polytrac				
155	3621	2361	1.5	1.5
C (woven up)	1465	1032	1.4	1.5
C (woven down)	1520	1008	1.5	
Polyweave				
R	1866	1371	1.4	
F	2764	2094	1.3	1.3
HR	4651	3486	1.3	
Propex				
2002	3506	2693	1.3	1.3
Terrafix				
310 R	1363	1540	0.9	0.9
360 R	1871	2267	0.8	
Terram				
700 SUV	934	820	1.1	
1000 SUV	1182	1094	1.1	1.1
3000 SUV	2547	2495	1.0	

4.2.2.4 Shape factors for practical use:

In the process of selecting geotextiles for use in the field, results of flat plunger CBR puncture tests are commonly available. Values of probable puncture load on fabrics are calculated assuming a particle diameter but not a shape. When angular or rounded aggregate is to be used, the flat plunger test value for a fabric must be multiplied by the appropriate shape factor in order to choose the appropriate fabric for the given loadings and aggregate shape.

Warwick (1991) quotes a shape factor of 3.0 for angular aggregate. This corresponds well with the results of the Polyfelt fabrics, but by using this value the strength of Bidim would be underestimated by 25 per cent, Polytrac C by 15 per cent and Terram by 30 per cent, under a pyramid-tipped plunger or an angular aggregate. A shape factor of 3.0 would overestimate the strength of Polyweave fabrics by 6.3 per cent, Propex by 21 per cent and Polytrac 155 by 33 per cent. A shape factor of 3.0 would underestimate the strength of staple fibre fabrics by about 300 per cent.

The shape factor quoted in the literature for rounded aggregate is 0.8 (Warwick, 1991; Lhote and Rigo, 1987). This value does not correspond well with the results of any of the fabrics tested. The values found for all fabrics are greater than one, except for the staple fibre fabrics which gave 0.9. The localisation of stress at the centre of the hemisphere leads to lower failure load values compared with a flat plunger, for all but staple fibre fabrics. Hence, the shape factor values given in Table 4.7 are more realistic than a value of 0.8.

4.3 Drop cone puncture test:

In the drop cone puncture tests conducted, most fabrics failed with very little instantaneous vertical displacement, except for the lightest continuous filament non-wovens, and both staple fibre non-wovens, which were displaced noticeably downwards by the impact of the cone on the specimen surface. These displacements were smaller for the continuous filament fabrics, but more significant for the staple fibre fabrics.

Table 4.8 shows the results of the drop cone tests for all fabrics. It includes values of d_{500} unless otherwise indicated. It also gives the ratio of hole diameters for a drop height ratio of two, for tests at 500mm and 250mm, and tests at 1000mm and 500mm, unless otherwise indicated. The corresponding exponent for Equation 2.10 (p. 38) is also given, which is to be compared with the value of 0.68 given in AS 3706.5 (1990). Note 1 in AS 3706.5 states that 0.68 was taken as the best approximation for a range of exponent values from 0.55-0.7.

For the d_{500}/d_{250} case, the Bidim fabrics produced average exponents close to that given in the Standard, as did the Propex fabric. The average exponent for the Polyfelt fabrics was slightly lower, but still inside the range of 0.55-0.7. Exponents outside this range were found for the Terram (average 0.71), Polytrac C (average 0.71), Polytrac 155 (0.47) and Polyweave (average 0.42) fabrics. By far the largest deviation from the Standard value was for the Terrafix fabrics, for which the average exponent was 1.47. It can be seen, then, that some of the geotextiles currently available have properties different from those upon which the relationships in AS 3706.5 (1990) are based, when comparing results from 500mm and 250mm tests.

Table 4.8 Exponents for drop cone tests at different heights.

Fabric Name	d_{500} (mm)	d_{500}/d_{250}	Exponent	d_{1000}/d_{500}	Exponent
Bidim					
A 12	26.8	1.52	0.61	N/A	N/A
A 14	26.9	1.54	0.62	1.61	0.71
A 24	20.9	1.48	0.57	1.53	0.62
A 29	19.9	1.79	0.84	1.62	0.71
A 34	17.2	1.52	0.61	1.59	0.68
A 44	15.3	1.63	0.70	1.48	0.57
Polyfelt					
TS 420	28.3	1.45	0.54	1.50	0.59
TS 500	24.8	1.31	0.39	1.51	0.62
TS 550	24.8	1.56	0.64	1.52	0.61
TS 600	23.6	1.63	0.71	1.54	0.62
TS 650	20.4	1.41	0.49	1.55	0.64
TS 700	17.7	1.51	0.59	1.48	0.57
TS 750	14.9	1.58	0.66	1.44	0.54
Polytrac					
155	13.6	1.38	0.47	1.50	0.59
C (woven up)	20.3	1.61	0.69	1.60	0.68
C (woven down)	17.6	1.64	0.72	1.60	0.69
Polyweave					
R	13.1	1.37	0.46	1.54	0.63
F	15.9	1.31	0.39	1.53	0.61
HR	9.0	1.33	0.41	1.69	0.76
Propex					
2002	11.5	1.57	0.65	1.70	0.77
Terrafix					
310 R	36.4*	2.49*	1.36*	N/A	N/A
360 R	29.2*	2.96*	1.58*	N/A	N/A
Terram					
700 SUV	30.9**	1.63**	0.70**	N/A	N/A
1000 SUV	30.5	1.55	0.63	N/A	N/A
3000 SUV	18.5	1.74	0.80	1.27	0.35

NOTE: * Actual values are for d_{1500} and d_{1500}/d_{750} respectively.

** Actual values are for d_{250} and d_{250}/d_{125} respectively.

For a drop height ratio of two with heights of 1000mm and 500mm, the results were found to be different from those obtained using the 500mm and 250mm tests. Except for the woven Propex fabric, the d_{1000}/d_{500} exponents were closer to 0.68 than the d_{500}/d_{250} values. The average exponent for the Bidim, Polytrac C and Polyweave fabrics was 0.66, 0.69 and 0.67 respectively. The Polyfelt range gave an average exponent of 0.60 and the Polytrac 155 fabric an average of 0.59. AS 3706.5 (1990) states that failure hole diameters should preferably be greater than 10mm. The Polyweave HR fabric had a d_{500} value of less than 10mm, but it gave an exponent closer to 0.68 than the Polyweave F fabric, for which d_{500} was 13.1mm.

The d_{1000}/d_{500} exponent for the Terram 3000 SUV fabric is considered to be not reliable. Tests at 1000mm did not produce any results for the two lighter grades (700 SUV and 1000 SUV) as the cone totally pierced 700 SUV specimens at both 500 and 1000mm, and 1000 SUV specimens at 1000mm. The value of 0.35 for the 3000 SUV fabric is not consistent with the results of other drop cone tests on this fabric. It is also well under the expected value and is not in line with other continuous filament non-wovens. Taking the average exponent from the d_{500}/d_{250}, d_{500}/d_{750} and d_{250}/d_{750} calculations (divide drop heights by two for 700 SUV) for all three Terram fabrics, an exponent of 0.69 is acceptable. The reason for such a low exponent for the d_{1000}/d_{500} case is not known, but is attributed to random sampling of sections of fabric with much higher strength characteristics.

The AS 3706.5 (1990) exponent value of 0.68 was more closely approximated by the results of tests at higher drop heights. It then follows that exponents calculated from tests at drop heights of 1.5, 2.0 and 2.5 metres may more closely approximate the AS 3706.5 (1990) value. These greater drop heights would produce larger hole diameters, but in the field, the aim is to have no hole, or to keep hole diameters as small as possible. It appears that, in order to obtain results that correspond well with the exponent in AS 3706.5, drop heights may be taken so high as to be removed from being relevant to separation applications.

The test results show that, for a drop height of 1000mm (1500mm for Terrafix fabrics), there were no failure hole diameters less than 15mm. For failure hole diameters above 15mm, the value of 0.68 is more closely approximated by a greater number of calculated exponent values (see Figure 4.1), than for tests at 500mm.

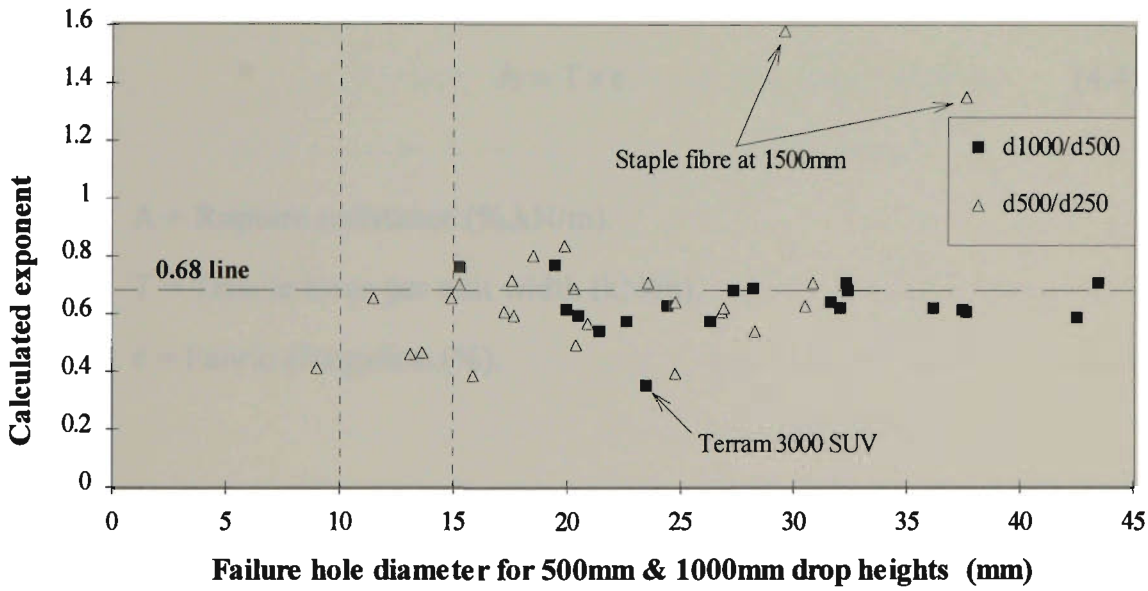

Figure 4.1 Failure hole diameter versus calculated exponent value.

4.4 Geotextile Rupture Index:

4.4.1 Introduction:

For a geotextile to resist bursting pressures and puncture or tensile forces, it must either have sufficient strength, or have the capacity to elongate in order to absorb the energy associated with these stresses.

The Swiss Association of Geotextile Experts defined rupture resistance as the product of tensile force per unit width and fabric elongation at failure in a wide strip tensile test (Foch, 1990), reproduced here as Equation 4.4.

$$A = T \times \varepsilon \tag{4.4}$$

Where:

A = Rupture resistance (%.kN/m).

T = Tensile force per unit width (kN/m).

ε = Fabric elongation (%).

The units of rupture resistance from this equation are not intuitively meaningful. The concept may be more readily understood if it were expressed in a form that had units more familiar to engineers.

For separation geotextiles, resistance to rupture caused by puncture and bursting is as important as resistance to tensile rupture. Giroud (1981) stated that a geotextile failing at less than 100 per cent elongation in a plane strain tensile test must have sufficient tensile strength in order to adequately resist puncturing. In the CBR puncture test, resistance to puncturing is due to both tensile strength and deformation capacity, and not to one or the other acting independently.

4.4.2 Definition and application of the Rupture Index:

As plunger load is increased geotextiles elongate until maximum load is reached, after which further elongation is detrimental to the fabric structure resulting in a decreased resistance to the applied load. The proposed Rupture Index is the product of CBR load at failure and the corresponding vertical plunger displacement, as shown in Equation 4.5.

$$RI = F_p \times \delta \qquad (4.5)$$

Where:

RI = Rupture Index (kN.mm).

F_p = CBR puncture test failure load using a flat plunger (kN).

δ = Vertical plunger displacement at failure load (mm).

With CBR load and vertical plunger displacement used together, the Rupture Index is a measure of the rupture energy, or the resistance to it in the fabric, at failure. The plunger load travelling through the plunger displacement is doing work, that is, force by distance. It is this work that is being resisted by the product of deformation and tensile stress in the fabric.

The Rupture Index is a measure of rupture energy for geotextiles in isolation. The addition of soil under the fabric in a CBR puncture test would reduce total plunger displacement at failure, but it would give higher measured strength values, according to Lhote and Rigo (1987). As testing with soil was not done, it is not known whether Rupture Index values would increase or decrease. However, the effect of underlying soil could be determined by comparing Rupture Index values for geotextiles tested in isolation with those for geotextiles tested with soil.

Comparing the two Rupture Index values would give an indication of the likely change in geotextile behaviour between the laboratory and the field. This would be more meaningful than only measuring the increase in CBR load at failure with soil, as both failure load and deformation will change, thereby better reflecting the field behaviour of the geotextile.

4.4.3 The use of vertical plunger displacement instead of elongation:

Stress in the fabric in the vicinity of the plunger, is related to plunger load through the angle β between the stretched fabric and the sides of the plunger. This is shown schematically in Figure 4.2.

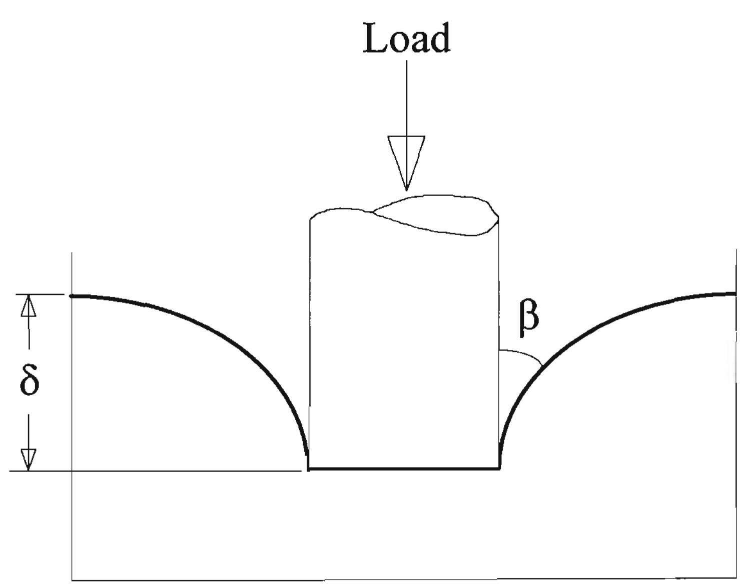

Figure 4.2 Schematic view of CBR puncture test showing exaggerated angle β (after Waters, 1984)

In the CBR puncture tests conducted, the fabric between the plunger and the clamping rings did not take the shape of a frustum of a cone with a constant β value, but took the form of a curved surface for which the angle β changed constantly from plunger tip to clamping rings (see Figure 4.2). In many fabrics, particularly non-wovens made of staple fibres, β approached zero at the plunger tip at failure, as the fabric made contact with the sides of the plunger near the tip. These types of geotextiles exhibited much higher elongation values than other types, hence, the more elongation capacity in a given geotextile, the lower the value of β at the perimeter of the plunger tip.

As the usual elongation calculations assume the geotextile to be planar between the plunger perimeter and the clamping rings, they cannot be considered to be exact. Vertical plunger displacement, on the other hand, is easily measured, and is not related to details of fabric behaviour such as the shape of the specimen at failure or the angle β. Rather, it is directly measured as the plunger movement from initial load uptake to the point of failure. Vertical plunger displacement is directly related to the plunger load as it represents the plunger travel in reaching the failure load. As it is easily measured, and requires no secondary calculations, manipulations or interpretations, vertical plunger displacement is considered to be the best way of expressing physical changes in the geotextile specimen being tested.

4.4.4 The use of modified plungers to calculate Rupture Index values:

For flat plunger CBR puncture tests, vertical plunger displacement is also the vertical distance from the initial fabric position to the point of failure - the perimeter of the plunger base.

For general geotextile applications the Rupture Index determined using a flat plunger is adequate, as it accounts for both tensile strength and fabric deformation. In situations where large angular aggregate is used, or tree branches or stumps project from the ground surface, the use of a Rupture Index obtained from tests using pyramid-tipped or hemispherical plungers may be thought to give a better representation of the effects of these more severe puncturing elements. However, in the case of the pyramid tip, the point has usually pierced and cut the fabric before the maximum load is reached. Therefore, the plunger displacement is not the distance from the initial fabric position to the point of failure, as it is when using the flat plunger. In the case of the hemispherical tip, rupture may occur at some point above the plunger tip, and the plunger displacement is, again, not the distance to the point of failure.

For tests using the pyramid-tipped plunger, the specimens were cut by the plunger after its tip protruded through the fabric. Displacements for this plunger are, therefore, not related to the energy required to rupture the geotextile. For tests using the hemispherical plunger, the location of the point of failure varied from the centre of the plunger tip to some point in contact with the side of the plunger, or in the vicinity of the plunger. For these tests, plunger displacements are not reliable, as plunger displacement is not necessarily equal to the vertical distance from the initial fabric position to the location of the point of failure for all specimens.

The determination of Rupture Index values using modified plungers, as well as being possibly unreliable, is also unnecessary. Rupture Index values based on a flat plunger used in conjunction with failure load values from pyramid-tipped plunger tests, will give a good indication of the suitability of a fabric for more demanding applications, especially when the aggregate to be used is very angular. Figure 4.3 shows CBR failure load values for the standard, pyramid-tipped and hemispherical plungers and Rupture Index values against fabric type. The Rupture Index values are multiplied by a factor of ten in order to make visual comparisons possible.

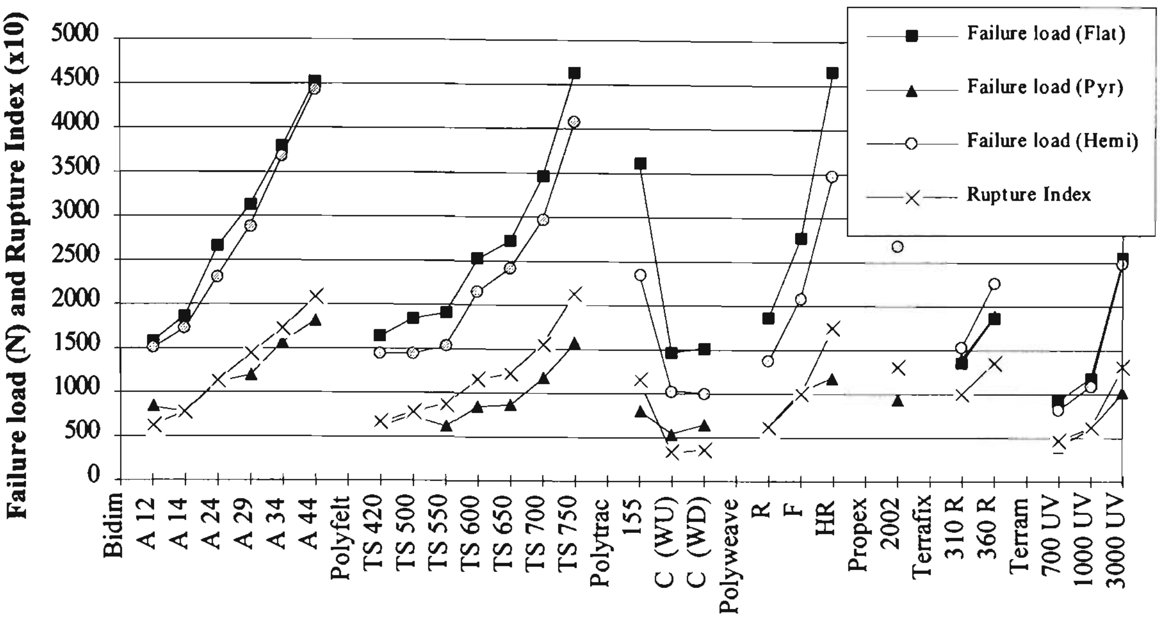

Figure 4.3 Comparison of Rupture Index values with CBR test failure loads.

Figure 4.3 clearly shows the closeness of the lines representing Rupture Index values (x10) and pyramid-tipped plunger failure load. The exceptions to this are the Polyweave HR fabric and the Terrafix fabrics.

Rupture Index values for the composite fabric (Polytrac C) were about half that of other fabrics with a similar CBR failure load. This is attributed to the loss of elongation capacity in the woven base caused by damage during the process of needling the non-woven web. However, Rupture Index values for this fabric correlated well with pyramid-tipped plunger failure load.

Figure 4.4 is a scatter plot of Rupture Index and pyramid-tipped plunger failure load values from Figure 4.3. Except for the two staple fibre fabrics, the data points occupy a reasonably narrow band. The line of best fit shown has a correlation coefficient of 0.853, indicating a very good correlation between it and the data points. The data points fall into reasonably well defined ranges labelled low, moderate, high and very high, with few exceptions. Each range label indicates the puncture resistance of the fabrics within that particular range.

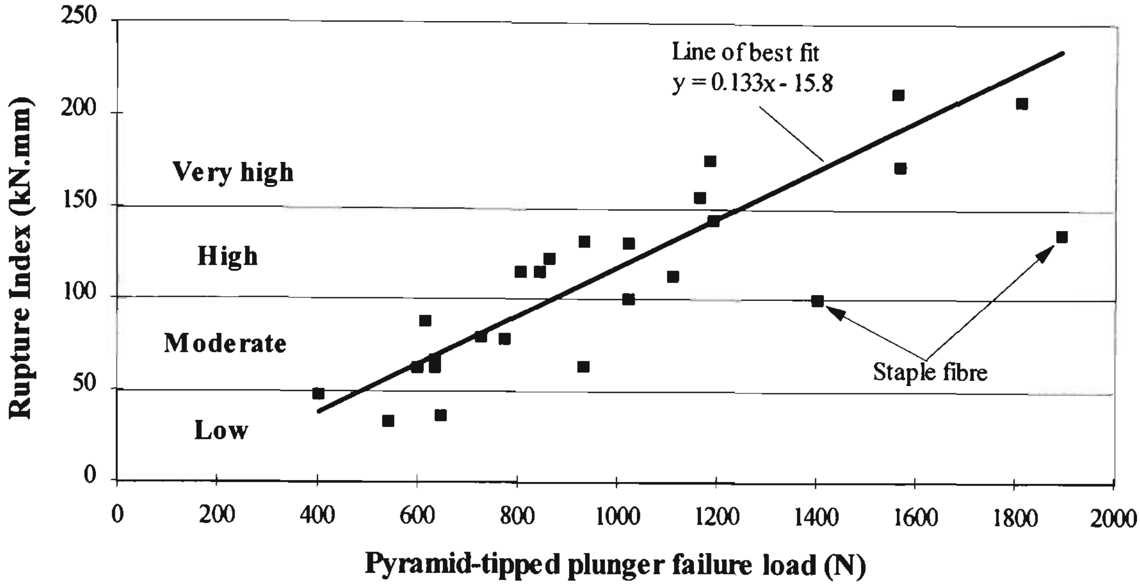

Figure 4.4 Rupture Index values versus pyramid-tipped plunger failure load.

The six G-Rating ranges currently used can be reduced to four equivalent Rupture Index ranges. Table 4.9 can be used to find an equivalent Rupture Index value for a given G-Rating value. The corresponding Rupture Index values given in this table fall into the ranges shown in Figure 4.4 reasonably well.

Table 4.9 G-Rating ranges and values with corresponding Rupture Index values.

G-Rating range	G-Rating values	Equivalent Rupture Index values	Rupture Index range
Weak	<600	<40	Low
Slightly Robust	600-900	40-50	Low
Robust	900-1350	50-70	Moderate
Moderately Robust	1350-2000	70-90	Moderate
Very Robust	2000-3000	90-125	High
Extremely Robust	>3000	>125	High/Very high

Figure 4.5 shows Rupture Index values plotted against G-Rating values. The line of best fit shown has a correlation coefficient of 0.59 indicating a trend but no clear relationship between the two sets of data.

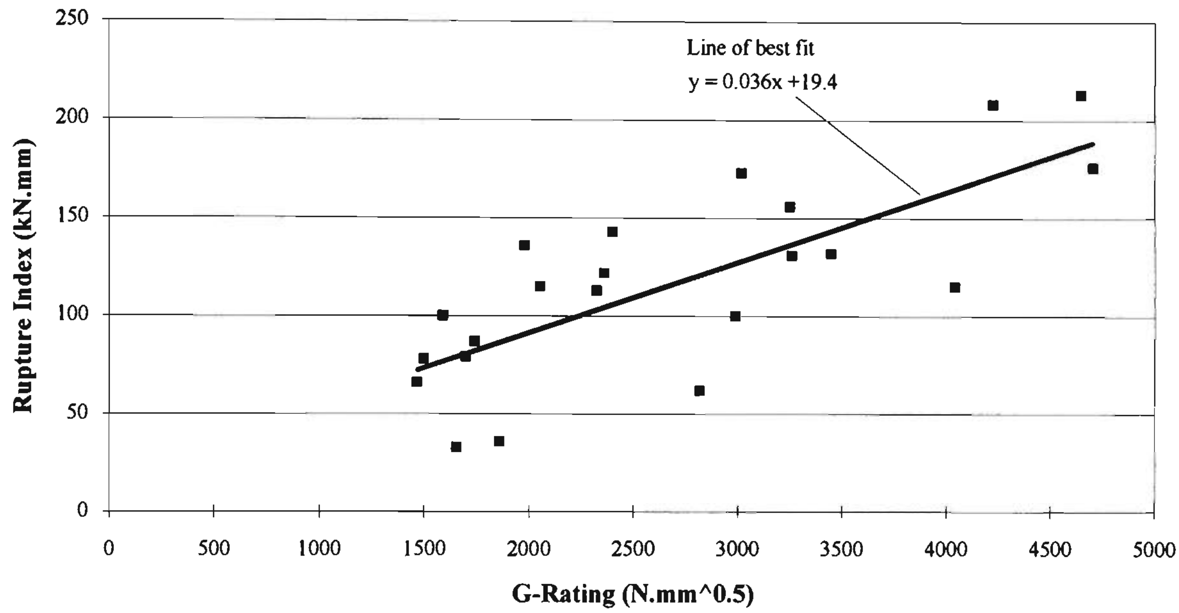

Figure 4.5 Rupture Index values against G-Rating values.

4.5 Mass per unit area of geotextiles:

All test specimens from the standard and modified CBR and drop cone tests were weighed in order to determine the average mass per unit area of the fabrics. In most cases, this was an average of at least 50 values.

In general, the values compared closely with those given in product specifications from manufacturers. However, there were some exceptions, but the particular manufacturers considered these discrepancies to be due to the variability of the manufacturing process. Table 4.10 shows the mass per unit area of each fabric tested compared with the values quoted by the manufacturers.

There were no non-woven fabrics that were underweight by more than one per cent, except for the Polyfelt TS 550 fabric, which was about 3.9 per cent under specification. This was also the only Polyfelt fabric with a different colouring from the other six. However, it was stated by the supplier that this discolouration would not cause any significant difference in physical characteristics or mechanical properties. However, it is interesting to note from Table 4.1 (p. 65), that this was the only continuous filament needle punched fabric with a measured CBR failure load less than that quoted by the manufacturer.

The results for the woven fabrics showed some variation. The woven and composite Polytrac fabrics were the same as or greater than the values specified by the manufacturer, and the Propex fabric was about three per cent under. The values quoted by the manufacturer for the two heavier materials in the Polyweave range of fabrics do not appear to match the physical composition of these fabrics. A visual examination of these two fabrics indicates that the values quoted by the manufacturer for mass per unit area should be interchanged. If this was done, both fabrics would then be above specification by 8.5 and 12.5 per cent respectively, instead of 9.4 per cent under and 26.1 per cent over. The manufacturer insists that their values are correct.

Table 4.10 Measured mass per unit area compared to manufacturer's stated value.

Fabric Name	Tested mass per unit area (g/m^2)	Manufacturer quoted per unit area (g/m^2)	Percentage difference
Bidim			
A 12	121	120	0.83
A 14	140	140	0.0
A 24	183	180	1.7
A 29	216	215	0.47
A 34	261	260	0.39
A 44	313	310	0.97
Polyfelt			
TS 420	132	130	1.5
TS 500	139	140	-0.71
TS 550	173	180	-3.9
TS 600	208	200	4.0
TS 650	234	235	-0.43
TS 700	282	280	0.71
TS 750	359	350	2.6
Polytrac			
155	155	155	0.0
C (woven up)	348	345	0.87
C (woven down)	346	345	0.29
Polyweave			
R	95	102	-6.9
F	163	180	-9.4
HR	203	150	26.1
Propex			
2002	150	155	-3.2
Terrafix			
310 R	309	310	-0.32
360 R	382	375	1.9
Terram			
700 SUV	113	110	2.7
1000 SUV	150	140	7.1
3000 SUV	285	280	1.8

4.5.1 Correlation between mass per unit area and mechanical properties:

The results of the CBR and drop cone tests were analysed in order to determine whether a correlation exists between mass per unit area and the specific mechanical properties of static (CBR puncture test) and dynamic (drop cone test) puncture resistance.

The form of analysis was a linear regression of the raw data using Microsoft Excel version 4.0, which used a least squares method to fit a line of best fit through the set of observations. The correlation coefficient for the particular lines of best fit and the raw data was generally above 90 per cent for all non-wovens and not less than 80 per cent. The wovens showed correlation coefficients generally above 80 per cent and not less than 70 per cent. These values show a very good correlation for the non-wovens and a good correlation for the wovens. The composite fabric showed no correlation between mass per unit area and either flat or modified plunger failure load. These correlations hold for the fabrics tested, but may not apply to other fabrics produced in different batches.

A possible use for the relationships found in this section would be on-site quality control. It takes much less time to weigh ten specimens than it does to perform, say, ten CBR puncture tests. Therefore, to within 10 per cent, specimens could be weighed to determine whether a delivery is to be accepted or rejected.

4.5.1.1 Flat plunger CBR puncture test:

It was found that the geotextiles tested showed a relationship between mass per unit area and CBR failure load under a flat plunger. The relationship approximated a straight line of the form given in Equation 4.6.

$$F_{cal} = A\mu + B \qquad (4.6)$$

Where:

F_{cal} = Predicted CBR puncture test failure load (N).

μ = Mass per unit area (g/m^2).

A = Gradient of line of best fit.

B = Intercept of line of best fit with F_{cal} axis.

For the geotextiles tested, only the composite fabric showed no clear relationship between mass per unit area and strength. Table 4.11 shows values of A and B for the other fabrics, which should only be used with the average mass per unit area of at least ten specimens. The only geotextile which does not fit in with other similar fabrics is the woven Polyweave F fabric, for which different values of A and B are given. It must be noted that all values of A and B quoted in this thesis are applicable to the materials tested, and may not be strictly related to other similar products.

Figure 4.6 shows a typical plot of an equation represented by the values given in Tables 4.11 through 4.13. The gradient of the line is represented by the value 'A' given in the tables, and the Y-intercept is the value 'B'. Many of the 'B' values are negative due to the form of linear regression which was carried out. Although this is theoretically correct, it was found that the correlations obtained using the values of 'A' and 'B' given, were better than those obtained with zero Y-intercepts. The valid region of each line is that portion representing the mass per unit area af fabrics actually available. Hence, a mass per unit area of zero can have a Y-intercept value of something other than zero (or indeed less than zero) for statistical analysis, as a fabric will never realistically have a mass per unit area of or less than zero.

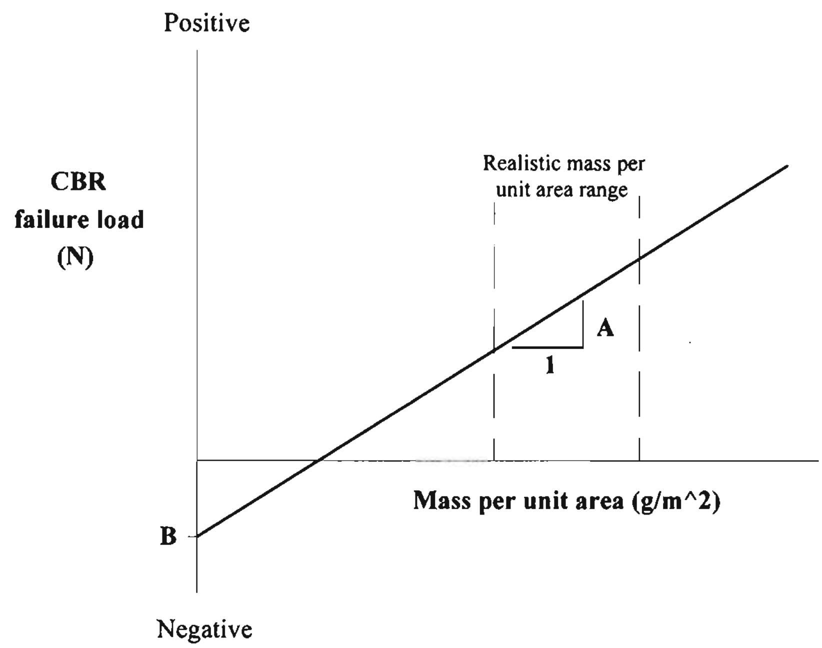

Figure 4.6 Idealised plot of mass per unit area against CBR failure load showing A and B values for Equation 4.6.

From Figure 4.6 and Table 4.11, it can be seen that the CBR failure load of wovens is most affected by mass per unit area values. The level of error was found to be less than ten per cent for all but the Polyfelt TS 500 (10.8%) and TS 550 (10.4%) fabrics. This was determined from comparisons of calculated values with measured values of failure load.

Table 4.11 A and B values to be used in Equation 4.6 for a flat CBR plunger.

Fabric Name	A	B
Bidim	15.51	-274
Polyfelt	12.95	-152
Woven*	25.04	-475
Polyweave F	19.46	-408
Terrafix	7.06	-810
Terram	9.56	-192

* NOTE: Does not include Polyweave F fabric, see separate entry.

4.5.1.2 Pyramid-tipped plunger CBR puncture test:

The relationship between mass per unit area and failure load for the pyramid-tipped plunger is also of the form given in Equation 4.6.

All fabrics conformed reasonably well with the line of best fit determined for them, except for the composite fabric. This fabric showed no particular slope or trend in the scatter of raw data points. Table 4.12 gives values for A and B for all other fabrics. Once again, these values should only be used with the average mass per unit area of at least ten specimens.

Table 4.12 A and B values to be used in Equation 4.6 for a pyramid-tipped plunger.

Fabric Name	A	B
Bidim	5.52	80.8
Polyfelt	4.00	43.5
Woven	5.05	138
Terrafix	6.90	-725
Terram	3.50	31.3

The correlation coefficients were similar to those determined for the flat CBR plunger. That is, at least 80 per cent, but generally above 90 per cent for non-wovens, and at least 70 per cent, but generally above 80 per cent, for wovens. The level of error was found to be less than ten per cent for most fabrics, except the Bidim A 12 (10.2%) and A 14 (10.3%), the Polyfelt TS 500 (17.4%), TS 550 (19.8%) and TS 650 (13.4%) and the Polytrac 155 (17.9%) fabrics.

4.5.1.3 Hemispherical plunger CBR puncture test:

The relationship between mass per unit area and failure load for the hemispherical plunger is also of the form given in Equation 4.6.

Except for the composite fabric and the woven Polyweave F fabric, all the calculated values of CBR failure load conformed well with the measured values. For the relationships described by the values in Table 4.13, the correlation coefficients were better than those determined for the flat CBR plunger. That is, well above 90 per cent for non-wovens and above 80 per cent for wovens. The level of error was less than ten per cent in most instances.

In Table 4.13, values of A and B are given for all other fabrics. It must be noted again that accuracy is greatly enhanced when using these values with the average mass per unit area of at least ten specimens.

Of the fabrics which conformed to the values in Table 4.13, only the lighter Terram fabrics produced slightly larger discrepancies (less than 13%). The relationship for the Terram fabrics is more accurate in the higher mass per unit area range for the hemispherical plunger.

Table 4.13 A and B values to be used in Equation 4.6 for a hemispherical plunger.

Fabric Name	A	B
Bidim	15.71	-464
Polyfelt	11.84	-295
Woven*	18.15	-411
Terrafix	10.10	-1571
Terram	9.95	-349

* NOTE: Does not include Polyweave F (no value calculated due to high error).

4.5.1.4 Standard and modified drop cone puncture tests:

The geotextiles tested showed a relationship between mass per unit area and d_{500}, which approximated a straight line of the form given in Equation 4.7. The value of both A and B varied for different fabrics, as was the case with the relationship between mass per unit area and CBR failure load.

$$D_{500} = A\mu + B \qquad (4.7)$$

Where:

D_{500} = Predicted d_{500} value (mm).

μ = Mass per unit area (g/m^2).

A = Gradient of line of best fit.

B = Intercept of line of best fit with D_{500} axis.

Table 4.14 shows values for A and B for all fabrics, which should only be used with the average mass per unit area of at least ten specimens. The woven fabrics differ slightly in their value of B, but their value of A is the same.

Table 4.14 A and B values to be used in Equation 4.7 for D_{500} values.

Fabric Name	A	B
Bidim	-0.064	34.34
Polyfelt	-0.055	34.10
Polytrac 155 (woven)	-0.029	18.10
Polyweave F (woven)	-0.029	20.50
Other wovens	-0.029	15.40
Composite	1.33	-442.5
Terrafix	-0.100	67.20
Terram	-0.077	40.72

The level of error was found to be less than ten per cent for all fabrics. The analysis of d_{250} and d_{750} values gave a range of expressions for each fabric at the two drop heights. However, it is sufficient to know the relationship between mass per unit area and d_{500}, as the relationship between d_{500}, d_{250} and d_{750} is simple to determine. Table 4.15 shows the ratio of failure hole diameters for a range of drop height ratios, using both AS 3706.5 (1990) and values found by linear regression of the drop cone test results at 250, 500 and 750mm.

Table 4.15 Hole diameter ratio from AS 3706.5 and linear regression.

		Failure hole diameter ratio	
Drop height	**Drop height ratio**	**AS 3706.5**	**Linear regression**
d_{500}/d_{250}	2.0	1.60	1.52
d_{750}/d_{500}	1.5	1.32	1.30
d_{750}/d_{250}	3.0	2.11	1.98

As can be seen from Table 4.15, the hole diameter ratios found are close to those given in AS 3706.5. Therefore, by using Equation 4.7, in conjunction with the appropriate factor from Table 4.15 (or AS 3706.5), failure hole diameters for a range of drop heights can be predicted reasonably accurately without conducting drop cone tests. Although the values determined in this thesis show good agreement with the AS 3706.5 value, they should not be taken as design values.

CHAPTER 5

5.O GEOTEXTILE USER SURVEY

5.1 Reason for survey:

As part of the original research program for this thesis, it was proposed to conduct substantial field trials of geotextiles in order to assess their in-situ performance. This program was to include the laying of two metre by two metre geotextile samples along a short section of access road for heavy vehicles. After a pre-determined number of axle passes, the geotextiles were to be exhumed and an inner square of side one metre was to be examined for holes, tears, rips and any other visible signs of damage. Testing of the exhumed samples was not envisaged, other than a small number of wide strip tensile tests to determine the amount of residual tensile strength in the geotextiles. However, logistically and financially, this proposal was beyond the resources of this project, and other forms of geotextile field performance evaluation were sought.

5.2 Geotextile user survey:

5.2.1 General:

A questionnaire was sent to every municipality, all VicRoads divisions, and the major earthworks and road contractors in Victoria. The respondents were asked to describe their experiences with geotextiles and their observations of field behaviour, for geotextiles used in 1992.

The questionnaire was developed to fulfil two basic aims. The first was to determine whether geotextiles were used by the respondents in 1992, and if so, which type was used and for what application. This information was required to determine whether specific geotextile types were used for particular applications. The second was to find out how the geotextiles were chosen, how they were laid, and if any of the geotextiles used showed any signs of failure. To fulfil this aim 12 questions were asked for each project on which geotextiles were used. The questionnaire is reproduced as Appendix B. The purpose of each question was as follows:

Question 1 - To have a general description of the soil conditions for the particular project being described, in order to determine if the subgrade could have been a source of damage to the geotextile, or if the geotextile used was the correct type and grade for the subgrade conditions encountered.

Question 2 - To see if the method of laying the geotextile, whether by hand or machine, could have caused any damage to the geotextile, or if it may have led to circumstances where damage was more likely to occur.

Question 3 - To determine whether any damage was caused by the type of aggregate used, hence indicating an incorrect choice of either geotextile type or grade.

Question 4 - To allow a comparison of the stated initial lift thicknesses quoted with minimum initial lift thicknesses recommended in overseas geotextile specifications. This could indicate possible reasons for any geotextile damage, such as insufficient cover over the geotextile.

Question 5 - To determine whether the loads imposed on the geotextile by construction equipment caused any failures, or whether the wrong grade of geotextile was used for the loads encountered.

Question 6 - To determine if undesirable geotextile behaviour during placement, such as excessive deformation or apparent overstressing, was observed during installation. Damage observed during installation was not to be considered in this question but in Question 7.

Question 7 - To give a description of any installation damage and the reasons for it. This would indicate whether or not the construction techniques used were incorrect and/or if the work was carried out to a sub-standard level. It would also show whether a suitable geotextile had been used.

Questions 8 and 9 - These two questions are inter-related. The first required a descriptive assessment of any failures that showed up subsequent to construction and were not thought to be specifically caused by the installation process. The second question required a physical description of any failed geotextile that had been exhumed, to determine what type of failure had occurred.

Question 10 - This question is similar in nature to Question 1, but it is specifically related to uneven or extremely inconsistent subgrades to ascertain whether any damage occurred over such subgrades and, if so, what form it took and whether it was directly related to the quality of subgrade preparation.

Question 11 - To determine the basis of geotextile selection. The geotextile selection criteria may vary - typical criteria include past experience, advertising by company sales representatives, cost, availability and strength characteristics (generally in the form of G-Rating values).

5.2.2 Results of the questionnaire:

5.2.2.1 Users surveyed:

Geotextile questionnaires were sent to 210 Victorian municipalities, 16 were sent to VicRoads regions and four were sent to major earthworks and road contractors. Of the 230 questionnaires sent out, 104 were returned, which is a return rate of just over 45 per cent. Ninety-five replies were received from municipalities (also just over 45 per cent of the 210 surveys sent out) with 51 of these reporting no geotextile usage in 1992. In fact, a large proportion of these municipalities had never used geotextiles. This lack of geotextile use was attributed by the respondents to the relatively high CBR of the subgrade within these municipalities.

Eight replies were received from VicRoads divisions, which is a return rate of 50 per cent. One of these replies reported no geotextile use in 1992. One reply was also received from a civil engineering contractor where geotextile use was indicated. The other three contractors declined to return the questionnaires and did not respond to follow-up requests for information.

There were some isolated instances where geotextiles were used to overcome soft spots, but the quantity used was much less than $100m^2$. Examples of this are the municipalities of Nunawading, Kew, Hawthorn and Werribee where geotextiles were used to treat several very small and isolated soft spots. The City of South Melbourne also used a very small amount of fabric under a footpath.

Three other municipalities used geotextiles but their use was less than 300m^2 and was therefore not included in the calculations of geotextile use. These were the municipalities of Waverley, Mordialloc and Berwick, where the respective uses quoted were to treat soft spots, as an asphalt overlay and for abutment stabilisation.

5.2.2.2 Geotextile functions quoted:

Approximately 344,000m^2 of geotextiles were used by the survey respondents of which approximately 71,500m^2 was paving fabric used for road resealing. The use of woven geotextiles predominated with the use of over 145,000m^2 being reported. Virtually all the woven fabric was used by various VicRoads divisions. The reply from the civil engineering contractor reported the use of over 18,000m^2 of woven geotextile.

The main function for the geotextiles was separation (22 replies) although reinforcement was indicated three times - once as a primary function and twice as a combined function with separation. Stabilisation as the main function was mentioned on ten occasions and on five occasions as a combined function with separation.

Non-woven geotextiles represented 29.7 per cent of the geotextiles used. The total area of non-woven geotextiles laid was approximately 102,100m^2. Not included in the results for the non-wovens is the use of 71,480m^2 of geotextiles for resealing of roads, where the fabric was used as a pavement overlay. This is generally the domain of paving fabrics which are not considered in this thesis. When subdivided according to method of manufacture, the breakdown is:

Needle punched:

- continuous filament 86,100 m^2 (84.3 per cent of non-woven)
- staple fibre 6,000 m^2 (5.9 per cent of non-woven)

Heat bonded:

10,000 m^2 (9.8 per cent of non-woven)

The needle punched non-wovens were used for separation 14 times, as filters two times and to provide extra stabilisation four times. They were also used for combined functions on five occasions. The combined functions were predominantly separation/stabilisation and separation/filtration.

The use of composite geotextiles was reported on two surveys. In both cases, the user was a VicRoads division. The reported functions for these geotextiles were separation/filtration and stabilisation. In total 25,000 m^2 of composite geotextiles were used. This represents 7.3 per cent of the reported total geotextile usage. The breakdown of geotextile use by fabric type is given in Figure 5.1 which shows that the use of woven geotextiles exceeded that of all other types of geotextile combined. However, it must be remembered that the figures shown are based on the questionnaires which were returned, and may not accurately represent the current state of the geotextile market in Victoria or the rest of Australia. Following discussions with various representatives of Australian geotextile manufacturers and suppliers, the current state of the market appears to be approximately 90 per cent non-wovens to 10 per cent wovens and composites. The breakdown for the non-wovens would be approximately 90-95 per cent continuous filament, with 5-10 per cent of these being heat bonded and the rest needle punched. The remaining 5-10 per cent of non-wovens are those composed of staple fibres.

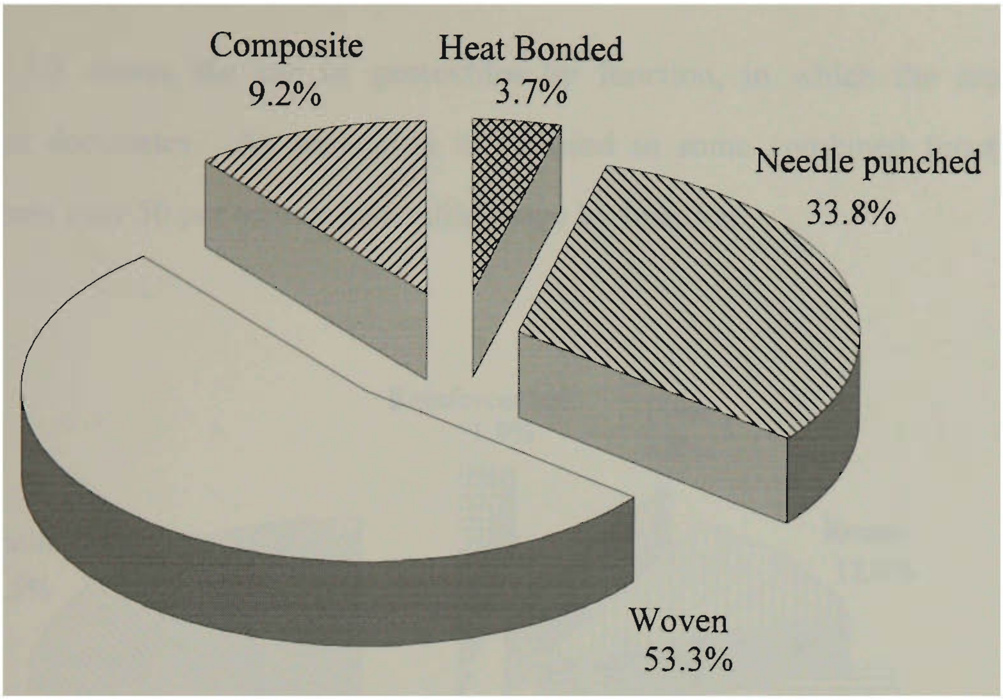

Figure 5.1 Geotextile use by type

Figure 5.2 shows a bar diagram of the number of applications for which geotextiles were used. It also shows a breakdown of functions for each geotextile type indicating the primary function for the geotextiles reported on.

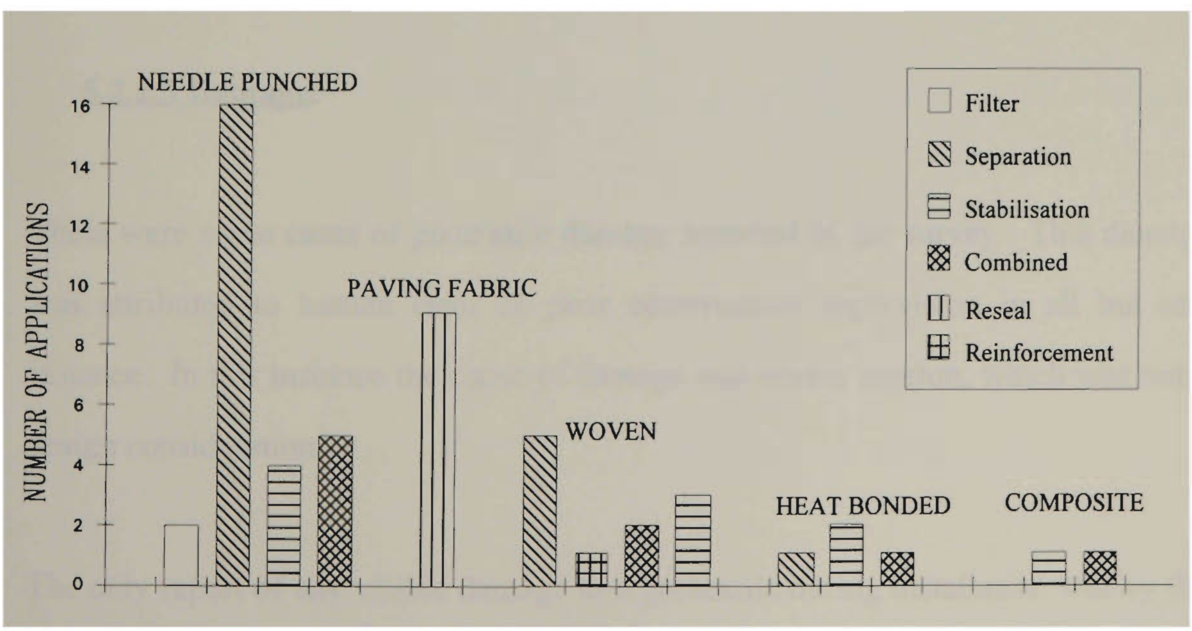

Figure 5.2 Geotextile type and corresponding application

Figure 5.3 shows the use of geotextiles by function, in which the separation function dominates. As separation is included in some combined functions, it represents over 50 per cent of geotextile usage by function.

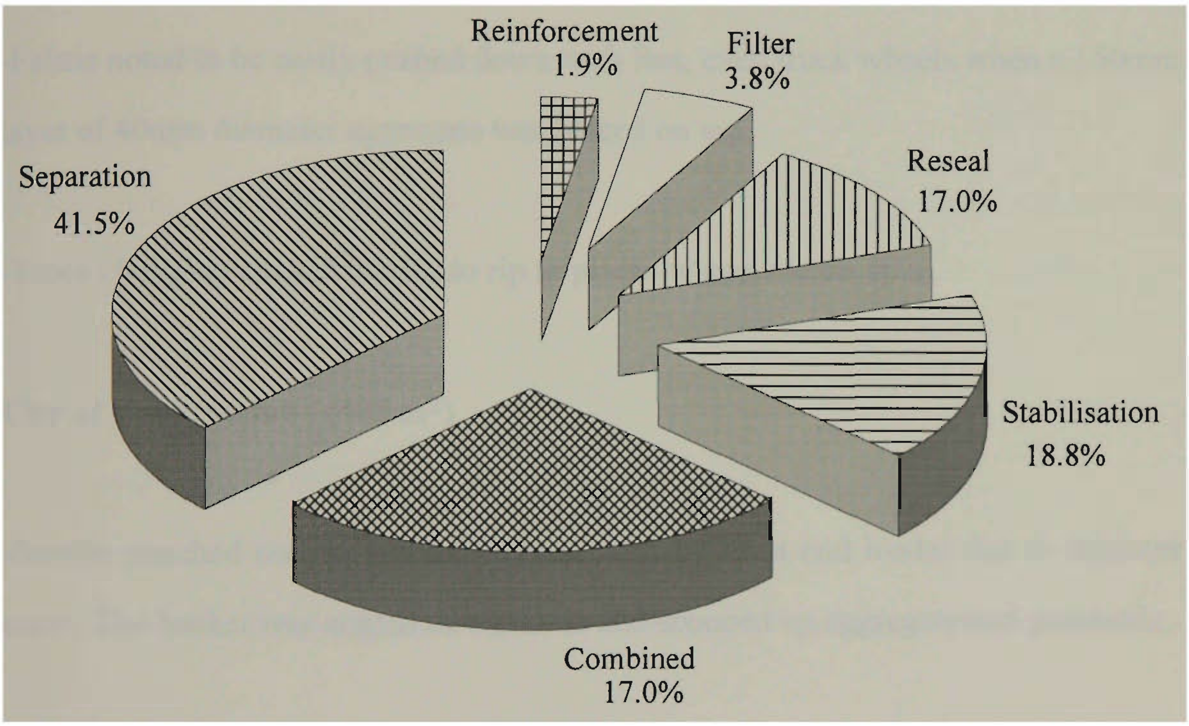

Figure 5.3 Geotextile use by function

5.2.2.3 Damage:

There were some cases of geotextile damage reported in the survey. This damage was attributed to human error or poor construction supervision in all but one instance. In this instance the cause of damage was severe erosion, which was not a design consideration.

The only report of any visible damage to a geotextile during installation was by the City of Knox. Isolated areas of fabric failed with the fabric rising through the crushed rock. There was no cause stated for this failure. There were also some reports of fabrics used as asphalt overlays sticking to the wheels of asphalt trucks, caused by insufficient tacking coat adhesion to the fabric. Some of the most descriptive survey responses are paraphrased below.

Shire of Kerang - (1,800 m^2)

-Fabric noted to be easily pushed down with feet, even truck wheels when a 150mm layer of 40mm diameter aggregate was placed on top.

-Trucks bogging caused fabrics to rip in places where wheels spun.

City of Castlemaine - (405 m^2)

-Needle punched non-woven fabric punctured by front end loader due to operator error. The bucket was angled downwards and scooped up aggregate and geotextile.

Shire of Walpeup - (2,000 m^2)

-Large lumps of limestone landed on a geotextile placed on a sand layer with no damage.

Shire of Kilmore - (?)

-Some geotextile movement observed but no damage evident.

Shire of Bulla - (600 m^2)

-Some stretching of the geotextile was noted due to deflection from wheel loads, but no damage was noted.

Shire of Myrtleford - (1,200 m^2)

-No movement or damage to the geotextile noted. Previous experience on the same job was of the geotextile tearing (reason not given). For the job described, the surface was smooth in order to avoid tears.

Shire of Maffra - (1,500 m^2)

-Some deformation of the under layer was noted but no damage to the geotextile.

City of Knox - (6,000 m^2)

-Isolated areas failed with the fabric rising through the layer of crushed rock.

John Holland Group - (18,000 m^2)

-The geotextile is being used to separate sediment and overburden. The geotextile is in considerable tension and has been found to perform well with no damage noted so far.

VicRoads Western Ring Road Maribyrnong - (1,500 m^2)

-The use of a slit film woven made compaction difficult as the soil moved over the "slick" geotextile in an apparent lack of bonding between geotextile and soil.

-A staple fibre fabric was used with excessive movement on quartz placement but with no damage to the geotextile. A slit film woven was used as well, as an additional reinforcement layer.

City of Collingwood - (2,500 m^2)

-The fabric moved and folded when being covered with aggregate.

5.2.2.4 Method of choice:

Some comments regarding geotextile choice by the respondents are paraphrased below.

Shire of Kerang

-The geotextile was chosen by design.

City of Castlemaine

-The geotextile was chosen by previous experience.

Shire of Walpeup

-The geotextile was chosen due to availability and the emergency nature of the work. The road repair was three days before Christmas and there was no other geotextile available.

Shire of Kilmore

-The geotextile was chosen due to cost and other [not specified] "construction" considerations.

Shire of Myrtleford

-The geotextile was chosen through past experience.

Shire of Maffra

-The geotextile was chosen as the price was competitive.

John Holland Group

-The geotextile was chosen for its relative cheapness and tensile strength.

VicRoads Western Ring Road Maribyrnong

-The geotextile was recommended by the Materials Technology Division.

-At another time a composite geotextile was used for filtration and separation on advice from the Materials Technology Division.

-At another time a staple fibre fabric was chosen because high elongation was required.

-At another time, a needle punched non-woven was used as the consensus was that "...it looked about right for the job."

5.3 Conclusions:

This chapter has shown that the use of geotextiles in the 45 per cent of Victorian municipalities who responded to the survey is either non existent, or extremely small. Several of the municipalities which did not respond to the survey were contacted and indicated no geotextile use in 1992. Resources did not allow an effective follow-up of all municipalities, but it appears that the information obtained from them would not have altered the conclusions of this survey significantly, as they were either extremely small rural municipalities or metropolitan councils in areas where high CBR values abound. Of the respondents to this survey, by far the most extensive user of geotextiles in Victoria was VicRoads.

Most of the respondents chose the geotextiles used on the technical advice of the suppliers. At one stage a woven fabric was used by the City of Footscray on the advice of VicRoads. Some respondents expressed the need to have technical notes from VicRoads regarding geotextile use and methods of specification and selection.

Information on total quantities of geotextiles sold in 1992 was sought from the geotextile suppliers. However, most suppliers were reluctant to reveal this information for commercial reasons. Hence, it is not possible to put any perspective on the figures quoted in this chapter.

The returned questionnaires gave very little information about observed damage to geotextiles. Therefore, field trials of geotextiles are essential in order to obtain information on the actual behaviour of geotextiles.

The criterion for geotextile selection was predominantly cost, but previous experience with certain geotextiles, and the experience of others, also figured significantly. The G-Rating was quoted as a consideration on less than five per cent of the surveys returned. Advice from the Materials Technology Division of VicRoads was also quoted as a source of geotextile selection information.

CHAPTER 6

6.O EVALUATION OF THE G-RATING CLASSIFICATION SYSTEM

6.1 Definition of the G-Rating:

The G-Rating is the geometric mean of the results of the CBR puncture test (AS 3706.4, 1990) and the drop cone puncture test (AS 3706.5, 1990). The work by Waters et al. (1983) led to the adoption of the G-Rating by the QMRD, and later to the formulation of the G-Rating classification system. This initial work was carried further in the Austroads report 'Guide to Geotextiles' (1990), which included an extra criterion as part of the G-Rating classification system, as it set a maximum elongation of 80 per cent in the CBR puncture test. The G-Rating is defined as:

$$G = \sqrt{F_p \times h_{50}} \tag{6.1}$$

Where:

G = Geotextile strength rating $(N.mm)^{1/2}$.

F_p = CBR puncture test failure load using a flat plunger (N).

h_{50} = Drop height required to produce a 50mm diameter hole (mm).

The value of h_{50} is calculated using the following relationship (Equation 6(4) in AS 3706.5, 1990).

$$h_{50} = 500 \times \left(\frac{50}{d_{500}} \right)^{1.47} \tag{6.2}$$

Where:

500 = Drop height of 500mm.

50 = Failure hole diameter corresponding to a drop height of h_{50} (mm).

d_{500} = Diameter of hole for a drop height of 500mm (mm).

6.2 The effect of elongation at failure in a CBR puncture test:

The G-Rating classification system requires that, when elongation at failure in the CBR puncture test exceeds 80 per cent, the load at 80 per cent elongation shall be used to calculate the G-Rating, and this is generally much lower than the failure load. According to the Austroads (1990) report (p. 7 of report), the restriction of elongation to 80 per cent was incorporated because "...in such cases, if actual failure load was used, unacceptable deformations may occur in service as the required strength of the geotextile is mobilised."

The 80 per cent rule was the result of a choice made within the QMRD after the staple fibre products which were tested in the early 1980s only reached full strength at elongations of about 150 per cent. As most of the non-woven materials reached their maximum strength, or failed, at 30-40 per cent, it was decided to double the greater value (40%) as a reasonable value with which to require staple fibre products to comply. This was done because working strain values are considered to be typically 10-20 per cent and most products, if used nominally as a separation layer beneath a road pavement or fill over very soft ground, do in fact fulfil a reinforcing function as well (Litwinowicz, 1992).

At present, the QMRD does not regard the inclusion of a geotextile as adding strength to a pavement. If reinforcing is needed this is achieved by the use of geogrids (Litwinowicz, 1993). Therefore, it seems unnecessary to restrict geotextile elongation if pavement designs assume them to have no tensile strength. If there is no fabric under the pavement, then intermixing of the subgrade and aggregate can occur, perhaps resulting in displacements or rutting. If a fabric is used under the pavement, and it has been correctly chosen, there should be no intermixing. If no tensile capacity is attributed to the geotextile, and no other reinforcement is provided, then the possibility of deformations due to causes other than intermixing, such as subgrade consolidation, still exists. As geotextiles do have some strength and stiffness, they can in fact provide some reinforcing in this situation.

All the geotextiles tested in this study failed at less than 80 per cent elongation in CBR puncture tests, with most fabrics failing at between 20 and 40 per cent. The maximum elongation for the staple fibre fabrics was 73 per cent, using the method of calculating elongation from AS 3706.4 (1990). The staple fibre products tested weighed approximately 310 and 380 grams per square metre respectively. Similar fabrics above this range are available with weights up to 2000 grams per square metre, and these may fail at elongations greater than 80 per cent. However, these fabrics are generally not used as separators in road applications and, therefore, are beyond the scope of this study.

<u>6.3 The effect of drop cone test results on G-Rating values</u>:

Another problem with the G-Rating concerns the exponent in Equation 6(4) of AS 3706.5 (1990), (Equation 6.2 in this thesis) used in the calculation of the drop height to cause a 50mm diameter hole (h_{50}).

It was shown in section 4.3 that the value of the exponent varies for different fabrics, and also for the drop heights used. Equation 6(1) of AS 3706.5 (1990) gives a ratio for d_{500}/d_{250} of 1.60, this value of 1.60 is the number 2 (drop height ratio) raised to a power of 0.68. Therefore, a value other than 1.60 means an exponent other than 0.68. As was shown in Table 4.8 (p. 83), the ratio of d_{500}/d_{250} varied between 1.31 and 1.79 (excluding values of 2.49 and 2.96 for the staple fibre fabrics). Equation 6(3) of AS 3706.5 gives a ratio of d_{500}/d_{1000} of 0.62, which becomes 1.61 for d_{1000}/d_{500}. Table 4.8 shows the ratio of d_{1000}/d_{500} to be between 1.44 and 1.70 (excluding a value of 1.27 for the Terram 3000 SUV fabric). The range for the d_{1000}/d_{500} case is narrower than for the d_{500}/d_{250} case.

It is possible to calculate h_{50} from a range of drop heights, choosing the best value to calculate a G-Rating. Calculated G-Rating values varied for the same fabrics tested at different drop heights. Table 6.1 gives G-Rating values found using h_{50} calculated by Equation 6(4) of AS 3706.5 (1990). It also shows G-Rating values calculated from tests at 500 and 250mm, and from tests at 1000 and 500mm, together with the percentage difference between these values and those found using AS 3706.5.

For the d_{500}/d_{250} test results, G-Ratings were within ten per cent of the AS 3706.5 value for 44 per cent of fabrics and within five per cent for 36 per cent of them. For the d_{1000}/d_{500} results, G-Ratings were within ten per cent of the AS 3706.5 value for 59 per cent of fabrics and within five per cent for 27 per cent of them. The greatest difference occurs for the Polyweave HR fabric, which goes from being 130 per cent over to 12.5 per cent under the AS 3706.5 value. All wovens showed considerably reduced G-Ratings in the d_{1000}/d_{500} calculations compared with the d_{500}/d_{250} results. For the Bidim A 12, Terram 700 SUV and 1000 SUV fabrics, no d_{1000} was obtained, hence no G-Ratings can be given for comparative purposes. However, it is predicted that the Bidim fabric would have remained virtually unchanged as this was the trend observed for that range of fabrics. The two lighter Terram fabrics also showed unchanged G-Rating values for calculations at other drop heights.

Table 6.1 G-Rating values using exponents calculated three different ways.

Fabric Name	G-Rating (AS 3706.5)	G-Rating (d_{500}/d_{250})	Difference to AS 3706.5 (%)	G-Rating (d_{1000}/d_{500})	Difference to AS 3706.5 (%)
Bidim					
A 12	1403	1486	5.9	N/A	N/A
A 14	1525	1594	4.5	1498	-1.8
A 24	2187	2480	13.4	2324	6.3
A 29	2460	2167	-11.9	2399	-2.5
A 34	3017	3326	10.2	3016	0.03
A 44	3590	3486	-2.9	4223	17.6
Polyfelt					
TS 420	1375	1535	11.6	1466	6.6
TS 500	1607	2366	47.2	1698	5.7
TS 550	1633	1686	3.2	1740	6.5
TS 600	1950	1911	-2.0	2051	5.2
TS 650	2258	2902	28.5	2359	4.5
TS 700	2818	3149	11.7	3250	15.3
TS 750	3706	3829	3.3	4646	25.4
Polytrac					
155	3503	5406	54.3	4043	15.4
C (woven up)	1663	1648	-0.9	1654	-0.5
C (woven down)	1878	1807	-3.8	1858	-1.1
Polyweave					
R	2585	4155	60.7	2817	9.0
F	2729	5155	88.9	2988	9.5
HR	5378	12376	130	4704	-12.5
Propex					
2002	3900	4094	49.7	3448	-11.6
Terrafix					
310 R	1806	N/A	N/A	1588*	-12.1
360 R	2488	N/A	N/A	1978*	-20.5
Terram					
700 SUV	688	679**	-1.3	N/A	N/A
1000 SUV	1106	1138	2.9	N/A	N/A
3000 SUV	2344	2100	-10.4	3260	39.1

NOTE: * Actual values are for d_{1500}/d_{750}.

** Actual values are for d_{250}/d_{125}.

As was shown in Figure 4.1 (p. 85), the scatter of calculated exponent values for the d_{500}/d_{250} case is greater than for the d_{1000}/d_{500} case. It also appears from the figure that a minimum failure hole diameter of 10mm, as suggested by AS 3706.5 (1990), will not necessarily result in a calculated exponent value close to 0.68. For the d_{1000}/d_{500} results, a minimum hole diameter of 15mm was measured, and for these results, the value of 0.68 was more closely approximated.

The relevance to currently available geotextiles of an exponent of 0.68, which is not not varied for different fabric types, is questioned. In AS 3706.5 (1990) the value of 0.68 is said to be applicable to any drop height indicated therein, although 500mm is termed the "standard test drop height" and Equation 6(1) relates d_{500} and d_{250}. The test results at 500 and 250mm show clearly that a single exponent for all fabrics is not correct, as the calculated exponents varied from 0.41-0.84 for the range of fabrics tested (see Table 4.8). For the tests at 1000 and 500mm, the exponents varied from 0.54-0.77, which is much closer to the range of 0.55-0.7 given in Note 1 of AS 3706.5. For the staple fibre fabrics, the exponents were 1.36 and 1.58 for the 310 R and 360 R fabrics respectively, for tests at 750 and 1500mm. The exponent for these fabrics at other drop heights ranged between 0.48 and 2.2.

Some fabrics gave exponent values close to 0.68 for the d_{500}/d_{250} case, and others for the d_{1000}/d_{500} case. However, this is impractical if a standardised testing method is to be achieved. The exponent to be used must be appropriate for the fabric tested at a particular drop height. Therefore, for a given drop height, different exponents for different fabrics should be given, according to their behaviour at these drop heights. Alternatively, tests should be conducted at various drop heights and the actual exponent for any given fabric calculated. This exponent would then be used to determine more reliable G-Rating values for each fabric.

6.4 Suggested modifications to the G-Rating:

As no geotextiles failed at elongations greater than 80 per cent in the CBR puncture tests, this criterion may be deleted or ignored for separation geotextiles. The latter course seems more appropriate as this criterion could be applicable for geotextile applications not relevant to this study and, hence, not investigated.

The exponent in AS 3706.5 (1990) should be varied for the different geotextile types to reflect their behaviour in drop cone tests. Alternatively, specific drop heights should be established which are relevant to different applications, such as 500-1000mm for separation under roads and 1500-2000mm for use under rip-rap. In order to determine the exact exponents required, further testing is recommended at a range of drop heights in order to produce more consistent results.

The behaviour of staple fibre fabrics is different from all other types in both the modified plunger CBR tests and drop cone tests. This different behaviour in the drop cone tests should be reflected in AS 3706.5. The average exponent for staple fibre fabrics is 1.46, the reciprocal of which is 0.68 which is used for calculating h_{50} values. An exponent of 0.68, compared with a value of 1.47 from AS 3706.5, leads to reduced h_{50} values for these fabrics when the failure hole diameter is less than 50mm, resulting in a lower G-Rating. Staple fibre fabrics at 750mm drop height gave smaller hole diameters than all but the Polyweave HR fabric. They did not exhibit a reduction in failure load under modified plungers as did all other fabrics. Using an exponent of 0.68 to calculate lower h_{50} values than those calculated using AS 3706.5 does not appear to reflect their likely field behaviour. For a separation application where no reinforcing is required, their performance in the laboratory indicates that their likely field behaviour would be satisfactory.

CHAPTER 7

7.O CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions:

This study has been concerned with the puncture resistance of geotextiles, related to the separation function. From the results of the testing program, and the geotextile user survey, the following conclusions can be drawn:

1. It is considered that Equation 3.4 (three-dimensional elongation) provides a better measure of elongation in a CBR puncture test than Equation 3.1 (two-dimensional elongation), as actual elongation behaviour is three-dimensional.

2. As friction between the plunger base and the geotextile specimen, and the fact that the actual deflected shape is different from that assumed, the precise value of elongation is not known. Therefore, it is considered that the use of vertical plunger displacement at failure is a simpler and clearer means of defining deformation at failure. In a CBR puncture test the strain rate, specimen diameter and plunger diameter are all standardised. The use of vertical displacement is measured directly during a test and is not based on assumptions of deformed specimen shape.

3. The behaviour of geotextiles under plungers with pyramidal and hemispherical tips is different from that under a flat CBR plunger. The use of these plungers led to stress localisation for all fabrics. This, in turn, led to reduced failure load values for all but staple fibre fabrics, which showed increased failure load values. The failure mechanism for staple fibre fabrics was slippage of fibres near the plunger

tip, whereas for all other fabrics failure occurred primarily through fibres being cut or broken.

4. Comparing results for the flat and pyramid-tipped plunger CBR puncture tests shows that the current use of a shape factor of 3.0 for angular aggregate is acceptable for very few fabrics. Therefore, shape factor values are not only shape dependent, but are fabric dependent as well, as all fabrics from a given manufacturer show essentially the same shape factor regardless of weight. This is especially true for the non-woven fabrics but less so for woven fabrics. The range of shape factor values for this plunger is 3.2-4.5 for woven fabrics, 1.0 for staple fibre fabrics, 2.6 for the composite fabric and 2.3-2.9 for continuous filament non-wovens.

5. Comparing results for the flat and hemispherical plunger CBR puncture tests shows that the current use of 0.8 as a shape factor for rounded aggregate is unrealistic. Stress concentrations under the hemispherical plunger led to reduced failure load values for all but staple fibre fabrics. Hence, the shape factor for rounded aggregate is greater than 1.0 for most fabrics, and 0.9 for staple fibre fabrics. The range of shape factor values for this plunger is 0.9-1.5, which is much narrower than the range of 1.0-4.5 for the pyramid-tipped plunger.

6. The relationship between CBR failure load F_p and tensile force per unit width T of $T \cong 2\pi.F_p$ quoted by Cazzuffi et al. (1986), and Waters et al. (1983) in a different form, does not hold for 200mm wide strip tensile tests when necking is not taken into account. Cazzuffi et al. recommend its application to 500mm wide strip tests but Waters et al. do not mention such an application. If wide strip test values are reduced by ten per cent for wovens and increased by 20 per cent for non-wovens

according to Myles and Carswell (1986), good agreement is obtained. As 500mm wide strip tests were not conducted as part of this investigation, it is not possible to say whether agreement would have resulted, although this is likely to have been the case.

7. An exponent close to 0.68 as given in AS 3706.5 (1990) is achievable at drop heights greater than one metre, and for failure hole diameters generally greater than 15mm, for all but staple fibre fabrics. The failure mechanism in staple fibre fabrics is more plastic than the quasi-elastic failure observed for other fabrics, leading to smaller hole diameters, and greater exponent values. These greater exponent values lead to smaller h_{50} and G-Rating values, even though the failure hole diameter for staple fibre fabrics is smaller than for most other fabrics at a given drop height.

8. The 80 per cent elongation limit in the G-Rating was found to not be applicable to the geotextiles tested, as failure elongation was less than 80 per cent for all fabrics. This limit should be ignored for separation geotextiles.

9. The proposed Rupture Index is a simple and effective measure of geotextile behaviour as it accounts for both tensile strength and deformation characteristics. The calculation of Rupture Index values for fabrics tested in isolation and on a soil will give an indication of the total change in behaviour from one case to the other. The measured increase in failure load with soil is quoted in the literature (Lhote and Rigo, 1987), but no plunger displacements are given. Therefore, the total behaviour of geotextiles tested on a soil is not known.

10. From the returned questionnares the use of geotextiles by Victorian municipalities appears to be small. The method of selection of geotextiles is usually by past experience or recommendations by sales engineers.

7.2 Suggestions for further work:

As a result of the testing program, and the findings of the literature review, the following suggestions for further work are made:

1. Look at the behaviour of CBR puncture test specimens, with a view to mathematically modelling the deformed specimen shape. The actual deformed shape is non-planar, and the degree of curvature varies with the stiffness of a fabric. Vertical plunger displacement is an index measure of deformation, but modelling the specimen shape will enable the effects of shear stress at the plunger base and membrane behaviour to be accounted for, resulting in more precise elongation values.

2. Conduct CBR puncture tests using other modified plungers, such as three or four-sided pyramids with different apex angles, or cones, to validate shape factor values proposed in this study. In particular, to observe the behaviour of staple fibre fabrics under these plungers and to determine whether stress localisation is the only factor contributing to a higher failure load compared with a flat plunger. The concentration of stress under a pyramid-tipped plunger is greater than that for a hemispherical plunger. However, under a hemispherical plunger, failure load values are greater. Tests using a plunger equipped with a conical tip will lead to higher stress concentrations than with a hemispherical plunger, without cutting fibres.

3. Conduct flat plunger CBR puncture tests on geotextiles in isolation and on soils of different bearing capacities, in order to model field behaviour and to determine a relationship between Rupture Index values for a given geotextile type and soil bearing capacity. Published test results of this type do not include deformation data, therefore, Rupture Index values cannot be calculated.

4. Conduct drop cone tests on a wide range of geotextiles at drop heights ranging from 250mm to 2000mm, in order to calculate exponents for the d_{500}/d_{250}, d_{1000}/d_{500}, d_{1500}/d_{750} and d_{2000}/d_{1000} cases. These exponents would be fabric specific, to a certain extent, and also drop height specific. An exponent of 0.68 was more closely approximated for d_{1000}/d_{500} than for d_{500}/d_{250}. This trend may continue for drop heights up to 2000mm but, as no tests were conducted above 1000mm for most fabrics, this is not known. In particular, the effect on failure hole diameters of plastic deformation at the point of impact of the cone should be observed, especially for staple fibre fabrics. The protrusion of the cone through the fabric is easily found using the geometry of the cone and the failure hole diameter. If the measured distance from the cone tip at rest to the initial fabric position is greater than this protrusion, the excess is a result of plastic deformation of the specimen. Conducting drop cone tests with and without underlying soil will indicate whether a relationship exists between this plastic deformation and subgrade reaction.

5. Look at other properties related to separation such as EOS, and the change in EOS with strain. Initially, it was intended to examine the change in EOS for geotextiles subjected to different amount of pre-straining, but this could not be accomodated in this investigation.

BIBLIOGRAPHY

BIBLIOGRAPHY

Alfheim, S. L. and Sorlie, A., "Testing and Classification of Fabrics for Application in Road Constructions," *C. R. Coll. Int. Soils Tex.*, Paris, 1977.

Anjiang, W., Bin, Z. and Lihua, L., "Research of Influence of Test Conditions on the Tensile Strength of Geotextile," *Proc. 4th Int. Conf. on Geotextiles, Geomembranes and Related Products,* The Hague, Netherlands, 1990.

AS 3706.1, "General Requirements, Sampling, Conditioning, Basic Physical Properties and Statistical Analysis," Standards Australia, 1990.

AS 3706.2, "Determination of Tensile Properties - Wide Strip Method," Standards Australia, 1990.

AS 3706.4, "Determination of Burst Strength - California Bearing Ratio (CBR) Plunger Method," Standards Australia, 1990.

AS 3706.5, "Determination of Puncture Resistance - Drop Cone Method," Standards Australia, 1990.

ASTM D 1682, "Standard Test Methods for Breaking Load and Elongation of Textile Fabrics," ASTM, Philadelphia, U. S. A., 1964.

ASTM D 3786, "Standard Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics - Diaphragm Bursting Strength Tester Method," ASTM, Philadelphia, U. S. A., 1987.

ASTM D 3787, "Standard Test Method for Bursting Strength of Knitted Goods - Constant-Rate-of-Traverse (CRT) Ball Burst Test," ASTM, Philadelphia, U. S. A., 1980.

ASTM D 4439, "Standard Terminology for Geotextiles," ASTM, Philadelphia, U. S. A., 1987.

Austroads, "Guide to Geotextiles," Technical Report, Australia, January, 1990.

Bonaparte, R., Ah-Line, C., Charron, R. and Tisinger, L., "Survivability and Durability of a Nonwoven Geotextile," *Proc. of Symp. on Geosynthetics for Soil Improvement,* Geotechnical Special Publication No. 18, Holtz (ed), ASCE, New York, New York, U. S. A., 1988.

Brorsson, I. and Eriksson, L., "Long-term Properties of Geotextiles and Their Function as a Separator in Road Construction," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Brown, R. G., Personal Communication, Senior Geotechnical Engineer, Geotechnical Group, VicRoads, Kew, Victoria, Australia, 1991.

BS 812, "Methods for Sampling and Testing of Mineral Aggregates, Sands and Fillers," British Standards Institution, London, England, 1951.

Cazzuffi, D., Venesia, S., Rinaldi, M. and Zocca, A., The Mechanical Properties of Geotextiles: Italian Standard and Interlaboratory Test Comparison," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Christopher, B. R., Personal Communication, Vice President, Technical Services, Polyfelt Incorporated, Atlanta, Georgia, U. S. A., 1992.

Christopher, B. R., and Holtz, R. D., *Geotextile Engineering Manual*, Federal Highway Administration Manual, National Highway Institute, Washington D. C., U. S. A., 1985.

Curiskis, J. I. Dr., Personal Communication, School of Fibre Science and Technology, Department of Textile Technology, University of New South Wales, Australia, 1994.

De Groot, M., Janse, E., Maagdenberg, T. A. C. and Van den Berg, C., "Design Method and Guidelines for Geotextile Application in Road Construction," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

DIN 54.307, "Testing of Textiles; Plunger Puncture Test (CBR)," Deutsche Norm, Germany, 1982.

Dixon, J. H. and Osborn, S., "Field Trials to Evaluate Geotextile Puncture Resistance, *Proc. 4th Int. Conf. on Geotextiles,* Geomembranes and Related Products, The Hague, Netherlands, 1990.

Finn, N. B. and Sadlier, M. A., "A Study of Geotextile Use in Australia," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Fluet, J. E., Jr., "Geosynthetics for Soil Improvement: A General Report and Keynote Address," *Proc. of Symp. on Geosynthetics for Soil Improvement,* Geotechnical Special Publication No. 18, Holtz (ed), ASCE, New York, New York, U. S. A., 1988.

Foch, G., "Geotextile Test Methods Under Scrutiny," *Highways,* October, 1990.

Giroud, J. P., "Behaviour of Geotextiles," Presented at NATO, Advanced Study Institute - Mechanics of Flexible Fibre Assemblies, Kilini, Greece, Aug. 19-Sept. 2, 1979.

Giroud, J. P., "Designing With Geotextiles," *Matériaux et Constructions,* Vol. 14, No. 82, 1981.

Giroud, J. P., "Geotextiles and Related Products," Chapter 8, *Geotechnical Modelling and Applications,* Sayed (ed), Gulf Publishing Co., Houston, Texas, U. S. A. 1987.

Giroud, J. P., "Biaxial Tensile State of Stress in Geosynthetics," *Geotextiles and Geomembranes,* Vol. 11, 1992.

Hausmann, M. R., Ring, G. J. and Pitsis, S. E., "Abrasion of Geotextiles in Railway Track Applications," *Proc. 4th Int. Conf. on Geotextiles, Geomembranes and Related Products,* The Hague, Netherlands, 1990.

Ingold, T. S., "Civil Engineering Requirements for Long-Term Behaviour of Geotextiles," *Durability of Geotextiles,* RILEM, Chapman and Hall, London, U. K., 1988.

John, N. W. M., *Geotextiles,* Blackie and Son, Bishopbriggs, Glasgow, Scotland, 1987.

Koerner, G. R. and Koerner, R. M., "The Installation Survivability of Geotextiles and Geogrids," *Proc. 4th Int. Conf. on Geotextiles, Geomembranes and Related Products,* The Hague, Netherlands, 1990.

Koerner, R. M., "Should I Specify a Woven or a Nonwoven?," *Geotechnical Fabrics Report,* Vol. 2, No. 2, 1984.

Koerner, R. M., *Designing With Geosynthetics,* Prentice Hall, Englewood Cliffs, New Jersey, U. S. A., 1990.

Koerner, R. M., Monteleone, M. J., Schmidt, J. R. and Roethe, A. T., "Puncture and Impact Resistance of Geosynthetics," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Lasalle, J., Fayoux, D. and Berthier, J. P., "Specifications and Recommendations of French Geotextiles Committee," *Proc. 2nd Int. Conf. on Geotextiles,* Las Vegas, U. S. A., 1982.

Lawson, C. R., "Geotextile Requirements for Erosion Control Structures," *Symp. on Recent Developments in Ground Improvement Techniques,* Bangkok, Thailand, 1982.

Lhote, F. and Rigo, J. M., "Study of the Puncturing Effect on Geotextiles," *The Post Vienna Conference on Geotextiles,* Singapore, 1987.

Litwinowicz, A., Personal Communication, Manager (Transport Services), Transport Technology Division, Queensland Department of Transport, Brisbane, Australia, 1992.

Litwinowicz, A., Personal Communication, Manager (Transport Services), Transport Technology Division, Queensland Department of Transport, Brisbane, Australia, 1993.

McGown, A., Andrawes, K. Z., Wilson-Fahmy, R. F. and Brady, K. C., "Strength Testing of Geotextiles," TRRL Supplementary Report 703, Department of the Environment, Department of Transport, Crowthorne, Berkshire, U. K., 1981.

Murphy, V. P. and Koerner, R. M., "CBR Strength (Puncture) of Geosynthetics," *ASTM Geotechnical Testing Journal,* Vol. 11, No. 3, September, 1988.

Myles, B. and Carswell, I. G., "Tensile Testing of Geotextiles," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Nijhof, B., Birkenfeld, S. and Nederlof, K., "Certification, Standardisation and Specification of Geotextiles in the Netherlands," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Nowatzki, E. A. and Pageau, S. R., "The Effect of Holes on the Tensile Performance of Geotextiles," *Geotechnical Fabrics Report,* Vol. 1, No. 4, 1984.

Pühringer, G., "Pyramid Puncture Test for Evaluating the Protection Function of Geotextiles," *Geosynthetic Testing for Waste Containment Applications,* ASTM STP 1081, Koerner (ed), ASTM, Philadelphia, U. S. A., 1990.

Rathmayer, H., "Experiences With 'VTT-GEO' Classified Non-Woven Geotextiles for Finnish Road Constructions," *Proc. 2nd Int. Conf. on Geotextiles,* Las Vegas, U. S. A., 1982.

Raumann, G., "Geotextiles: Construction Materials in Evolution," *Proc. 2nd Int. Conf. on Geotextiles,* Las Vegas, U. S. A., 1982.

Ruddock, E. C., "Tests on Woven and Non-Woven Fabrics for Pore Size and Damage by Aggregate," *C. R. Coll. Int. Soils Tex.*, Paris, 1977.

Sadlier, M. A., "Geotextiles in Australian Roads - A Review," Proc. *14th ARRB Conference,* Canberra, Australia, 1988.

Shrestha, S. C. and Bell, J. R., "A Wide Strip Tensile Test of Geotextiles," *Proc. 2nd Int. Conf. on Geotextiles,* Las Vegas, U. S. A., 1982.

Sprague, C. J. and Cicoff, G., "A Study of Permanent Road Stabilisation: Low Cost Pavement Structures and Lightweight Geotextiles," *Proc. Geosynthetics '89,* U. S. A., 1989.

Warwick, D., *Design With Geotextiles*, Design Manual, School of Civil Engineering, Curtin University of Technology, Perth, Australia, 1991.

Warwick, R. G. "Woven Fabrics," Low Brothers & Co. (Dundee) Ltd, Geofabrics Australasia file, year unknown.

Waters, T. J., "Evaluation of Geotextiles for Drainage and Reinforcement Applications," *Proc. 12th ARRB Conference,* Hobart, Australia, 1984.

Waters, T. J., Robertson, N. F., and Carter, M. I., *Evaluation of Geotextiles*, Queensland Department of Main Roads Materials Branch, Report R1324, Brisbane, Australia, September, 1983.

Wehr, H., Separation Function of Non-Woven Geotextiles in Railway Construction," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

Werner, G., "Design Criteria for the Separation Function of Geotextiles on the Basis of Mechanical Test Procedures," *Proc. 3rd Int. Conf. on Geotextiles,* Vienna, Austria, 1986.

APPENDIX A

APPENDIX A DERIVATION OF α-δ RELATIONSHIP FOR THE HEMISPHERICAL PLUNGER

A.1 Derivation of α-δ relationship for δ < r:

The relationship between α and δ is the same regardless of the value of either α or δ. However, for $\delta < r$, $\delta = r$ and $\delta > r$, the derivations are different, although the end result is the same. Figure A.1 shows the case for $\delta < r$, and all the variables required to derive the relationship between δ and α.

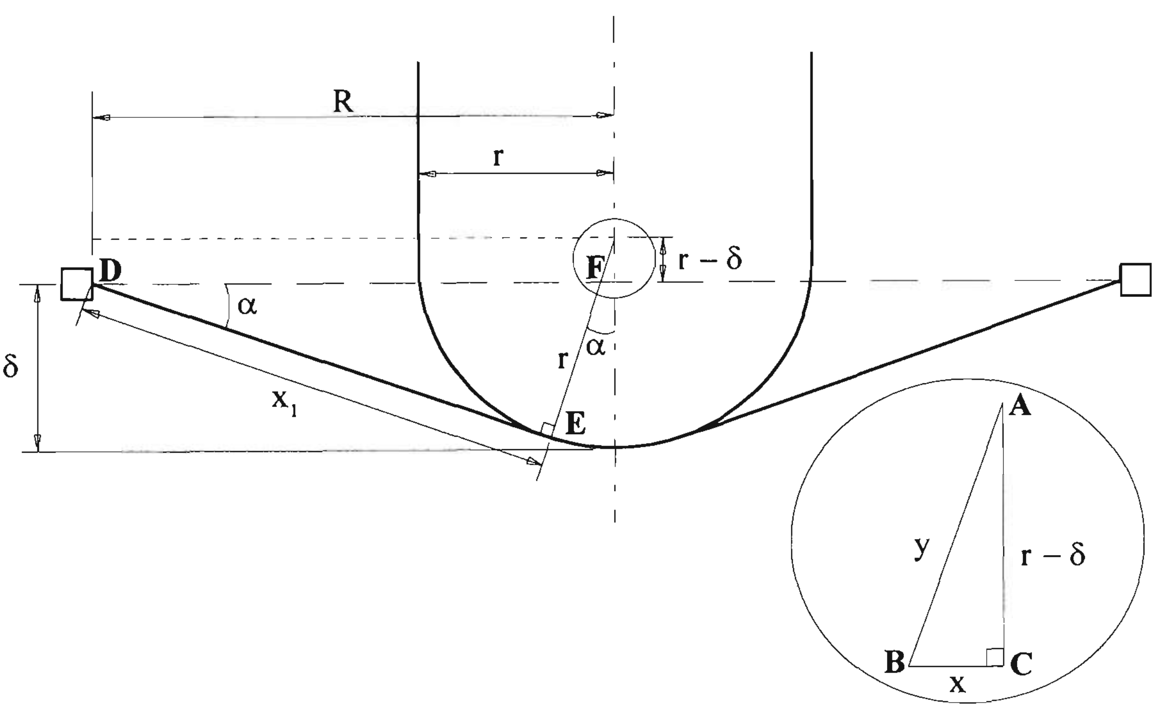

Figure A.1 Schematic view of specimen under a hemispherical plunger for $\delta < r$.

For triangle ABC, the relationships between the sides and α are as follows:

$\tan\alpha = \dfrac{x}{(r-\delta)}$ $\quad \therefore x = (r - \delta)\tan\alpha$

$\cos\alpha = \dfrac{(r-\delta)}{y}$ $\quad \therefore y = \dfrac{(r - \delta)}{\cos\alpha}$

For triangle DEF $\sin\alpha = \dfrac{r-y}{R-x}$. Substituting the expressions for x and y found above, the expression for sin α becomes:

$$\sin\alpha = \frac{r - \dfrac{(r-\delta)}{\cos\alpha}}{R-(r-\delta)\tan\alpha}$$

$$= \frac{r\cos\alpha - r + \delta}{R\cos\alpha - (r-\delta)\sin\alpha}$$

$$\sin\alpha R\cos\alpha - (r-\delta)\sin^2\alpha = r\cos\alpha - r + \delta$$

$$\delta + (r-\delta)\sin^2\alpha = \sin\alpha R\cos\alpha - r\cos\alpha + r$$

$$\delta + r\sin^2\alpha - \delta\sin^2\alpha = \sin\alpha R\cos\alpha + +r + -r\cos\alpha$$

$$\delta\left(1-\sin^2\alpha\right) = R\sin\alpha\cos\alpha - r\sin^2\alpha - r\cos\alpha + r$$

$$\delta = \frac{R\sin\alpha\cos\alpha - r\left(\cos\alpha + \sin^2\alpha\right) + r}{\left(1-\sin^2\alpha\right)}$$

$$\delta = \frac{75\sin\alpha\cos\alpha - 25\left(\cos\alpha + \sin^2\alpha\right) + 25}{\cos^2\alpha}$$

A.2 The α-δ relationship for δ = r:

When δ = r no expression is necessary as δ is 25mm in this case. Figure A.2 shows the case for δ = r.

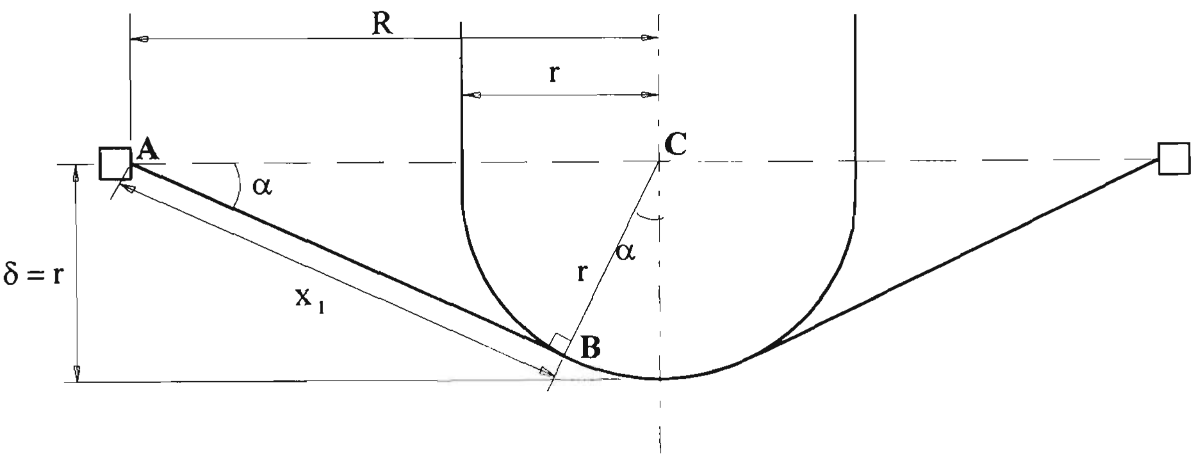

Figure A.2 Schematic view of specimen under a hemispherical plunger for δ = r.

For triangle ABC, $\sin\alpha = \frac{r}{R}$ and α becomes:

$$\alpha = \sin^{-1}\left(\frac{25}{75}\right)$$

$$= 19.47^{o}$$

A.3 Derivation of α-δ relationship for δ > r:

Figure A.3 shows the case for δ > r, and all the variables required to derive the relationship between δ and α.

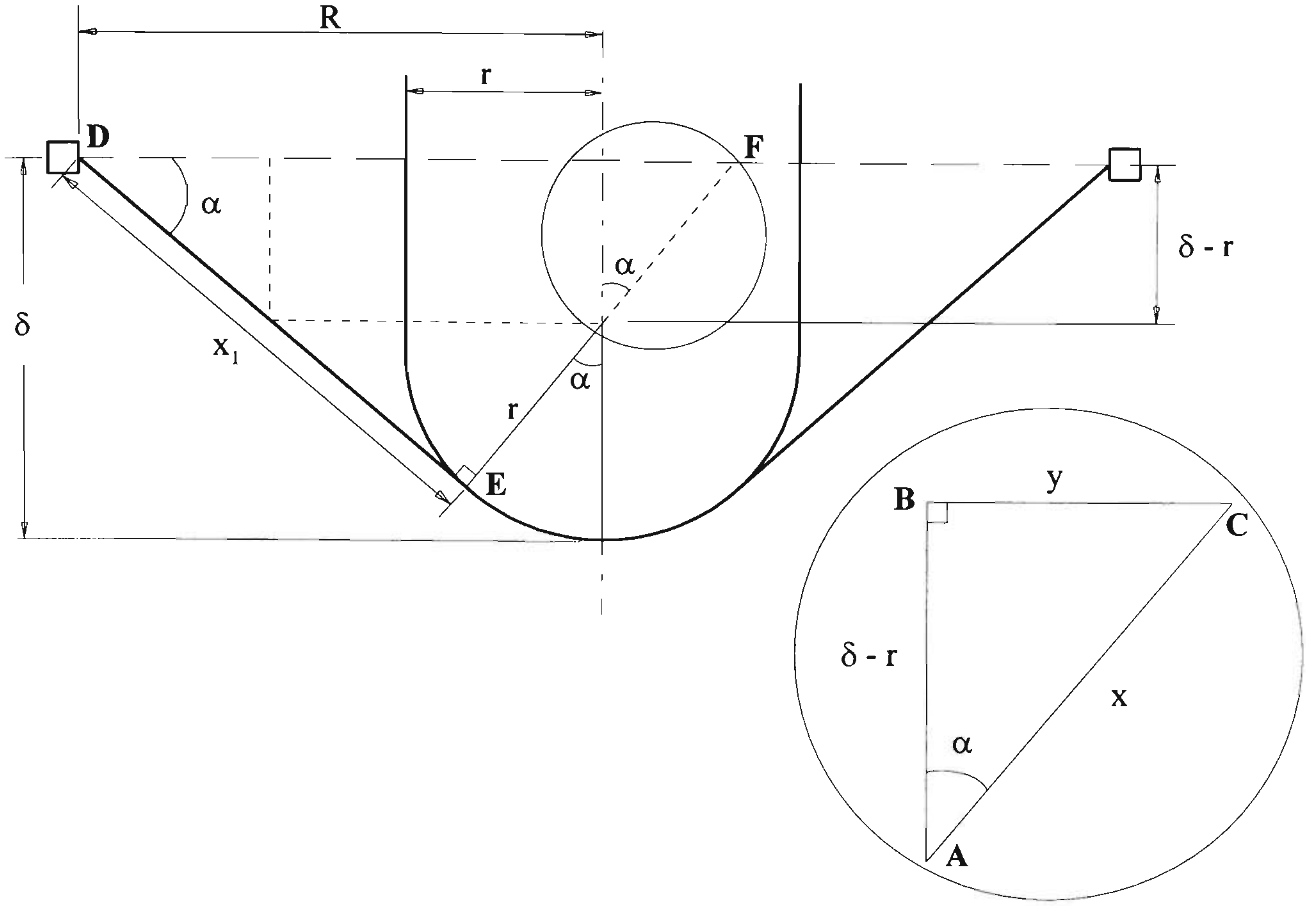

Figure A.3 Schematic view of specimen under a hemispherical plunger for δ > r.

For triangle ABC, the relationships between the sides and α are as follows:

$$\cos\alpha = \frac{(\delta - r)}{x} \qquad \therefore x = \frac{(\delta - r)}{\cos\alpha}$$

$$\tan\alpha = \frac{y}{(\delta - r)} \qquad \therefore y = (\delta - r)\tan\alpha$$

For triangle DEF $\sin\alpha = \dfrac{r + x}{R + y}$. Substituting the expressions for x and y found above, the expression for sin α becomes:

$$\sin\alpha = \frac{r + \dfrac{(\delta - r)}{\cos\alpha}}{R + (\delta - r)\sin\alpha}$$

$$= \frac{r\cos\alpha + \delta - r}{R\cos\alpha + (\delta - r)\sin\alpha}$$

$$\sin\alpha R\cos\alpha + (\delta - r)\sin^2\alpha = r\cos\alpha + \delta - r$$

$$R\sin\alpha\cos\alpha + \delta\sin^2\alpha - r\sin^2\alpha = r\cos\alpha + \delta - r$$

$$\delta\sin^2\alpha - \delta = r\cos\alpha - r + r\sin^2\alpha - R\sin\alpha\cos\alpha \quad (\times \text{ both sides by -1})$$

$$\delta - \delta\sin^2\alpha = r - r\cos\alpha - r\sin^2\alpha + R\sin\alpha\cos\alpha$$

$$\delta\left(1 - \sin^2\alpha\right) = R\sin\alpha\cos\alpha - r\left(\cos\alpha + \sin^2\alpha\right) + r$$

$$\delta = \frac{R\sin\alpha\cos\alpha - r\left(\cos\alpha + \sin^2\alpha\right) + r}{\left(1 - \sin^2\alpha\right)}$$

$$\delta = \frac{75\sin\alpha\cos\alpha - 25\left(\cos\alpha + \sin^2\alpha\right) + 25}{\cos^2\alpha}$$

APPENDIX B

GEOTEXTILES QUESTIONNAIRE

Date ___/___/___

VicRoads region: ____________________________

Name: ______________________________________

Position: ____________________________________

Contact telephone number: ___________________

- **Geotextile products used during the past year:**

Job Name & Location	Date	Product Name	Quantity (m^2)	Application

JOB NAME: ______________________________

Please give as much information as possible about the following: *

1. **Ground conditions (e.g. soil type, consistency, ground and surface water conditions)**

2. **Method of laying geotextile**

3. **Type of fill placed on geotextile (particle size, angularity, etc...)**

4. **Initial lift thickness**

5. **Spreading and compacting equipment used**

6. **Observed behaviour of geotextile during placement (under feet, vehicle wheels, earth-moving and compacting machinery)**

7. **If damage was seen during placement, what was it, what is thought to have caused it and what might have been done to prevent it?**

8. **Has geotextile failure been observed subsequent to construction and, if so, how did the failure show up?**

9. **Has failed geotextile been uncovered and/or removed? If so, what was observed?**

10. **If geotextile was laid over very rough or uneven surfaces, (e.g. over tree stumps or coarse rock fill) what behaviour was observed?**

11. On what basis was the geotextile chosen for this application?

* **N.B. ORIGINAL SHEETS:** Please photocopy as many copies of questions 1 to 11 as required.

12. Further comments

APPENDIX C

CBR PUNCTURE TEST RESULTS									
BIDIM A 12									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1514.000	12.202	50.930	803.800	17.290	50.520	1436.000	14.371	52.320
2	1510.000	10.101	51.810	1090.000	14.253	52.090	1352.000	13.285	56.270
3	1774.000	9.539	50.840	812.900	17.613	51.660	1647.000	12.917	60.240
4	1296.000	9.586	47.700	820.700	15.841	48.510	1659.000	12.627	58.310
5	1861.000	9.521	51.980	643.500	16.132	47.720	1403.000	15.411	60.730
6	1842.000	9.148	50.430						
7	1573.000	9.395	50.710						
8	1436.000	10.054	48.580						
9	1467.000	11.708	50.460						
10	1476.000	10.361	48.370						
MEAN	1574.900	10.162	50.181	834.180	16.226	50.100	1499.400	13.722	57.574
S.D. (s)	188.345	1.019	1.465	160.748	1.333	1.921	143.437	1.152	3.425
C.V%	11.959	10.033	2.918	19.270	8.214	3.835	9.566	8.398	5.948
Mean - 1.65s	1264.132	8.479	47.765	568.945	14.027	46.930	1262.728	11.821	51.923
Mean + 1.65s	1885.668	11.844	52.597	1099.415	18.425	53.270	1736.072	15.624	63.225

CBR PUNCTURE TEST RESULTS									
BIDIM A 14									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2144.000	6.149	49.280	927.500	12.166	46.420	1578.000	14.028	59.850
2	1685.000	8.004	48.790	772.600	13.090	47.130	1461.000	11.749	57.800
3	1329.000	9.421	50.280	601.900	14.343	42.990	2107.000	10.513	60.490
4	2193.000	6.679	48.660	665.500	14.397	45.820	1710.000	9.648	58.040
5	1901.000	7.627	50.160	903.400	12.597	45.380	1788.000	10.607	57.400
6	1911.000	7.252	46.870						
7	2150.000	6.104	49.470						
8	1902.000	7.549	49.780						
9	1703.000	8.022	48.460						
10	1776.000	7.422	48.610						
MEAN	1869.400	7.423	49.036	774.180	13.319	45.548	1728.800	11.309	58.716
S.D. (s)	263.544	0.983	1.001	142.915	1.014	1.574	245.637	1.694	1.366
C.V%	14.098	13.239	2.041	18.460	7.614	3.455	14.209	14.975	2.326
Mean - 1.65s	1434.553	5.801	47.384	538.370	11.645	42.951	1323.498	8.515	56.463
Mean + 1.65s	2304.247	9.044	50.688	1009.990	14.992	48.145	2134.102	14.103	60.969

CBR PUNCTURE TEST RESULTS									
BIDIM A 24									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2566.000	7.079	50.940	1144.000	13.892	51.220	2745.000	9.644	57.970
2	2709.000	6.149	48.590	1075.000	12.969	45.870	2534.000	9.584	60.730
3	2475.000	6.983	49.370	1326.000	13.041	51.480	2240.000	10.476	57.640
4	2209.000	7.548	48.070	902.300	12.045	43.060	1919.000	11.227	56.030
5	2591.000	6.951	50.240	1116.000	11.417	46.560	2146.000	10.522	57.650
6	2685.000	6.128	47.940						
7	2695.000	6.175	48.210						
8	2519.000	7.258	49.990						
9	3389.000	5.499	51.190						
10	2706.000	6.433	47.620						
MEAN	2654.400	6.620	49.216	1112.660	12.673	47.638	2316.800	10.291	58.004
S.D. (s)	299.740	0.639	1.309	151.803	0.959	3.634	325.518	0.686	1.702
C.V%	11.292	9.651	2.661	13.643	7.570	7.629	14.050	6.666	2.934
Mean - 1.65s	2159.828	5.566	47.055	862.185	11.090	41.641	1779.696	9.159	55.196
Mean + 1.65s	3148.972	7.674	51.377	1363.135	14.256	53.635	2853.904	11.422	60.812

CBR PUNCTURE TEST RESULTS									
BIDIM A 29									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	3421.000	4.808	52.940	1107.000	10.597	46.030	2938.000	8.581	61.630
2	2558.000	5.282	49.880	1106.000	10.116	45.770	3106.000	7.975	61.290
3	3013.000	4.900	52.900	1137.000	10.244	44.270	3295.000	7.783	61.760
4	3043.000	5.460	49.420	1315.000	9.639	47.830	2587.000	7.692	60.660
5	2776.000	5.100	50.150	1301.000	10.794	47.770	2526.000	9.143	58.410
6	3758.000	4.707	53.010						
7	3699.000	4.571	50.970						
8	2961.000	5.815	50.840						
9	3268.000	4.999	50.920						
10	2757.000	5.823	49.350						
MEAN	3125.400	5.147	51.038	1193.200	10.278	46.334	2890.400	8.235	60.750
S.D. (s)	403.196	0.440	1.439	105.651	0.448	1.498	330.639	0.615	1.376
C.V%	12.901	8.555	2.819	8.854	4.361	3.232	11.439	7.463	2.264
Mean - 1.65s	2460.126	4.420	48.664	1018.875	9.538	43.863	2344.845	7.221	58.480
Mean + 1.65s	3790.674	5.873	53.412	1367.525	11.018	48.805	3435.955	9.249	63.020

CBR PUNCTURE TEST RESULTS									
BIDIM A 34									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	3785.000	5.508	52.200	1720.000	8.216	47.090	4030.000	7.571	63.200
2	3749.000	5.519	52.120	1656.000	9.862	48.060	4060.000	7.513	63.410
3	3462.000	5.922	50.220	1593.000	9.398	47.980	3529.000	7.670	61.560
4	3973.000	5.528	50.610	1684.000	8.305	46.700	2579.000	8.039	62.700
5	3217.000	5.752	48.440	1195.000	9.490	42.480	3235.000	7.859	60.280
6	3677.000	5.757	51.210						
7	4152.000	5.353	52.230						
8	3862.000	5.056	51.350						
9	4165.000	4.812	53.140						
10	3878.000	5.528	48.820						
MEAN	3792.000	5.474	51.034	1569.600	9.054	46.462	3486.600	7.730	62.230
S.D. (s)	292.201	0.332	1.528	214.502	0.746	2.300	615.002	0.217	1.304
C.V%	7.706	6.074	2.994	13.666	8.236	4.951	17.639	2.805	2.096
Mean - 1.65s	3309.868	4.925	48.513	1215.671	7.824	42.667	2471.847	7.373	60.078
Mean + 1.65s	4274.132	6.022	53.555	1923.529	10.285	50.257	4501.353	8.088	64.382

CBR PUNCTURE TEST RESULTS									
BIDIM A 44									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	4711.000	5.159	52.330	1806.000	9.567	46.030	4408.000	8.840	63.720
2	4940.000	5.582	51.270	1521.000	8.474	41.950	4832.000	7.884	61.440
3	4490.000	4.965	50.480	1837.000	8.702	44.710	3933.000	4.909	27.280
4	4404.000	5.243	50.400	2309.000	8.522	49.640	4421.000	8.434	59.850
5	4816.000	5.493	50.820	1600.000	9.109	43.670	4621.000	6.859	61.410
6	4177.000	4.661	51.860						
7	4589.000	4.588	50.810						
8	5028.000	3.727	52.640						
9	3597.000	5.342	48.100						
10	4443.000	4.175	50.980						
MEAN	4519.500	4.894	50.969	1814.600	8.875	45.200	4443.000	7.385	54.740
S.D. (s)	415.422	0.602	1.264	307.108	0.461	2.896	333.472	1.571	15.413
C.V%	9.192	12.293	2.479	16.924	5.191	6.407	7.506	21.274	28.156
Mean - 1.65s	3834.053	3.901	48.884	1307.872	8.115	40.422	3892.771	4.793	29.309
Mean + 1.65s	5204.947	5.886	53.054	2321.328	9.635	49.978	4993.229	9.978	80.171

CBR PUNCTURE TEST RESULTS POLYFELT TS 420									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1604.000	12 077	53.510	512 500	9 943	39 490	1413.000	8 594	56 360
2	1574 000	11 113	52 770	709 500	9 325	50 000	1457.000	8 208	58 470
3	1649 000	10 008	51.230	568 100	9 071	41 380	1375 000	8 215	54 440
4	1491 000	8 564	53 360	703.600	9 316	45 560	1466 000	9 144	58 570
5	1723 000	6 732	49 540	681.600	9 775	48 970	1495 000	8 121	57.370
6	1626.000	3 782	46 840						
7	1373 000	5 333	43 770						
8	1810 000	4 493	49.220						
9	1791 000	4 857	48.700						
10	1744 000	3 720	49.390						
MEAN	1638 500	7.068	49.833	635.060	9 486	45 080	1441 200	8 456	57 042
S.D. (s)	136 952	3 144	3.059	89.316	0 360	4 596	47.267	0 425	1 712
C.V%	8 358	44 488	6.138	14 064	3 799	10 196	3.280	5 032	3 000
Mean - 1.65s	1412 529	1 880	44 786	487.688	8 891	37 496	1363 209	7 754	54 218
Mean + 1.65s	1864 471	12.256	54.880	782 432	10 081	52 664	1519 191	9 158	59 866

CBR PUNCTURE TEST RESULTS POLYFELT TS 500									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2015.000	9.764	52.480	531.300	12.238	41 660	1138 000	10 915	53.530
2	1499.000	8.583	47.330	598 400	14 578	45 270	1382.000	11.120	57 280
3	1979.000	5.555	50.090	776.400	8 803	44 370	1782 000	10 845	59 880
4	1849.000	4.857	46.930	752 000	9 537	48 580	1649.000	10.905	61.670
5	1781 000	5.654	48.630	978 800	11 260	51 430	1260.000	11.421	55.910
6	1866.000	4 248	48.880						
7	1873.000	6.843	48.110						
8	1643.000	6.263	46.630						
9	2140.000	5.202	51.390						
10	1785.000	6.850	49.360						
MEAN	1843.000	6.382	48.983	727 380	11 283	46 262	1442 200	11.042	57 654
S.D. (s)	183 575	1.707	1.908	174 144	2.290	3 802	268 137	0 236	3 212
C.V%	9.961	26 742	3.896	23 941	20.292	8 219	18.592	2 141	5.571
Mean - 1.65s	1540 101	3 566	45.834	440.043	7 505	39 989	999.775	10.651	52.354
Mean + 1.65s	2145.899	9.198	52.132	1014.717	15.061	52.535	1884.625	11.432	62.954

CBR PUNCTURE TEST RESULTS POLYFELT TS 550									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1993.000	4.871	51.920	699.900	8.220	46.480	1456.000	6.847	55.010
2	1996.000	4.982	51.510	595.700	10.708	45.910	1698.000	6.919	59.160
3	1750.000	4.443	49.310	680.500	7.990	46.540	1380.000	6.980	54.910
4	1705.000	4.767	48.760	518.900	9.608	46.830	1307.000	7.340	55.550
5	1830.000	4.378	50.760	593.800	8.522	47.010	1808.000	6.706	62.400
6	2064.000	4.500	50.340						
7	1823.000	4.516	50.540						
8	2111.000	4.950	52.630						
9	1770.000	4.332	49.180						
10	1988.000	4.261	50.240						
MEAN	1903.000	4.600	50.519	617.760	9.010	46.554	1529.800	6.958	57.406
S.D. (s)	143.446	0.268	1.244	73.344	1.134	0.420	214.017	0.237	3.295
C.V%	7.538	5.831	2.462	11.873	12.586	0.901	13.990	3.399	5.740
Mean - 1.65s	1666.315	4.157	48.467	496.743	7.139	45.862	1176.672	6.568	51.969
Mean + 1.65s	2139.685	5.043	52.571	738.777	10.881	47.246	1882.928	7.349	62.843

CBR PUNCTURE TEST RESULTS POLYFELT TS 600									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2353.000	4.570	49.260	837.300	8.036	46.170	2497.000	6.846	59.400
2	2489.000	4.776	50.590	864.700	9.631	47.520	2024.000	7.210	56.090
3	2734.000	4.782	51.740	771.600	10.055	48.980	2561.000	6.452	61.460
4	2344.000	4.749	48.250	970.700	9.149	46.620	1568.000	6.798	52.210
5	2687.000	4.234	52.260	779.600	9.062	48.000	2109.000	6.629	57.870
6	2455.000	4.462	49.700						
7	2460.000	4.164	48.370						
8	2615.000	3.600	50.650						
9	2295.000	5.444	49.570						
10	2805.000	3.616	51.640						
MEAN	2523.700	4.440	50.203	844.780	9.186	47.458	2151.800	6.787	57.406
S.D. (s)	177.035	0.563	1.403	80.487	0.757	1.115	401.745	0.283	3.513
C.V%	7.015	12.684	2.795	9.528	8.241	2.350	18.670	4.166	6.119
Mean - 1.65s	2231.591	3.511	47.887	711.977	7.937	45.618	1488.921	6.321	51.610
Mean + 1.65s	2815.809	5.369	52.519	977.583	10.436	49.298	2814.679	7.253	63.202

CBR PUNCTURE TEST RESULTS POLYFELT TS 650									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2431.000	7.647	50.350	925.900	11.138	50.780	2419.000	7.618	57.390
2	2761.000	4.908	49.810	886.200	10.987	46.540	2550.000	7.452	59.040
3	2613.000	5.263	47.900	962.700	9.369	42.570	2298.000	8.085	56.790
4	2666.000	5.790	50.590	834.600	11.662	42.600	2729.000	7.624	61.410
5	2417.000	8.100	48.700	716.800	9.832	49.770	2089.000	6.668	55.070
6	2583.000	5.117	50.870						
7	2995.000	7.858	52.650						
8	2793.000	5.048	51.640						
9	2826.000	5.626	51.420						
10	3200.000	5.170	54.120						
MEAN	2728.500	6.053	50.805	865.240	10.598	46.452	2417.000	7.489	57.940
S.D. (s)	243.131	1.284	1.813	95.643	0.958	3.862	243.301	0.516	2.404
C.V%	8.911	21.216	3.569	11.054	9.041	8.314	10.066	6.891	4.149
Mean - 1.65s	2327.334	3.934	47.813	707.428	9.017	40.080	2015.553	6.638	53.974
Mean + 1.65s	3129.666	8.172	53.797	1023.052	12.179	52.824	2818.447	8.341	61.906

CBR PUNCTURE TEST RESULTS POLYFELT TS 700									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	3843.000	12.526	58.460	1143.000	6.720	43.140	3091.000	8.925	59.000
2	3499.000	6.339	50.110	1084.000	6.402	39.030	2562.000	9.043	53.720
3*	N/A	N/A	N/A	1168.000	10.991	42.360	3034.000	9.077	58.830
4	3477.000	5.748	50.320	1330.000	9.442	50.110	3521.000	9.680	61.360
5	2972.000	4.167	48.810	1105.000	6.760	45.210	2636.000	7.600	55.340
6	3463.000	6.766	51.200						
7*	N/A	N/A	N/A						
8	3297.000	6.563	49.770						
9	3152.000	4.487	50.960						
10	3901.000	4.684	52.470						
MEAN	3450.500	6.410	51.512	1166.000	8.063	43.970	2968.800	8.865	57.650
S.D. (s)	316.644	2.665	3.007	97.306	2.045	4.090	387.412	0.766	3.072
C.V%	9.177	41.572	5.838	8.345	25.368	9.302	13.049	8.636	5.330
Mean - 1.65s	2928.037	2.013	46.550	1005.445	4.688	37.221	2329.571	7.602	52.580
Mean + 1.65s	3972.963	10.807	56.475	1326.555	11.438	50.719	3608.029	10.128	62.720

*NOTE: Excluded due to specimen slippage during test.

CBR PUNCTURE TEST RESULTS POLYFELT TS 750									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	5071.000	3.638	54.330	1730.000	9.242	45.140	4298.000	7.805	59.840
2	4584.000	4.476	51.210	1799.000	7.469	44.100	3862.000	6.841	57.590
3	4816.000	4.028	51.140	1513.000	8.078	42.960	3632.000	7.991	57.720
4	4423.000	4.158	51.300	1102.000	8.681	38.760	4717.000	7.224	61.810
5	4426.000	1.450	37.550	1697.000	8.664	45.250	3917.000	7.802	78.890
6	4373.000	7.622	53.750						
7	4707.000	6.091	52.400						
8	4899.000	6.587	53.240						
9	4779.000	5.979	54.110						
10	4268.000	4.895	50.330						
MEAN	4634.600	4.892	50.936	1568.200	8.427	43.242	4085.200	7.533	63.170
S.D. (s)	260.988	1.758	4.908	281.259	0.675	2.671	426.601	0.482	8.957
C.V%	5.631	35.939	9.635	17.935	8.014	6.177	10.443	6.403	14.179
Mean - 1.65s	4203.971	1.991	42.838	1104.122	7.312	38.835	3381.308	6.737	48.391
Mean + 1.65s	5065.229	7.794	59.034	2032.278	9.541	47.649	4789.092	8.328	77.949

CBR PUNCTURE TEST RESULTS POLYTRAC 155									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	N/A	N/A	N/A	847.800	4.182	39.220	2464.000	3.380	36.780
2	3638.000	2.100	33.500	677.300	3.401	30.260	2462.000	3.499	37.970
3	3640.000	2.394	34.740	872.000	3.854	37.480	2311.000	2.599	35.790
4	3360.000	1.800	32.710	796.300	3.360	36.600	2239.000	3.092	36.450
5	3643.000	1.323	33.590	842.400	3.971	38.110	2330.000	2.942	36.430
6	3652.000	1.626	33.330						
7	3639.000	1.488	33.090						
8	3605.000	1.542	32.820						
9	3768.000	1.524	33.570						
10	3647.000	1.958	33.950						
MEAN	3621.333	1.751	33.478	807.160	3.753	36.334	2361.200	3.102	36.684
S.D. (s)	107.866	0.343	0.616	77.587	0.361	3.527	98.938	0.358	0.803
C.V%	2.979	19.620	1.839	9.612	9.610	9.707	4.190	11.550	2.190
Mean - 1.65s	3443.355	1.184	32.462	679.141	3.158	30.514	2197.953	2.511	35.358
Mean + 1.65s	3799.312	2.317	34.494	935.179	4.349	42.154	2524.447	3.694	38.010

CBR PUNCTURE TEST RESULTS POLYTRAC C (Woven up)									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1427.000	2.924	25.170	628.200	5.320	31.120	957.300	4.996	29.140
2	1442.000	2.471	24.310	510.100	5.893	29.030	995.400	5.003	29.100
3	1404.000	2.730	24.920	518.900	5.415	34.760	840.500	4.939	31.380
4	1406.000	2.810	23.810	463.600	5.828	29.340	1189.000	4.932	30.980
5	1435.000	2.691	25.070	589.300	5.840	32.630	1180.000	5.282	33.030
6	1419.000	2.628	23.840						
7	1567.000	2.311	25.860						
8	1448.000	2.268	24.050						
9	1512.000	3.004	26.110						
10	1591.000	2.793	25.820						
MEAN	1465.100	2.663	24.896	542.020	5.659	31.376	1032.440	5.030	30.726
S.D. (s)	67.469	0.246	0.864	65.889	0.270	2.384	150.120	0.144	1.655
C.V%	4.605	9.251	3.470	12.156	4.762	7.599	14.540	2.868	5.387
Mean - 1.65s	1353.776	2.257	23.471	433.303	5.215	27.442	784.742	4.792	27.995
Mean + 1.65s	1576.424	3.069	26.321	650.737	6.104	35.310	1280.138	5.268	33.457

CBR PUNCTURE TEST RESULTS										
POLYTRAC C (Woven down)										
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger			
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1432 000	2.346	25.650	641 900	5 871	33 770	1014 000	4 566	32 780
2	1458 000	2 235	24 100	664 200	5 329	33 310	1002 000	4 939	29 040
3	1195 000	2 266	27 840	691 000	5 353	35 330	991 700	4 642	31 460
4	1416 000	2 172	24 060	604 300	6 122	35 060	1130 000	5 136	31 890
5	1937 000	2 383	29 400	634 900	5 499	30 080	903 400	5 147	28 130
6	1526 000	2 109	24 190						
7	1596.000	2 422	26 060						
8	1308 000	2 152	27 290						
9	1790 000	3 581	29 460						
10	1546 000	2 582	24 880						
MEAN	1520 400	2 425	26 293	647 260	5 635	33 510	1008 220	4 886	30 660
S.D. (s)	217 626	0.431	2.102	32.509	0.348	2 097	80 874	0 272	1 979
C.V%	14 314	17.758	7 993	5.022	6 177	6 257	8 021	5 562	6 456
Mean - 1.65s	1161.318	1.714	22 825	593.621	5 061	30 050	874 777	4 438	27 394
Mean + 1.65s	1879.482	3.135	29.761	700.899	6.209	36.970	1141 663	5.334	33 926

CBR PUNCTURE TEST RESULTS										
POLYWEAVE R										
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger			
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1906.000	3.838	37.170	579.600	7.892	43 620	1347 000	6 644	41 720
2	1772 000	4.530	37.350	693.200	7.016	42 350	1315 000	5 705	41 220
3	1958 000	3.654	38 170	629.800	8 185	38 910	1386 000	6 389	42 650
4	1732.000	4.622	36.020	652 900	7 180	42 470	1334 000	5 802	41 070
5	1769 000	3.641	36.020	618 300	7 357	40 310	1471 000	6 051	42 190
6	1815.000	4.211	36.520						
7	1946.000	3.743	37.380						
8	1787 000	4.504	36 420						
9	2009.000	4.039	37.480						
10	1969.000	4.412	39.290						
MEAN	1866.300	4.120	37.182	634 760	7.526	41 532	1370 600	6 118	41 770
S.D. (s)	101.414	0.385	1.016	42 079	0.494	1.889	61.857	0 395	0.661
C.V%	5.434	9.354	2.733	6 629	6 565	4 549	4 513	6.461	1 582
Mean - 1.65s	1698.966	3.484	35.505	565.330	6.711	38 415	1268 536	5 466	40 680
Mean + 1.65s	2033 634	4.755	38.859	704.190	8 341	44 649	1472 664	6.770	42 860

CBR PUNCTURE TEST RESULTS										
POLYWEAVE F										
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger			
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2777.000	2.413	39.220	1042.000	4.830	44.340	2083.000	4.754	44 260
2	2799.000	2.153	38.060	1101.000	4.797	40.570	2209.000	4 438	45 490
3	2777.000	2.406	39.220	1206.000	4.928	44 850	2034 000	4 334	44 110
4	2707 000	2.117	37.320	920 800	4.597	46 640	1984 000	4.680	43 050
5	N/A	N/A	N/A	847.300	4 980	41.550	2160 000	4 805	45 310
6	2694.000	1.943	37.230						
7	2789.000	2.527	38.900						
8	2760 000	2.040	37.760						
9	2766 000	2.752	38.890						
10	2808 000	2.262	38 700						
MEAN	2764.111	2.290	38.367	1023.420	4.826	43.590	2094 000	4.602	44.444
S.D. (s)	39.200	0.258	0.789	142.521	0.148	2.487	91.381	0.206	0.992
C.V%	1.418	11.244	2.055	13.926	3.063	5.705	4.364	4.468	2.231
Mean - 1.65s	2699.432	1.865	37.065	788.261	4.582	39.487	1943.221	4.263	42 808
Mean + 1.65s	2828 791	2.715	39.668	1258 579	5.070	47.693	2244.779	4 941	46 080

CBR PUNCTURE TEST RESULTS

POLYWEAVE HR

	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	4385 000	2 265	40.890	1165 000	3.860	36 610	3458 000	4 223	44 200
2	5109.000	2 295	44 520	1394 000	4 244	37 380	3682 000	4 698	45 160
3	4326 000	2 173	34 690	1215 000	4 414	40 640	3373 000	4 375	41 300
4	4897 000	2 537	41 290	1006 000	3 840	30 470	3644 000	4 188	42 200
5	4404 000	2 393	42 100	1162 000	4 510	38 590	3272 000	4 114	39 770
6	4980 000	2 530	41 650						
7	4322 000	1 628	34 140						
8	4891 000	2 055	43 890						
9	4223 000	2 088	34 140						
10	4980 000	2 288	40 600						
MEAN	4651 700	2 225	39 791	1188 400	4 173	36 738	3485 800	4 320	42 526
S.D. (s)	345 313	0 266	3 971	139 188	0 310	3 820	175 163	0 232	2 176
C.V%	7 423	11 945	9 981	11 712	7 439	10 398	5.025	5 369	5 118
Mean - 1.65s	4081 933	1 787	33 238	958 740	3 661	30 435	3196 780	3 937	38 935
Mean + 1.65s	5221 467	2 664	46 344	1418 060	4 686	43 041	3774 820	4 702	46 117

CBR PUNCTURE TEST RESULTS

PROPEX 2002

	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	3291 000	2 283	38 540	863 400	4.255	38 330	2660 000	3 987	45 290
2	3681 000	2 556	41.310	884 600	4 470	40 880	2631 000	4 283	48 300
3	3490 000	2 148	39 020	1003 000	3.876	41.450	2440 000	3 327	43 610
4	3458 000	2 811	41 910	866 900	4 394	37 610	2909 000	4 311	47 740
5	3639 000	2.047	40.260	1055 000	4 014	39 470	2823 000	3 163	46 220
6	3656 000	2 495	41.010						
7	3383.000	2 220	38.220						
8	3487 000	2 105	39.760						
9	3464 000	2 196	38 630						
10	3511 000	2.164	40.030						
MEAN	3506 000	2 302	39.869	934 580	4 202	39 548	2692 600	3 814	46 232
S.D. (s)	123 323	0.242	1 268	88 498	0.252	1 631	182 001	0 538	1 892
C.V%	3 517	10 499	3 181	9.469	5.987	4 123	6 759	14 106	4 092
Mean - 1.65s	3302 516	1 904	37.776	788.559	3.787	36 857	2392 299	2 926	43 111
Mean + 1.65s	3709.484	2.701	41 962	1080.601	4.617	42 239	2992 901	4 702	49 353

CBR PUNCTURE TEST RESULTS

TERRAFIX 310 R

	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1235.000	20.481	93.940	1424.000	39.013	114.700	1461.000	34 679	114 900
2	1263 000	19.929	93.460	1223.000	38.702	111.300	1538.000	34 205	115 100
3	1497 000	17.030	86.090	1323.000	39.405	117.500	1349.000	35 593	117.600
4	1342 000	19.246	91.720	1627.000	36.166	116.000	1647.000	32 661	111 800
5	1295.000	19.439	90.820	1421.000	39.008	120.000	1708.000	32.827	117.400
6	1524.000	18.494	92.000						
7	1459 000	18.874	93.430						
8	1436 000	20.473	95.550						
9	1289 000	21.468	97.250						
10	1293 000	22.738	95.720						
MEAN	1363 300	19.817	92.998	1403.600	38.459	115.900	1540.600	33.993	115.360
S.D. (s)	105.539	1.599	3.134	149.783	1.306	3.240	143.525	1.246	2.352
C.V%	7.741	8.070	3.370	10.671	3.395	2.795	9.316	3.665	2.039
Mean - 1.65s	1189 161	17.178	87.827	1156.459	36.304	110.555	1303.784	31.937	111.479
Mean + 1.65s	1537.439	22.456	98.169	1650.741	40.613	121.245	1777.416	36.049	119.241

CBR PUNCTURE TEST RESULTS TERRAFIX 360 R									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1567 000	19 023	87 750	1816 000	33 312	109 100	2176 000	28 374	106 300
2	2162 000	16 385	89 610	1866 000	31 654	105 600	2160 000	27 841	106 900
3	1896 000	19 210	96 380	2012 000	31 951	109 900	2450 000	26 053	106 800
4	2090 000	17 575	91 290	2012 000	31 029	106 700	2248 000	27 561	110 200
5	1394 000	20 744	92 230	1766 000	33 944	110 500	2303 000	27 014	109 400
6	1883 000	17 534	90 240						
7	1857 000	16 120	86 620						
8	1684 000	18 638	88 950						
9	1720 000	19 049	92 870						
10	2454 000	16 092	92 800						
MEAN	1870 700	18 037	90 874	1894 400	32 378	108 360	2267 400	27 369	107 920
S.D. (s)	307 537	1 553	2 859	113 026	1 209	2 114	117 127	0 884	1 754
C.V%	16 440	8 612	3 146	5 966	3 735	1 951	5 166	3 231	1 625
Mean - 1.65s	1363 264	15 474	86 156	1707 908	30 382	104 872	2074 140	25 910	105 026
Mean + 1.65s	2378 136	20 600	95 592	2080 892	34 374	111 848	2460 660	28 828	110 814

CBR PUNCTURE TEST RESULTS TERRAM 700 SUV									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	990 600	3 185	55 000	361 600	4 717	41 580	868 700	5 155	70 940
2	968 100	3 023	53 670	422 300	5 115	49 620	826 300	4 895	64 510
3	898 000	2 983	53 350	396 800	4 957	46 480	771 000	5 015	65 960
4	709 800	2 520	43 670	460 400	5 222	45 810	809 400	5 055	64 640
5	868 200	2 494	43 450	375 800	4 709	45 700	826 300	5 002	68 560
6	798 400	2 694	50 960						
7	907 100	2 433	54 030						
8	1069 000	2 537	55 150						
9	1036 000	2 901	54 580						
10	1092 000	2 485	55 970						
MEAN	933 720	2 726	51 983	403 380	4 944	45 838	820 340	5 024	66 922
S.D. (s)	121 546	0 273	4 639	39 239	0 231	2 866	35 227	0 094	2 774
C.V%	13 017	10 029	8 923	9 728	4 672	6 253	4.294	1 870	4 145
Mean - 1.65s	733 169	2 274	44 329	338 636	4 563	41 108	762 215	4 869	62 345
Mean + 1.65s	1134 271	3 177	59 637	468 124	5 325	50 568	878 465	5 179	71 499

CBR PUNCTURE TEST RESULTS TERRAM 1000 SUV									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	1206.000	2.496	57.450	659 300	4 031	43.650	1061.000	4 289	63 310
2	1346.000	2.165	55.420	533 400	4 080	45.980	978.800	4 030	69 900
3	1264 000	2 176	55.000	546 600	4 595	48.020	1095.000	3 774	64 810
4	1227 000	2 100	53.670	542 300	4 799	45.090	1168.000	3 604	70 870
5	1141 000	2 076	55 120	723 200	4 307	49 650	1166.000	N/A	66 640
6	1110.000	2 054	51.440						
7	1150.000	2.240	56 250						
8	1185.000	2 088	56 890						
9	1086.000	2.417	51.560						
10	1107.000	2.192	51.160						
MEAN	1182.200	2.200	54 396	600.960	4.362	46.478	1093.760	3.924	67 106
S.D. (s)	80.939	0.148	2.326	85.596	0 331	2.378	79.090	0.300	3.235
C.V%	6.846	6.731	4.276	14.243	7.580	5.115	7.231	7 636	4.821
Mean - 1.65s	1048.651	1.956	50.558	459.727	3.817	42.555	963.262	3.430	61.768
Mean + 1.65s	1315.749	2.445	58.234	742.193	4.908	50.401	1224.258	4.419	72 444

CBR PUNCTURE TEST RESULTS									
TERRAM 3000 SUV									
	Flat Plunger			Pyramid-Tipped Plunger			Hemispherical Plunger		
Specimen No.	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)	CBR Puncture Strength (N)	Seating Displacement (mm)	Displacement at Maximum (mm)
1	2754 000	1.150	55 630	940.400	2 772	36 500	2652 000	2 300	64 490
2	2397 000	1.252	49.840	978 800	3 020	38 640	2448 000	2 870	70 210
3	2699 000	1 264	52 000	1180 000	2 718	41 690	2301 000	2 680	66 270
4	2462 000	1 017	50 650	1194 000	2 867	53 650	2506.000	2 570	67 450
5	2525 000	1.248	54 980	816 700	2 492	33 770	2570.000	2 547	70 940
6	2788.000	1.093	57 570						
7	2573.000	1.068	55.320						
8	2385 000	1 712	49 100						
9	2631.000	1 254	52 510						
10	2259 000	1.170	47 050						
MEAN	2547.300	1 223	52 465	1021.980	2 774	40 850	2495 400	2 593	67.872
S.D. (s)	173 577	0.193	3.360	162 189	0 195	7 721	132 513	0 208	2 695
C.V%	6 814	15.771	6 404	15 870	7 024	18 902	5 310	8 014	3 971
Mean - 1.65s	2260 897	0.905	46 921	754 368	2 452	28 110	2276 753	2 250	63 425
Mean + 1.65s	2833.703	1.541	58.009	1289 592	3 095	53 590	2714 047	2 936	72 319

APPENDIX D

DROP CONE RESULTS FOR ALL DROP HEIGHTS						
BIDIM A 12						
	Standard Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)
1	30.50	1034	17.50	1173	32.50	1410
2	24.00	1471	17.00	1224	32.50	1410
3	26.00	1308	19.00	1039	33.75	1334
4	27.50	1204	17.75	1148	37.25	1154
5	31.50	986	17.00	1224	35.00	1264
6	25.00	1385				
7	24.75	1406				
8	27.75	1188				
9	26.00	1308				
10	25.00	1385				
MEAN	26.80	1267	17.65	1161	34.20	1314
S.D.	2.52	162	0.82	76	2.00	108
C.V%	9.39	13	4.65	7	5.83	8
Mean - 3s	19.25	782	15.19	934	28.21	989
Mean + 3s	34.35	1752	20.11	1389	40.19	1639

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
BIDIM A 14								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	27.00	1237	22.75	796	34.00	1322	45.00	1751
2	30.00	1059	19.00	1037	37.50	1145	40.00	2082
3	30.25	1047	14.50	1542	38.50	1101	40.50	2045
4	29.50	1086	17.75	1146	32.50	1413	39.75	2102
5	25.25	1365	15.75	1366	38.00	1123	47.00	1643
6	25.75	1326					42.75	1888
7	30.50	1034					44.25	1795
8	22.50	1617					50.00	1500
9	25.25	1365					43.75	1825
10	23.25	1541					41.75	1955
MEAN	26.93	1268	17.95	1177	36.10	1221	43.48	1859
S.D.	2.98	211	3.20	290	2.68	139	3.27	196
C.V%	11.07	17	17.82	25	7.42	11	7.52	11
Mean - 3s	17.98	635	8.35	309	28.06	805	33.66	1271
Mean + 3s	35.87	1900	27.55	2046	44.14	1636	53.29	2447

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
BIDIM A 24								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	22.50	1617	14.75	1504	29.75	1609	40.50	2045
2	19.50	1996	14.75	1504	26.00	1961	33.25	2732
3	20.00	1923	12.00	2037	26.00	1961	30.00	3178
4	21.00	1790	14.00	1624	24.50	2140	30.75	3065
5	20.25	1888	15.50	1398	26.50	1907	28.75	3384
6	21.00	1790					30.50	3102
7	22.50	1617					32.50	2826
8	22.00	1671					30.75	3065
9	21.25	1759					31.75	2924
10	19.00	2073					31.75	2924
MEAN	20.90	1812	14.20	1614	26.55	1916	32.05	2925
S.D.	1.21	156	1.34	250	1.94	193	3.23	360
C.V%	5.81	9	9.43	15	7.31	10	10.09	12
Mean - 3s	17.26	1344	10.18	864	20.73	1337	22.35	1844
Mean + 3s	24.54	2281	18.22	2363	32.37	2494	41.75	4005

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
BIDIM A 29								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	19.25	2034	12.50	1919	27.00	1855	32.00	2891
2	17.75	2292	9.25	2987	27.25	1830	33.75	2673
3	20.00	1923	12.00	2037	25.50	2018	35.50	2482
4	20.00	1923	11.75	2101	23.00	2349	N/A	N/A
5	21.00	1790	10.75	2395	28.25	1736	32.50	2826
6	21.25	1759					32.50	2826
7	17.25	2390					32.75	2794
8	21.25	1759					32.25	2858
9	21.00	1790					30.50	3102
10	20.00	1923					28.75	3384
MEAN	19.88	1958	11.25	2288	26.20	1958	32.28	2870
S.D.	1.42	222	1.29	428	2.04	241	1.89	254
C.V%	7.15	11	11.44	19	7.79	12	5.85	9
Mean - 3s	15.61	1292	7.39	1003	20.07	1235	26.61	2107
Mean + 3s	24.14	2624	15.11	3573	32.33	2681	37.95	3634

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
BIDIM A 34								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	17.75	2292	11.00	2315	22.00	2507	28.00	3518
2	15.50	2797	10.75	2395	21.50	2593	30.00	3178
3	17.50	2340	11.50	2169	22.25	2466	25.00	4155
4	16.50	2551	11.00	2315	21.00	2685	27.50	3612
5	19.75	1959	12.25	1976	21.75	2550	24.75	4217
6	16.25	2609					29.00	3341
7	18.75	2114					24.25	4346
8	16.25	2609					30.25	3140
9	16.75	2495					26.00	3923
10	16.50	2551					28.75	3384
MEAN	17.15	2432	11.30	2234	21.70	2560	27.35	3681
S.D.	1.30	254	0.60	166	0.48	84	2.22	446
C.V%	7.57	10	5.28	7	2.22	3	8.11	12
Mean - 3s	13.26	1669	9.51	1737	20.26	2307	20.70	2342
Mean + 3s	21.04	3194	13.09	2731	23.14	2813	34.00	5021

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
BIDIM A 44								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	16.00	2669	9.75	2764	19.25	3051	20.00	5769
2	15.75	2732	8.00	3697	20.50	2781	23.00	4697
3	14.50	3085	9.25	2987	20.75	2732	21.75	5099
4	15.00	2935	10.25	2568	18.25	3300	24.25	4346
5	15.50	2797	10.00	2663	21.50	2593	22.50	4851
6	15.00	2935					22.75	4773
7	15.00	2935					22.50	4851
8	15.50	2797					21.50	5187
9	17.00	2442					23.50	4551
10	13.50	3427					24.75	4217
MEAN	15.28	2875	9.45	2936	20.05	2892	22.65	4834
S.D.	0.93	263	0.89	453	1.29	282	1.38	446
C.V%	6.10	9	9.43	15	6.44	10	6.07	9
Mean - 3s	12.48	2087	6.78	1577	16.17	2045	18.52	3496
Mean + 3s	18.07	3664	12.12	4295	23.93	3738	26.78	6172

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 420								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	26.25	1289	17.25	1195	38.00	1123	43.25	1856
2	27.00	1237	21.25	879	40.00	1041	40.00	2082
3	28.50	1142	19.75	979	37.00	1168	41.75	1955
4	29.25	1100	20.00	961	33.50	1351	39.75	2102
5	30.50	1034	19.50	998	36.50	1191	41.00	2008
6	28.75	1128					48.00	1593
7	27.25	1220					43.00	1872
8	27.75	1188					41.75	1955
9	28.50	1142					43.75	1825
10	29.00	1114					42.75	1888
MEAN	28.28	1159	19.55	1003	37.00	1175	42.50	1914
S.D.	1.24	75	1.45	117	2.37	114	2.35	146
C.V%	4.38	6	7.42	12	6.41	10	5.54	8
Mean - 3s	24.56	935	15.20	653	29.88	833	35.44	1475
Mean + 3s	31.99	1384	23.90	1353	44.12	1517	49.56	2353

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 500								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	23.50	1517	18.75	1057	33.00	1381	35.00	2534
2	21.50	1729	16.25	1305	38.00	1123	39.00	2161
3	28.50	1142	17.25	1195	38.50	1101	39.25	2141
4	25.50	1345	21.00	895	30.75	1533	44.50	1780
5	21.50	1729	23.00	783	35.00	1267	37.50	2290
6	24.25	1449					34.25	2616
7	22.25	1644					33.75	2673
8	24.25	1449					34.25	2616
9	31.50	986					34.75	2561
10	25.25	1365					42.50	1905
MEAN	24.80	1435	19.25	1047	35.05	1281	37.48	2328
S.D.	3.16	241	2.76	213	3.29	181	3.78	321
C.V%	12.74	17	14.32	20	9.39	14	10.08	14
Mean - 3s	15.32	712	10.98	408	25.18	738	26.15	1366
Mean + 3s	34.28	2159	27.52	1685	44.92	1824	48.80	3289

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 550								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	24.25	1449	15.25	1432	29.00	1670	39.00	2161
2	23.25	1541	15.25	1432	28.00	1759	41.25	1990
3	26.00	1308	15.00	1467	27.25	1830	36.00	2431
4	24.50	1427	16.00	1335	34.00	1322	36.00	2431
5	25.00	1385	18.50	1078	32.00	1445	35.75	2456
6	27.50	1204					35.25	2508
7	23.75	1494					38.00	2245
8	23.25	1541					37.50	2290
9	24.75	1406					36.75	2359
10	25.75	1326					41.00	2008
MEAN	24.80	1408	16.00	1349	30.05	1605	37.65	2288
S.D.	1.33	107	1.45	159	2.85	215	2.15	185
C.V%	5.37	8	9.04	12	9.49	13	5.72	8
Mean - 3s	20.80	1086	11.66	871	21.49	962	31.19	1734
Mean + 3s	28.80	1730	20.34	1827	38.61	2249	44.11	2842

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 600								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	25.00	1385	12.50	1919	24.75	2109	32.25	2858
2	25.50	1345	14.50	1542	30.50	1551	32.50	2826
3	24.00	1471	15.50	1398	23.75	2240	35.00	2534
4	24.00	1471	14.00	1624	29.00	1670	45.75	1709
5	23.25	1541	16.25	1305	26.25	1934	34.00	2644
6	21.50	1729					38.00	2245
7	21.50	1729					30.75	3065
8	23.75	1494					43.00	1872
9	23.50	1517					34.25	2616
10	23.50	1517					36.25	2407
MEAN	23.55	1520	14.55	1558	26.85	1901	36.18	2478
S.D.	1.28	126	1.44	237	2.84	289	4.83	432
C.V%	5.45	8	9.90	15	10.59	15	13.35	17
Mean - 3s	19.70	1143	10.23	847	18.32	1033	21.69	1183
Mean + 3s	27.40	1897	18.87	2268	35.38	2769	50.66	3772

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 650								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	20.50	1854	13.25	1761	21.75	2550	29.00	3341
2	21.50	1729	16.00	1335	22.75	2387	30.75	3065
3	19.25	2034	15.25	1432	23.25	2312	32.50	2826
4	21.75	1700	13.25	1761	22.00	2507	33.00	2763
5	19.50	1996	15.00	1467	26.25	1934	32.00	2891
6	20.75	1822					31.25	2993
7	20.00	1923					32.50	2826
8	20.75	1822					33.25	2732
9	20.75	1822					30.50	3102
10	18.75	2114					31.25	2993
MEAN	20.35	1881	14.55	1551	23.20	2338	31.60	2953
S.D.	0.97	133	1.24	198	1.81	245	1.31	185
C.V%	4.75	7	8.54	13	7.79	10	4.14	6
Mean - 3s	17.45	1481	10.82	959	17.78	1603	27.68	2397
Mean + 3s	23.25	2281	18.28	2144	28.62	3072	35.52	3510

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 700								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	17.00	2442	11.00	2315	20.00	2884	26.00	3923
2	17.75	2292	10.50	2479	21.50	2593	27.25	3661
3	18.00	2245	12.00	2037	21.50	2593	26.50	3814
4	17.00	2442	12.75	1863	22.25	2466	24.25	4346
5	18.75	2114	12.75	1863	20.50	2781	25.25	4095
6	16.00	2669					29.25	3299
7	17.25	2390					28.75	3384
8	18.75	2114					24.00	4412
9	18.25	2200					24.50	4281
10	18.25	2200					27.00	3711
MEAN	17.70	2311	11.80	2112	21.15	2664	26.28	3892
S.D.	0.88	175	1.02	276	0.89	167	1.83	390
C.V%	4.97	8	8.66	13	4.23	6	6.96	10
Mean - 3s	15.06	1786	8.74	1283	18.47	2163	20.79	2721
Mean + 3s	20.34	2836	14.86	2940	23.83	3165	31.76	5064

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYFELT TS 750								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	12.75	3727	9.50	2872	18.00	3367	22.50	4851
2	14.00	3248	10.25	2568	17.00	3663	20.00	5769
3	15.50	2797	8.00	3697	19.00	3110	20.75	5465
4	14.25	3165	9.50	2872	20.75	2732	23.00	4697
5	14.50	3085	10.25	2568	17.00	3663	23.25	4623
6	14.00	3248					20.00	5769
7	17.50	2340					21.25	5277
8	17.00	2442					22.00	5014
9	15.00	2935					19.00	6220
10	14.00	3248					22.75	4773
MEAN	14.85	3023	9.50	2916	18.35	3307	21.45	5246
S.D.	1.46	413	0.92	463	1.58	395	1.47	544
C.V%	9.82	14	9.67	16	8.59	12	6.86	10
Mean - 3s	10.47	1784	6.74	1528	13.62	2121	17.04	3613
Mean + 3s	19.23	4263	12.26	4303	23.08	4493	25.86	6879

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYTRAC 155								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	13.50	3427	11.00	2315	17.75	3437	21.75	5099
2	14.50	3085	8.50	3382	17.00	3663	19.50	5987
3	13.75	3335	10.00	2663	17.75	3437	20.75	5465
4	14.25	3165	9.00	3109	16.25	3914	20.50	5563
5	14.25	3165	11.25	2240	18.75	3171	22.00	5014
6	13.75	3335					20.00	5769
7	13.50	3427					19.50	5987
8	12.25	3953					20.00	5769
9	13.25	3522					19.75	5876
10	13.00	3622					20.75	5465
MEAN	13.60	3404	9.95	2742	17.50	3524	20.45	5599
S.D.	0.67	256	1.20	496	0.94	279	0.88	344
C.V%	4.92	8	12.10	18	5.35	8	4.30	6
Mean - 3s	11.59	2636	6.34	1253	14.69	2689	17.81	4568
Mean + 3s	15.61	4171	13.56	4231	20.31	4360	23.09	6631

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYTRAC C (Woven up)								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	19.50	1996	14.25	1582	28.00	1759	30.75	3065
2	19.75	1959	13.00	1811	26.00	1961	34.00	2644
3	20.75	1822	11.25	2240	27.50	1806	34.00	2644
4	19.25	2034	12.75	1863	29.50	1629	36.00	2431
5	20.25	1888	12.00	2037	29.75	1609	30.50	3102
6	20.00	1923					31.25	2993
7	19.00	2073					32.50	2826
8	20.00	1923					34.00	2644
9	23.75	1494					28.75	3384
10	20.25	1888					32.50	2826
MEAN	20.25	1900	12.65	1907	28.15	1753	32.43	2856
S.D.	1.33	161	1.13	247	1.54	144	2.15	283
C.V%	6.58	8	8.90	13	5.46	8	6.63	10
Mean - 3s	16.25	1417	9.27	1165	23.54	1322	25.97	2008
Mean + 3s	24.25	2383	16.03	2648	32.76	2183	38.88	3703

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYTRAC C (Woven down)								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	16.50	2551	11.50	2169	22.00	2507	31.25	2993
2	17.50	2340	10.75	2395	23.25	2312	27.00	3711
3	18.00	2245	10.50	2479	22.00	2507	27.25	3661
4	18.75	2114	9.75	2764	25.50	2018	25.00	4155
5	19.25	2034	11.25	2240	29.50	1629	29.50	3258
6	18.00	2245					26.00	3923
7	15.75	2732					33.00	2763
8	17.00	2442					27.50	3612
9	15.25	2865					28.00	3518
10	20.00	1923					27.50	3612
MEAN	17.60	2349	10.75	2409	24.45	2195	28.20	3521
S.D.	1.51	302	0.68	233	3.16	374	2.41	416
C.V%	8.61	13	6.37	10	12.94	17	8.56	12
Mean - 3s	13.06	1444	8.70	1709	14.96	1072	20.96	2272
Mean + 3s	22.14	3254	12.80	3109	33.94	3317	35.44	4769

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYWEAVE R								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	16.50	2551	11.50	2169	21.25	2638	21.00	5369
2	15.75	2732	12.25	1976	21.25	2638	26.75	3762
3	16.25	2609	11.75	2101	24.00	2206	21.75	5099
4	15.50	2797	12.00	2037	24.75	2109	25.25	4095
5	16.50	2551	10.50	2479	25.50	2018	27.00	3711
6	17.75	2292					23.00	4697
7	16.25	2609					23.50	4551
8	14.50	3085					24.25	4346
9	14.50	3085					27.00	3711
10	15.50	2797					25.00	4155
MEAN	15.90	2711	11.60	2152	23.35	2322	24.45	4350
S.D.	0.98	246	0.68	196	1.99	296	2.15	580
C.V%	6.17	9	5.82	9	8.52	13	8.78	13
Mean - 3s	12.96	1974	9.57	1564	17.38	1433	18.01	2610
Mean + 3s	18.84	3447	13.63	2741	29.32	3211	30.89	6089

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYWEAVE F								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	12.75	3727	10.25	2568	17.00	3663	20.00	5769
2	12.75	3727	10.25	2568	19.00	3110	20.50	5563
3	12.75	3727	9.75	2764	19.00	3110	19.50	5987
4	13.00	3622	9.75	2764	17.25	3585	20.00	5769
5	13.50	3427	10.00	2663	17.50	3510	19.25	6102
6	13.00	3622					21.00	5369
7	13.00	3622					19.50	5987
8	13.00	3622					20.00	5769
9	13.25	3522					19.50	5987
10	13.75	3335					20.75	5465
MEAN	13.08	3595	10.00	2666	17.95	3395	20.00	5777
S.D.	0.33	132	0.25	98	0.97	266	0.59	247
C.V%	2.56	4	2.50	4	5.43	8	2.95	4
Mean - 3s	12.07	3200	9.25	2372	15.03	2597	18.23	5036
Mean + 3s	14.08	3991	10.75	2960	20.87	4194	21.77	6517

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
POLYWEAVE HR								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	9.25	5973	7.00	4499	10.75	7184	17.00	4883
2	8.50	6764	7.00	4499	11.75	6304	16.75	4991
3	10.00	5327	6.50	5017	11.00	6945	14.75	6017
4	9.00	6219	6.75	4746	11.50	6506	14.00	6496
5	9.50	5744	6.75	4746	9.25	8960	13.25	7044
6	9.50	5744					14.00	6496
7	8.25	7068					17.25	4780
8	8.00	7395					14.25	6330
9	9.50	5744					14.25	6330
10	8.75	6482					16.75	4991
MEAN	9.03	6246	6.80	4702	10.85	7180	15.23	5836
S.D.	0.64	666	0.21	215	0.98	1054	1.53	837
C.V%	7.09	11	3.08	5	9.01	15	10.02	14
Mean - 3s	7.11	4247	6.17	4056	7.92	4017	10.65	3325
Mean + 3s	10.94	8245	7.43	5347	13.78	10343	19.80	8346

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
PROPEX 2002								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	12.25	3953	6.75	4746	17.50	3510	20.00	5769
2	11.00	4630	7.50	4065	17.00	3663	21.50	5187
3	10.00	5327	8.00	3697	15.75	4098	17.75	6875
4	12.25	3953	7.50	4065	15.00	4402	20.25	5664
5	11.25	4480	7.00	4499	18.50	3234	20.00	5769
6	11.25	4480					17.75	6875
7	12.50	3837					21.00	5369
8	11.00	4630					18.75	6343
9	11.75	4202					20.50	5563
10	11.75	4202					17.50	7020
MEAN	11.50	4369	7.35	4215	16.75	3781	19.50	6043
S.D.	0.75	443	0.49	411	1.39	467	1.45	678
C.V%	6.56	10	6.63	10	8.31	12	7.45	11
Mean - 3s	9.24	3042	5.89	2981	12.57	2380	15.14	4009
Mean + 3s	13.76	5697	8.81	5448	20.93	5183	23.86	8078

DROP CONE RESULTS FOR ALL DROP HEIGHTS										
	TERRAFIX 310 R						TEST #1 *		TEST #2 **	
	Standard Height		Modified Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 750 (mm)	H 50 (mm)	D 875 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)	D 1500 (mm)	H 50 (mm)	D 1500 (mm)	H 50 (mm)
1	17.00	3655	14.50	1542	20.00	2884	29.00	3341	32.50	2826
2	12.00	6099	17.00	1221	25.00	2078	38.25	2224	39.00	2161
3	11.25	6706	17.00	1221	22.50	2426	43.00	1872	38.00	2245
4	14.50	4618	23.50	759	22.00	2507	36.75	2359	38.00	2245
5	17.00	3655	13.00	1811	24.00	2206	35.00	2534	38.50	2203
6	15.25	4288					26.25	3868	34.75	2561
7	12.50	5744					36.75	2359	39.75	2102
8	17.25	3578					36.00	2431	34.50	2588
9	20.75	2727					44.25	1795	40.50	2045
10	14.25	4738					40.50	2045	40.75	2026
MEAN	15.18	4581	17.00	1311	22.70	2420	36.58	2483	37.63	2300
S.D.	2.91	1267	4.02	395	1.92	311	5.63	649	2.78	267
C.V%	19.15	28	23.62	30	8.47	13	15.39	26	7.40	12
Mean - 3s	6.46	780	4.95	125	16.93	1488	19.69	535	29.27	1499
Mean + 3s	23.89	8381	29.05	2497	28.47	3352	53.46	4431	45.98	3101

DROP CONE RESULTS FOR ALL DROP HEIGHTS										
	TERRAFIX 360 R						TEST #1 *		TEST #2 **	
	Standard Height		Modified Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 750 (mm)	H 50 (mm)	D 875 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)	D 1500 (mm)	H 50 (mm)	D 1500 (mm)	H 50 (mm)
1	11.00	6931	13.00	1811	17.50	3510	24.50	4281	31.50	2958
2	10.00	7974	11.50	2169	18.50	3234	25.00	4155	33.00	2763
3	10.25	7689	18.50	1078	19.00	3110	36.25	2407	27.75	3564
4	8.00	11069	15.00	1467	13.50	5140	29.50	3258	35.00	2534
5	10.00	7974	14.00	1624	15.00	4402	30.75	3065	26.50	3814
6	11.00	6931					27.75	3564	32.50	2826
7	9.00	9309					35.00	2534	27.50	3612
8	10.75	7170					30.25	3140	25.25	4095
9	10.00	7974					30.50	3102	30.25	3140
10	9.75	8276					23.75	4481	26.50	3814
MEAN	9.98	8130	14.40	1630	16.70	3879	29.33	3399	29.58	3312
S.D.	0.92	1252	2.63	404	2.36	867	4.22	712	3.32	534
C.V%	9.26	15	18.27	25	14.14	22	14.38	21	11.22	16
Mean - 3s	7.20	4373	6.51	417	9.62	1278	16.68	1262	19.62	1709
Mean + 3s	12.75	11887	22.29	2843	23.78	6480	41.97	5536	39.53	4915

* NOTE: Test #1 refers to tests conducted in May 1993

** NOTE: Test #2 refers to tests conducted in October 1993

DROP CONE RESULTS FOR ALL DROP HEIGHTS						
TERRAM 700 SUV						
	Standard Height		Modified Height		Modified Height	
Specimen No.	D 250 (mm)	H 50 (mm)	D 125 (mm)	H 50 (mm)	D 375 (mm)	H 50 (mm)
1	28.75	565	23.75	375	45.50	431
2	30.00	531	16.50	641	46.00	424
3	29.25	551	19.00	521	32.50	707
4	37.00	390	16.50	641	41.50	493
5	30.00	531	20.75	457	35.50	621
6	27.75	595				
7	30.00	531				
8	30.00	531				
9	40.00	348				
10	26.25	646				
MEAN	30.90	522	19.30	527	40.20	535
S.D.	4.24	89	3.07	116	6.02	124
C.V%	13.74	17	15.90	22	14.97	23
Mean - 3s	18.17	254	10.09	179	22.15	163
Mean + 3s	43.63	789	28.51	875	58.25	907

DROP CONE RESULTS FOR ALL DROP HEIGHTS						
TERRAM 1000 SUV						
	Standard Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)
1	29.50	1086	21.50	866	41.25	993
2	35.25	836	19.50	1000	39.25	1068
3	31.75	975	18.75	1059	38.75	1089
4	29.50	1086	21.00	897	42.75	942
5	34.50	863	18.25	1102	33.75	1334
6	27.00	1237				
7	25.75	1326				
8	30.25	1047				
9	29.00	1114				
10	32.75	931				
MEAN	30.53	1050	19.80	985	39.15	1085
S.D.	3.06	156	1.41	102	3.42	151
C.V%	10.03	15	7.11	10	8.73	14
Mean - 3s	21.34	582	15.58	680	28.90	633
Mean + 3s	39.71	1518	24.02	1290	49.40	1538

DROP CONE RESULTS FOR ALL DROP HEIGHTS								
TERRAM 3000 SUV								
	Standard Height		Modified Height		Modified Height		Modified Height	
Specimen No.	D 500 (mm)	H 50 (mm)	D 250 (mm)	H 50 (mm)	D 750 (mm)	H 50 (mm)	D 1000 (mm)	H 50 (mm)
1	15.50	2797	10.00	2663	30.25	1570	19.50	5987
2	18.00	2245	11.00	2315	27.50	1806	23.50	4551
3	17.50	2340	10.00	2663	26.25	1934	20.50	5563
4	19.25	2034	11.00	2315	21.25	2638	25.25	4095
5	19.00	2073	11.25	2240	23.25	2312	24.25	4346
6	21.00	1790					26.00	3923
7	21.25	1759					23.50	4551
8	17.75	2292					22.75	4773
9	18.25	2200					24.75	4217
10	17.50	2340					24.50	4281
MEAN	18.50	2187	10.65	2439	25.70	2052	23.45	4629
S.D.	1.72	300	0.60	207	3.54	424	2.05	659
C.V%	9.28	14	5.65	8	13.76	21	8.76	14
Mean - 3s	13.35	1287	8.84	1819	15.09	781	17.29	2652
Mean + 3s	23.65	3087	12.46	3060	36.31	3323	29.61	6605

APPENDIX E

WIDE STRIP TENSILE TEST RESULTS										
BIDIM A 12										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.472	3.352	8.955	43.190	7.433	0.481	9.583	7.070	51.050	5.377
2	0.368	3.923	7.460	42.520	6.088	0.659	10.657	7.535	56.080	5.568
3	2.858	17.959	7.480	45.630	4.339	0.423	6.517	7.345	50.330	5.329
4	0.336	3.081	7.775	42.170	6.129	0.507	8.322	8.575	52.910	6.136
5	0.311	3.351	5.915	37.190	5.404	0.458	6.913	7.380	46.110	5.793
MEAN	0.869	6.333	7.517	42.140	5.879	0.505	8.398	7.581	51.296	5.641
S.D. (s)	1.114	6.506	1.085	3.079	1.131	0.091	1.750	0.580	3.653	0.332
Mean - 1.65s	-0.968	-4.402	5.727	37.059	4.012	0.355	5.510	6.623	45.268	5.093
Mean + 1.65s	2.706	17.069	9.307	47.221	7.745	0.656	11.287	8.539	57.324	6.188

WIDE STRIP TENSILE TEST RESULTS										
BIDIM A 14										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.486	3.663	8.385	40.600	6.793	0.570	8.517	9.515	54.770	6.398
2	0.428	3.750	8.275	46.750	6.145	0.577	6.858	9.515	51.340	6.673
3	0.483	4.551	8.810	46.820	6.356	0.583	6.849	10.130	55.430	6.962
4	0.456	2.623	8.035	34.770	7.340	0.542	6.724	8.985	47.430	6.837
5	0.501	3.885	9.565	47.690	6.985	0.518	6.552	9.085	51.140	6.473
MEAN	0.471	3.694	8.614	43.326	6.724	0.558	7.100	9.446	52.022	6.669
S.D. (s)	0.029	0.693	0.601	5.559	0.480	0.027	0.802	0.453	3.221	0.238
Mean - 1.65s	0.423	2.551	7.622	34.154	5.931	0.513	5.777	8.699	46.708	6.276
Mean + 1.65s	0.518	4.838	9.606	52.498	7.516	0.603	8.423	10.193	57.336	7.061

WIDE STRIP TENSILE TEST RESULTS										
BIDIM A 24										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.719	3.725	11.900	43.330	9.607	0.761	6.285	12.150	52.040	8.887
2	0.713	2.987	13.180	43.140	10.506	0.815	6.787	12.475	52.740	9.083
3	0.584	3.658	9.415	35.430	8.810	0.634	5.284	12.730	53.270	8.657
4	0.711	3.827	12.575	44.630	9.943	0.697	6.414	11.015	47.670	8.673
5	0.706	3.223	11.900	42.890	9.613	0.915	6.515	13.375	44.330	11.431
MEAN	0.687	3.484	11.794	41.884	9.696	0.764	6.257	12.349	50.010	9.346
S.D. (s)	0.058	0.361	1.433	3.670	0.616	0.108	0.574	0.871	3.871	1.178
Mean - 1.65s	0.592	2.888	9.430	35.829	8.680	0.586	5.309	10.912	43.623	7.402
Mean + 1.65s	0.782	4.080	14.158	47.939	10.712	0.943	7.205	13.786	56.397	11.291

WIDE STRIP TENSILE TEST RESULTS										
BIDIM A 29										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.774	2.788	14.515	43.990	11.123	1.034	5.753	15.290	50.820	10.530
2	0.542	1.885	18.310	49.370	13.015	0.872	5.283	16.350	59.020	10.214
3	0.666	2.227	17.095	45.680	12.825	0.757	4.563	14.955	54.780	9.482
4	0.670	2.583	16.955	49.370	11.940	0.983	5.361	15.530	52.330	10.578
5	1.046	2.953	17.095	44.050	11.684	0.879	5.858	12.640	49.280	8.992
MEAN	0.740	2.487	16.794	46.492	12.117	0.905	5.364	14.953	53.246	9.959
S.D. (s)	0.190	0.432	1.387	2.713	0.793	0.108	0.511	1.392	3.813	0.696
Mean - 1.65s	0.426	1.774	14.505	42.015	10.809	0.727	4.521	12.657	46.955	8.811
Mean + 1.65s	1.053	3.200	19.083	50.969	13.426	1.083	6.206	17.249	59.537	11.107

WIDE STRIP TENSILE TEST RESULTS										
BIDIM A 34										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	1.805	4.063	18.780	42.600	13.722	0.832	3.049	18.130	57.770	11.110
2	15.899	30.314	21.605	51.530	14.094	0.760	2.959	18.340	53.080	11.116
3	0.737	2.151	19.505	52.600	13.385	14.523	36.262	19.395	56.380	10.720
4	1.378	3.251	19.915	52.890	13.667	1.030	3.163	20.770	54.900	13.574
5	2.244	5.093	17.825	45.590	13.147	1.099	4.023	20.465	58.540	13.162
MEAN	4.413	8.974	19.526	49.042	13.603	3.649	9.891	19.420	56.134	11.936
S.D. (s)	6.445	11.978	1.407	4.666	0.359	6.080	14.748	1.199	2.201	1.325
Mean - 1.65s	-6.222	-10.789	17.204	41.344	13.011	-6.384	-14.443	17.442	52.503	9.751
Mean + 1.65s	15.047	28.738	21.848	56.740	14.195	13.682	34.225	21.398	59.765	14.122

WIDE STRIP TENSILE TEST RESULTS										
BIDIM A 44										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.903	3.164	19.190	51.220	13.941	17.389	35.958	23.360	60.810	12.942
2	1.280	3.391	23.895	52.230	17.482	14.221	31.955	22.510	61.220	11.939
3	1.191	3.824	23.160	50.610	17.933	12.208	27.260	21.300	59.060	12.474
4	1.133	3.629	21.080	50.730	15.415	11.523	25.118	21.630	60.240	12.829
5	1.020	3.223	20.565	48.520	15.490	9.812	21.185	21.840	55.550	12.541
MEAN	1.105	3.446	21.578	50.662	16.052	13.031	28.295	22.128	59.376	12.545
S.D. (s)	0.147	0.278	1.927	1.357	1.640	2.904	5.784	0.819	2.288	0.391
Mean - 1.65s	0.862	2.988	18.399	48.423	13.346	8.240	18.751	20.777	55.601	11.900
Mean + 1.65s	1.349	3.905	24.757	52.901	18.759	17.821	37.839	23.479	63.151	13.190

WIDE STRIP TENSILE TEST RESULTS										
POLYFELT TS 420										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.348	2.754	7.515	63.540	4.249	1.745	4.817	10.035	43.480	10.892
2	0.129	1.557	8.500	67.360	4.898	2.008	5.717	9.840	41.550	10.328
3	1.879	10.762	9.700	78.900	4.868	2.044	6.151	8.765	38.290	9.698
4	1.180	5.780	9.240	65.630	6.001	2.230	7.027	9.830	42.030	9.132
5	0.172	1.301	8.620	60.990	6.462	2.568	6.690	11.390	44.910	11.105
MEAN	0.742	4.431	8.715	67.284	5.296	2.119	6.080	9.972	42.052	10.231
S.D. (s)	0.765	3.961	0.828	6.916	0.908	0.305	0.866	0.937	2.481	0.822
Mean - 1.65s	-0.521	-2.105	7.349	55.873	3.798	1.616	4.651	8.427	37.959	8.875
Mean + 1.65s	2.004	10.967	10.081	78.695	6.793	2.622	7.510	11.517	46.145	11.587

WIDE STRIP TENSILE TEST RESULTS										
POLYFELT TS 500										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.170	2.056	8.885	65.610	4.358	1.623	5.622	11.585	42.910	8.874
2	2.346	11.050	10.390	63.890	5.910	1.004	3.584	10.625	37.290	8.861
3	1.936	10.360	9.805	68.980	5.221	3.297	9.754	11.740	42.970	9.480
4	3.173	18.081	9.820	71.130	4.778	2.779	6.917	11.670	38.000	11.575
5	2.213	10.296	10.585	67.100	6.009	2.983	7.587	11.320	35.640	11.239
MEAN	1.968	10.369	9.897	67.342	5.255	2.337	6.693	11.388	39.362	10.006
S.D. (s)	1.106	5.680	0.662	2.829	0.713	0.977	2.293	0.455	3.377	1.309
Mean - 1.65s	0.143	0.997	8.804	62.675	4.080	0.725	2.909	10.637	33.791	7.846
Mean + 1.65s	3.792	19.741	10.990	72.009	6.431	3.950	10.476	12.139	44.933	12.165

WIDE STRIP TENSILE TEST RESULTS										
POLYFELT TS 550										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	1.813	10.191	10.310	85.210	4.975	2.864	4.429	12.295	37.200	19.666
2	1.781	11.284	9.075	74.400	4.388	2.668	4.451	11.340	35.150	18.228
3	1.536	8.720	8.765	66.810	4.977	2.966	4.787	12.240	34.670	18.662
4	2.050	9.694	10.315	74.450	5.935	2.894	4.651	12.570	43.050	18.822
5	2.223	10.884	10.570	80.440	5.690	3.200	4.817	13.330	39.140	19.992
MEAN	1.881	10.155	9.807	76.262	5.193	2.919	4.627	12.355	37.842	19.074
S.D. (s)	0.264	1.010	0.824	6.957	0.620	0.192	0.182	0.715	3.411	0.732
Mean - 1.65s	1.445	8.488	8.448	64.783	4.169	2.601	4.327	11.176	32.215	17.867
Mean + 1.65s	2.317	11.821	11.166	87.741	6.217	3.236	4.927	13.534	43.469	20.281

WIDE STRIP TENSILE TEST RESULTS

POLYFELT TS 600

	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	2.095	10.255	11.150	71.390	5.713	3.487	5.618	14.555	35.220	18.339
2	2.695	11.192	12.040	65.560	6.698	3.387	5.962	14.940	42.310	16.610
3	1.583	6.160	12.415	74.090	7.488	2.832	5.925	13.395	39.110	13.995
4	2.764	9.462	12.785	63.900	8.207	3.447	5.962	15.065	36.960	16.933
5	2.196	11.089	10.870	72.240	5.512	1.817	3.086	12.410	32.140	19.259
MEAN	2.267	9.632	11.852	69.436	6.724	2.994	5.311	14.073	37.148	17.027
S.D. (s)	0.483	2.063	0.819	4.444	1.148	0.710	1.252	1.139	3.851	2.005
Mean - 1.65s	1.470	6.227	10.501	62.103	4.829	1.823	3.245	12.193	30.793	13.719
Mean + 1.65s	3.063	13.036	13.203	76.769	8.618	4.165	7.376	15.953	43.503	20.335

WIDE STRIP TENSILE TEST RESULTS

POLYFELT TS 650

	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.176	1.327	12.220	73.710	6.381	1.855	3.685	18.170	44.940	15.837
2	2.868	10.185	14.115	69.970	7.876	3.550	6.081	15.750	40.620	17.056
3	0.192	1.320	13.915	86.760	7.605	3.561	6.956	17.220	47.910	14.756
4	2.405	10.216	12.570	78.630	6.585	3.580	5.353	17.955	41.040	19.847
5	0.215	1.317	14.015	81.070	7.905	4.756	9.294	16.450	45.610	14.401
MEAN	1.171	4.873	13.367	78.028	7.270	3.460	6.274	17.109	44.024	16.379
S.D. (s)	1.348	4.863	0.899	6.508	0.732	1.035	2.072	1.017	3.120	2.198
Mean - 1.65s	-1.052	-3.152	11.884	67.289	6.063	1.752	2.855	15.431	38.875	12.753
Mean + 1.65s	3.395	12.898	14.850	88.767	8.478	5.169	9.693	18.787	49.173	20.006

WIDE STRIP TENSILE TEST RESULTS

POLYFELT TS 700

	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	3.548	11.120	17.960	87.890	8.880	5.528	7.284	22.545	42.670	21.756
2	3.325	9.528	16.640	76.380	9.798	1.799	3.291	21.495	50.960	17.606
3	3.450	10.527	17.290	84.200	9.138	4.123	6.121	21.155	46.170	19.657
4	0.231	1.450	16.375	77.770	8.756	3.701	5.056	20.870	42.510	21.852
5	3.086	10.054	16.925	80.490	8.594	5.385	6.861	25.060	50.200	22.648
MEAN	2.728	8.536	17.038	81.346	9.033	4.107	5.723	22.225	46.502	20.704
S.D. (s)	1.407	4.004	0.617	4.721	0.471	1.512	1.601	1.707	4.009	2.055
Mean - 1.65s	0.407	1.929	16.019	73.556	8.255	1.612	3.081	19.409	39.888	17.313
Mean + 1.65s	5.049	15.143	18.057	89.136	9.811	6.602	8.364	25.041	53.116	24.095

WIDE STRIP TENSILE TEST RESULTS										
POLYFELT TS 750										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	3.511	8.324	22.705	81.780	11.970	3.376	4.983	26.575	46.300	21.227
2	1.297	4.226	21.670	91.350	9.415	6.298	7.350	27.665	52.850	24.558
3	0.346	1.646	22.945	92.430	12.475	3.102	4.284	27.785	46.990	22.154
4	0.377	1.461	21.435	79.750	11.508	3.384	5.289	28.255	55.390	20.681
5	0.302	2.258	21.605	93.260	10.786	3.413	4.761	27.800	48.960	21.656
MEAN	1.167	3.583	22.072	87.714	11.231	3.915	5.333	27.616	50.098	22.055
S.D. (s)	1.375	2.868	0.698	6.420	1.190	1.338	1.185	0.624	3.904	1.501
Mean - 1.65s	-1.101	-1.149	20.920	77.121	9.267	1.706	3.378	26.587	43.657	19.579
Mean + 1.65s	3.435	8.315	23.224	98.307	13.195	6.123	7.289	28.645	56.539	24.531

WIDE STRIP TENSILE TEST RESULTS										
POLYTRAC 155										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	1.581	1.785	26.780	23.720	49.043	3.570	1.529	23.470	20.610	99.671
2	1.601	1.683	23.025	17.150	50.027	3.854	1.617	26.175	18.750	99.791
3	1.545	2.027	26.280	22.480	46.889	4.219	1.658	25.450	18.790	104.813
4	1.438	1.780	27.035	22.710	47.252	4.886	1.884	23.920	17.430	100.038
5	1.498	2.029	26.080	22.600	46.324	3.803	1.620	24.310	18.420	98.483
MEAN	1.533	1.861	25.840	21.732	47.907	4.066	1.662	24.665	18.800	100.559
S.D. (s)	0.066	0.158	1.619	2.608	1.562	0.514	0.133	1.119	1.151	2.452
Mean - 1.65s	1.424	1.600	23.168	17.428	45.330	3.219	1.442	22.819	16.901	96.513
Mean + 1.65s	1.641	2.121	28.512	26.036	50.484	4.914	1.881	26.511	20.699	104.606

WIDE STRIP TENSILE TEST RESULTS										
POLYTRAC C										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	1.236	1.460	14.495	11.640	43.591	7.568	3.515	13.085	7.580	68.224
2	3.440	3.161	14.700	12.910	41.524	9.004	4.820	12.140	7.470	56.109
3	3.421	3.224	14.065	11.960	43.301	10.732	5.621	12.865	7.340	56.101
4	1.243	1.887	13.490	11.920	41.689	9.537	5.150	13.150	8.150	55.231
5	1.350	1.793	14.255	11.940	42.716	8.719	4.256	13.045	8.010	62.731
MEAN	2.138	2.305	14.201	12.074	42.564	9.112	4.672	12.857	7.710	59.679
S.D. (s)	1.181	0.826	0.464	0.485	0.931	1.157	0.816	0.415	0.352	5.649
Mean - 1.65s	0.190	0.942	13.435	11.273	41.028	7.203	3.326	12.173	7.130	50.358
Mean + 1.65s	4.086	3.668	14.967	12.875	44.101	11.021	6.019	13.541	8.290	69.001

WIDE STRIP TENSILE TEST RESULTS

POLYWEAVE R

	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	3.454	5.287	14.810	26.300	20.528	8.336	10.454	12.240	18.640	22.255
2	3.452	5.120	15.470	25.290	20.916	3.507	3.191	12.685	19.090	35.700
3	3.397	4.993	15.035	26.580	20.958	3.415	3.117	12.705	21.430	35.765
4	3.377	5.081	14.660	24.960	20.990	3.405	3.293	12.905	22.960	33.256
5	3.403	5.421	13.530	25.640	19.909	3.552	3.221	12.080	16.590	35.706
MEAN	3.417	5.180	14.701	25.754	20.660	4.443	4.655	12.523	19.742	32.536
S.D. (s)	0.035	0.172	0.722	0.678	0.460	2.177	3.242	0.347	2.489	5.846
Mean - 1.65s	3.360	4.897	13.509	24.635	19.902	0.851	-0.694	11.950	15.635	22.890
Mean + 1.65s	3.474	5.464	15.893	26.873	21.418	8.035	10.005	13.096	23.849	42.182

WIDE STRIP TENSILE TEST RESULTS

POLYWEAVE F

	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	9.130	5.317	38.415	39.750	50.939	2.725	3.495	11.575	32.580	24.768
2	9.493	5.682	38.765	40.320	49.201	2.035	2.418	11.215	32.300	29.420
3	10.799	6.387	38.575	40.320	49.129	2.117	2.460	11.605	30.730	29.941
4*	10.080	5.796	38.820	38.710	51.063	2.019	2.320	11.610	32.500	30.799
5	N/A	N/A	N/A	N/A	N/A	2.581	3.215	11.475	28.650	25.913
MEAN	9.876	5.796	38.644	39.775	50.083	2.295	2.782	11.496	31.352	28.168
S.D. (s)	0.730	0.444	0.185	0.759	1.062	0.332	0.535	0.166	1.689	2.659
Mean - 1.65s	8.672	5.063	38.338	38.522	48.331	1.747	1.899	11.222	28.565	23.781
Mean + 1.65s	11.079	6.528	38.949	41.028	51.835	2.844	3.665	11.770	34.139	32.555

* NOTE: Only four samples tested due to slippage of one incorrectly clamped specimen.

WIDE STRIP TENSILE TEST RESULTS

POLYWEAVE HR

	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	1.417	2.815	35.235	32.530	43.195	13.074	4.165	34.375	19.300	96.392
2	1.507	2.521	30.525	30.860	42.242	6.035	2.047	34.630	25.860	109.730
3	1.612	2.361	26.845	26.260	44.097	7.318	2.323	34.940	23.440	112.107
4	1.726	2.254	33.130	25.140	44.267	10.510	3.352	28.860	19.590	100.315
5	1.270	1.788	31.610	32.020	38.639	12.107	4.190	35.475	22.920	88.771
MEAN	1.506	2.348	31.469	29.362	42.488	9.809	3.216	33.656	22.222	101.463
S.D. (s)	0.176	0.378	3.132	3.420	2.298	3.036	1.004	2.712	2.769	9.615
Mean - 1.65s	1.217	1.725	26.301	23.719	38.696	4.799	1.559	29.181	17.653	85.599
Mean + 1.65s	1.796	2.971	36.637	35.005	46.280	14.819	4.872	38.131	26.791	117.327

WIDE STRIP TENSILE TEST RESULTS										
PROPEX 2002										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.899	1.724	22.575	33.780	29.454	5.576	3.483	20.215	25.720	50.972
2	9.286	7.757	23.115	29.760	34.151	9.812	6.384	23.230	23.550	44.631
3	0.930	1.387	23.295	33.400	31.141	6.859	4.261	22.750	21.330	49.282
4	10.530	9.691	23.960	34.810	30.560	5.732	3.427	21.945	21.410	53.335
5	8.072	6.955	21.515	31.110	33.447	6.601	3.994	22.745	21.560	51.225
MEAN	5.943	5.503	22.892	32.572	31.751	6.916	4.310	22.177	22.714	49.889
S.D. (s)	4.672	3.740	0.915	2.074	1.981	1.709	1.211	1.190	1.916	3.273
Mean - 1.65s	-1.766	-0.668	21.382	29.151	28.481	4.096	2.311	20.214	19.553	44.489
Mean + 1.65s	13.653	11.674	24.402	35.993	35.020	9.736	6.308	24.140	25.875	55.289

WIDE STRIP TENSILE TEST RESULTS										
TERRAFIX 310 R										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.628	50.450	5.195	171.300	1.267	1.074	32.154	12.055	115.000	4.231
2	0.503	63.581	3.768	179.200	0.979	0.977	29.851	10.840	111.900	3.983
3	0.529	58.184	3.675	165.300	1.043	0.891	29.261	9.730	106.800	3.659
4	0.689	52.630	5.765	169.600	1.489	0.946	30.282	9.690	106.500	3.680
5	0.655	53.960	4.943	160.300	1.364	1.078	30.118	11.985	113.900	4.237
MEAN	0.601	55.761	4.669	169.140	1.228	0.993	30.333	10.860	110.820	3.958
S.D. (s)	0.081	5.203	0.916	7.053	0.215	0.082	1.089	1.155	3.967	0.283
Mean - 1.65s	0.467	47.176	3.159	157.503	0.874	0.859	28.536	8.954	104.274	3.492
Mean + 1.65s	0.734	64.346	6.180	180.777	1.583	1.128	32.131	12.766	117.366	4.424

WIDE STRIP TENSILE TEST RESULTS										
TERRAFIX 360 R										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	0.799	57.662	6.240	168.400	1.700	1.409	30.317	16.630	118.700	5.737
2	0.792	57.362	6.710	172.100	1.732	1.293	30.325	14.350	114.100	5.085
3	0.748	57.386	5.675	157.200	1.645	1.152	30.463	13.955	118.600	4.630
4	0.906	62.416	7.115	176.900	1.873	1.240	28.163	14.435	113.300	5.210
5	0.693	60.224	5.650	182.500	1.436	1.290	31.955	15.080	123.400	4.859
MEAN	0.787	59.010	6.278	171.420	1.677	1.277	30.245	14.890	117.620	5.104
S.D. (s)	0.078	2.250	0.642	9.547	0.159	0.093	1.353	1.053	4.080	0.417
Mean - 1.65s	0.658	55.298	5.219	155.667	1.415	1.123	28.013	13.152	110.888	4.415
Mean + 1.65s	0.917	62.722	7.337	187.173	1.939	1.431	32.476	16.628	124.352	5.793

WIDE STRIP TENSILE TEST RESULTS										
TERRAM 1000 SUV										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	2.758	2.731	9.510	72.280	34.085	2.404	2.360	7.155	67.780	36.103
2	2.505	2.317	8.285	58.250	38.478	2.255	2.350	5.970	59.400	33.840
3	2.757	2.650	8.970	53.070	35.511	2.427	2.459	6.645	55.210	34.431
4	2.731	2.525	9.310	59.030	37.463	2.334	2.355	7.220	65.070	35.121
5	3.174	2.521	10.640	58.890	43.655	2.482	2.360	6.635	58.180	37.295
MEAN	2.785	2.549	9.343	60.304	37.838	2.380	2.377	6.725	61.128	35.358
S.D. (s)	0.242	0.157	0.862	7.134	3.670	0.088	0.046	0.504	5.160	1.372
Mean - 1.65s	2.386	2.290	7.921	48.532	31.782	2.235	2.301	5.894	52.615	33.095
Mean + 1.65s	3.184	2.808	10.765	72.076	43.895	2.525	2.453	7.556	69.641	37.621

WIDE STRIP TENSILE TEST RESULTS										
TERRAM 3000 SUV										
	Machine Direction					Cross-Machine Direction				
Specimen No.	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)	Yield Tensile Strength (kN/m)	Elongation at Yield Force (%)	Ultimate Tensile Strength (kN/m)	Elongation at Ultimate Force (%)	Modulus (MPa)
1	4.932	2.255	18.075	63.890	78.684	4.754	2.327	17.980	82.650	72.199
2	4.199	1.891	19.900	100.200	85.512	6.974	4.260	18.905	70.910	50.077
3	4.042	1.828	19.270	87.800	86.932	5.554	2.681	18.980	58.580	70.228
4	5.431	2.563	19.880	96.270	72.777	5.224	2.354	19.220	62.790	78.090
5	5.664	2.659	19.840	65.760	72.235	0.801	1.085	20.065	68.650	43.727
MEAN	4.853	2.239	19.393	82.784	79.228	4.662	2.541	19.030	68.716	62.864
S.D. (s)	0.722	0.378	0.782	17.008	6.886	2.311	1.137	0.746	9.176	15.024
Mean - 1.65s	3.663	1.615	18.103	54.720	67.867	0.848	0.665	17.799	53.575	38.074
Mean + 1.65s	6.044	2.863	20.683	110.848	90.589	8.475	4.418	20.261	83.857	87.655

APPENDIX F

MASS PER UNIT AREA

BIDIM A 12

Specimen No.	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone	
	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	3.63	119.09	3.57	117.12	3.73	122.37	3.48	114.17	3.89	127.62	3.61	118.44
2	3.46	113.52	4.06	133.20	3.80	124.67	3.80	124.67	3.57	117.12	3.49	114.50
3	3.92	128.61	3.36	110.23	3.57	117.12	3.83	125.65	3.82	125.33	3.91	128.28
4	3.74	122.70	3.70	121.39	3.60	118.11	4.12	135.17	3.65	119.75	3.94	129.26
5	3.83	125.65	3.68	120.73	3.53	115.81	3.51	115.16	3.60	118.11	3.34	109.58
6	3.79	124.34	3.89	127.62								
7	3.24	106.30	3.86	126.64								
8	3.66	120.08	3.94	129.26								
9	3.63	119.09	3.62	118.76								
10	3.64	119.42	3.70	121.39								
MEAN	3.65	119.88	3.74	122.64	3.65	119.62	3.75	122.96	3.71	121.59	3.66	120.01
S.D. (s)	0.19	6.36	0.20	6.69	0.11	3.74	0.26	8.62	0.14	4.63	0.26	8.60
C.V%	5.30	5.30	5.45	5.45	3.13	3.13	7.01	7.01	3.81	3.81	7.16	7.16
Mean - 1.65s	3.33	109.39	3.40	111.60	3.46	113.44	3.31	108.74	3.47	113.94	3.23	105.83
Mean + 1.65s	3.97	130.37	4.07	133.67	3.83	125.80	4.18	137.19	3.94	129.23	4.09	134.20

MASS PER UNIT AREA

BIDIM A 14

	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	4.53	148.62	4.27	140.09	4.34	142.39	4.03	132.22	4.24	139.11	4.21	138.12	4.40	144.29
2	4.28	140.42	3.85	126.31	4.12	135.17	4.13	135.50	4.04	132.54	4.56	149.60	4.39	144.06
3	3.60	118.11	4.12	135.17	4.17	136.81	4.36	143.04	4.30	141.07	4.79	157.15	4.33	141.93
4	4.33	142.06	4.25	139.43	3.94	129.26	4.12	135.17	4.39	144.03	4.42	145.01	4.48	146.95
5	4.15	136.15	4.27	140.09	4.73	155.18	4.16	136.48	4.34	142.39	4.10	134.51	4.26	139.70
6	4.43	145.34	4.41	144.68									4.51	147.96
7	4.42	145.01	4.22	138.45									4.33	141.89
8	4.07	133.53	4.46	146.32									3.91	128.11
9	4.34	142.39	4.30	141.07									4.23	138.61
10	4.04	132.54	5.03	165.02									4.36	142.91
MEAN	4.22	138.42	4.32	141.66	4.26	139.76	4.16	136.48	4.26	139.83	4.42	144.88	4.32	141.64
S.D. (s)	0.27	8.85	0.30	9.86	0.30	9.81	0.12	4.00	0.14	4.45	0.28	9.03	0.08	2.72
C.V%	6.39	6.39	6.96	6.96	7.02	7.02	2.93	2.93	3.18	3.18	6.23	6.23	1.92	1.92
Mean - 1.65s	3.77	123.82	3.82	125.39	3.77	123.58	3.96	129.88	4.04	132.48	3.96	129.98	4.18	137.15
Mean + 1.65s	4.66	153.01	4.81	157.93	4.75	155.94	4.36	143.08	4.49	147.17	4.87	159.78	4.45	146.14

MASS PER UNIT AREA														
BIDIM A 24														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	5.42	177.82	5.48	179.79	5.18	169.94	5.76	188.97	5.83	191.27	5.82	190.94	5.65	185.36
2	5.49	180.12	5.83	191.27	5.41	177.49	5.61	184.05	5.13	168.30	5.81	190.61	5.49	179.95
3	5.17	169.62	5.42	177.82	5.20	170.60	5.26	172.57	5.99	196.52	5.01	164.37	5.64	184.94
4	5.49	180.12	5.55	182.08	5.16	169.29	5.28	173.23	6.19	203.08	5.84	191.60	5.86	192.39
5	5.42	177.82	5.27	172.90	5.42	177.82	5.38	176.51	5.19	170.27	5.41	177.49	6.16	202.23
6	6.02	197.50	5.72	187.66									5.86	192.39
7	6.04	198.16	5.80	190.29									5.31	174.34
8	5.72	187.66	5.34	175.19									5.39	176.74
9	6.34	208.00	5.49	180.12									6.03	197.90
10	5.89	193.24	6.11	200.46									5.50	180.41
MEAN	5.70	187.00	5.60	183.76	5.27	173.03	5.46	179.07	5.67	185.89	5.58	183.00	5.69	186.66
S.D. (s)	0.36	11.93	0.26	8.51	0.13	4.25	0.22	7.17	0.48	15.74	0.36	11.96	0.26	8.63
C.V%	6.38	6.38	4.63	4.63	2.46	2.46	4.01	4.01	8.47	8.47	6.54	6.54	4.62	4.62
Mean - 1.65s	5.10	167.32	5.17	169.72	5.06	166.02	5.10	167.23	4.87	159.92	4.98	163.26	5.26	172.42
Mean + 1.65s	6.30	206.69	6.03	197.80	5.49	180.04	5.82	190.90	6.46	211.85	6.18	202.74	6.12	200.91

MASS PER UNIT AREA														
BIDIM A 29														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	6.64	217.84	6.95	228.01	6.90	226.37	6.82	223.75	6.84	224.41	6.54	214.56	6.27	205.77
2	5.81	190.61	6.54	214.56	6.84	224.41	6.74	221.12	7.69	252.29	6.70	219.81	6.62	217.12
3	6.09	199.80	6.39	209.64	7.00	229.65	6.69	219.48	6.39	209.64	6.25	205.05	6.21	203.70
4	6.44	211.28	6.27	205.71	6.57	215.55	6.38	209.31	6.97	228.67	6.61	216.86	6.19	202.98
5	6.56	215.22	6.39	209.64	6.09	199.80	6.27	205.71	7.17	235.23	6.35	208.33	6.23	204.49
6	7.08	232.28	6.59	216.20									6.17	202.46
7	7.57	248.36	7.07	231.95									6.30	206.66
8	6.33	207.67	6.13	201.11									6.36	208.59
9	6.81	223.42	7.12	233.59									6.28	206.10
10	6.80	223.09	6.24	204.72									6.60	216.63
MEAN	6.61	216.96	6.57	215.51	6.68	219.16	6.58	215.88	7.01	230.05	6.49	212.92	6.32	207.45
S.D. (s)	0.50	16.37	0.36	11.76	0.37	12.02	0.24	7.89	0.48	15.59	0.19	6.10	0.18	5.85
C.V%	7.54	7.54	5.45	5.45	5.48	5.48	3.66	3.66	6.78	6.78	2.86	2.86	2.82	2.82
Mean - 1.65s	5.79	189.95	5.98	196.12	6.08	199.33	6.18	202.86	6.23	204.33	6.18	202.86	6.03	197.79
Mean + 1.65s	7.44	243.96	7.16	234.91	7.28	238.98	6.98	228.90	7.80	255.77	6.80	222.98	6.62	217.11

MASS PER UNIT AREA														
BIDIM A 34														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	7.11	233.26	8.04	263.78	8.57	281.16	8.10	265.74	7.66	251.31	7.71	252.95	7.84	257.21
2	8.04	263.78	8.09	265.42	8.09	265.42	7.90	259.18	8.28	271.65	7.64	250.65	7.65	251.11
3	7.59	249.01	7.81	256.23	7.97	261.48	7.58	248.68	8.13	266.73	7.84	257.21	8.37	274.73
4	8.03	263.45	8.14	267.06	8.14	267.06	7.77	254.92	8.17	268.04	8.09	265.42	7.98	261.68
5	7.66	251.31	7.89	258.85	7.82	256.56	7.68	251.96	7.80	255.90	8.05	264.10	8.19	268.76
6	7.50	246.06	8.20	269.02									7.91	259.38
7	8.04	263.78	8.17	268.04									8.60	281.98
8	7.45	244.42	8.07	264.76									7.72	253.15
9	7.75	254.26	8.29	271.98									8.21	269.29
10	8.19	268.70	7.91	259.51									7.78	255.34
MEAN	7.74	253.80	8.06	264.46	8.12	266.33	7.81	256.10	8.01	262.73	7.87	258.07	8.02	263.26
S.D. (s)	0.34	11.12	0.15	4.97	0.28	9.23	0.20	6.63	0.26	8.67	0.20	6.56	0.28	9.31
C.V%	4.38	4.38	1.88	1.88	3.46	3.46	2.59	2.59	3.30	3.30	2.54	2.54	3.54	3.54
Mean - 1.65s	7.18	235.45	7.81	256.27	7.65	251.11	7.47	245.15	7.57	248.42	7.54	247.24	7.56	247.90
Mean + 1.65s	8.30	272.15	8.31	272.66	8.58	281.56	8.14	267.04	8.44	277.03	8.20	268.90	8.49	278.63

MASS PER UNIT AREA														
BIDIM A 44														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	9.74	319.55	9.99	327.75	9.70	318.24	9.37	307.41	9.34	306.43	10.22	335.30	9.62	315.48
2	9.99	327.75	9.53	312.66	9.39	308.07	9.36	307.08	9.86	323.49	9.39	308.07	9.67	317.35
3	9.12	299.21	9.80	321.52	9.71	318.56	9.57	313.97	9.53	312.66	9.94	326.11	10.49	344.19
4	9.38	307.74	9.77	320.53	9.41	308.72	9.55	313.31	9.61	315.28	10.20	334.64	9.34	306.46
5	9.44	309.71	9.44	309.71	9.53	312.66	9.46	310.36	9.30	305.11	9.12	299.21	9.37	307.54
6	9.21	302.16	9.73	319.22	9.30	305.11							9.54	312.95
7	9.44	309.71	9.68	317.58									9.03	296.22
8	9.76	320.20	9.46	310.36									9.79	321.16
9	8.85	290.35	9.07	297.57									9.39	308.20
10	9.29	304.78	9.70	318.24									8.69	285.10
MEAN	9.42	309.12	9.62	315.51	9.51	311.89	9.46	310.43	9.53	312.59	9.77	320.66	9.49	311.46
S.D. (s)	0.34	11.05	0.25	8.35	0.17	5.59	0.10	3.21	0.23	7.41	0.50	16.26	0.47	15.29
C.V%	3.58	3.58	2.65	2.65	1.79	1.79	1.03	1.03	2.37	2.37	5.07	5.07	4.91	4.91
Mean - 1.65s	8.87	290.88	9.20	301.74	9.23	302.68	9.30	305.13	9.16	300.36	8.96	293.83	8.72	286.24
Mean + 1.65s	9.98	327.35	10.04	329.28	9.79	321.11	9.62	315.72	9.90	324.83	10.59	347.50	10.26	336.69

MASS PER UNIT AREA POLYFELT TS 420														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	3.50	114.83	3.93	128.93	3.99	130.90	3.97	130.25	4.61	151.24	4.17	136.81	3.85	126.38
2	3.96	129.92	3.61	118.44	4.27	140.09	4.09	134.18	3.71	121.72	3.89	127.62	4.39	143.93
3	3.86	126.64	4.09	134.18	4.06	133.20	3.96	129.92	4.07	133.53	3.71	121.72	4.25	139.43
4	3.61	118.44	4.40	144.35	4.13	135.50	3.70	121.39	4.56	149.60	4.20	137.79	3.98	130.71
5	3.83	125.65	3.72	122.05	4.12	135.17	4.24	139.11	4.19	137.46	4.27	140.09	4.11	134.97
6	3.84	125.98	3.67	120.40									3.99	131.00
7	4.37	143.37	3.72	122.05									4.57	149.93
8	4.07	133.53	3.98	130.58									4.35	142.62
9	4.00	131.23	3.81	125.00									3.66	120.21
10	3.92	128.61	3.95	129.59									4.44	145.57
MEAN	3.90	127.82	3.89	127.56	4.11	134.97	3.99	130.97	4.23	138.71	4.05	132.81	4.16	136.47
S.D. (s)	0.24	7.87	0.24	7.77	0.10	3.40	0.20	6.52	0.37	12.18	0.24	7.81	0.21	6.93
C.V%	6.16	6.16	6.09	6.09	2.52	2.52	4.98	4.98	8.78	8.78	5.88	5.88	5.08	5.08
Mean - 1.65s	3.50	114.83	3.50	114.74	3.94	129.36	3.66	120.21	3.62	118.62	3.66	119.93	3.81	125.04
Mean + 1.65s	4.29	140.80	4.28	140.37	4.28	140.58	4.32	141.72	4.84	158.80	4.44	145.69	4.51	147.91

MASS PER UNIT AREA														
POLYFELT TS 500														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	4.14	135.82	4.27	140.09	4.13	135.50	4.09	134.18	4.33	142.06	4.01	131.56	4.56	149.70
2	4.37	143.37	4.19	137.46	4.04	132.54	3.99	130.90	4.56	149.60	3.97	130.25	4.49	147.34
3	4.31	141.40	4.34	142.39	4.23	138.78	4.42	145.01	4.12	135.17	4.13	135.50	4.38	143.83
4	4.30	141.07	4.30	141.07	4.45	145.99	4.06	133.20	4.19	137.46	4.59	150.59	4.13	135.59
5	4.07	133.53	4.19	137.46	3.60	118.11	3.42	112.20	4.24	139.11	4.13	135.50	4.39	144.03
6	4.23	138.78	4.52	148.29									4.61	151.24
7	4.55	149.28	4.56	149.60									4.32	141.80
8	4.99	163.71	4.25	139.43									3.92	128.57
9	4.30	141.07	3.74	122.70									4.42	144.88
10	4.37	143.37	4.09	134.18									4.08	133.86
MEAN	4.36	143.14	4.25	139.27	4.09	134.18	4.00	131.10	4.29	140.68	4.17	136.68	4.33	142.08
S.D. (s)	0.26	8.42	0.23	7.52	0.31	10.29	0.36	11.88	0.17	5.58	0.25	8.12	0.16	5.35
C.V%	5.88	5.88	5.40	5.40	7.67	7.67	9.06	9.06	3.97	3.97	5.94	5.94	3.76	3.76
Mean - 1.65s	3.94	129.25	3.87	126.86	3.57	117.21	3.40	111.50	4.01	131.47	3.76	123.28	4.06	133.26
Mean + 1.65s	4.79	157.03	4.62	151.67	4.61	151.16	4.59	150.70	4.57	149.89	4.57	150.08	4.60	150.90

MASS PER UNIT AREA

POLYFELT TS 550

	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	5.63	184.71	5.48	179.79	4.79	157.15	5.01	164.37	5.73	187.99	5.22	171.26	5.18	170.04
2	5.64	185.04	5.69	186.68	4.38	143.70	5.24	171.91	5.91	193.89	5.21	170.93	5.49	179.95
3	5.17	169.62	5.22	171.26	5.15	168.96	5.16	169.29	5.84	191.60	5.24	171.91	5.46	179.13
4	5.41	177.49	5.51	180.77	4.29	140.75	4.76	156.17	5.31	174.21	4.84	158.79	5.54	181.76
5	5.37	176.18	5.63	184.71	4.91	161.09	5.61	184.05	5.38	176.51	4.83	158.46	6.00	196.85
6	6.10	200.13	5.10	167.32									5.41	177.52
7	4.85	159.12	5.16	169.29									5.08	166.53
8	5.76	188.97	5.33	174.87									5.63	184.71
9	5.24	171.91	5.63	184.71									6.04	198.06
10	5.30	173.88	5.37	176.18									5.28	173.32
MEAN	5.45	178.70	5.41	177.56	4.70	154.33	5.16	169.16	5.63	184.84	5.07	166.27	5.51	180.79
S.D. (s)	0.35	11.47	0.21	6.85	0.36	11.89	0.31	10.26	0.27	8.94	0.21	6.99	0.30	9.68
C.V%	6.42	6.42	3.86	3.86	7.70	7.70	6.07	6.07	4.84	4.84	4.20	4.20	5.35	5.35
Mean - 1.65s	4.87	159.78	5.07	166.25	4.11	134.71	4.64	152.23	5.18	170.08	4.72	154.74	5.02	164.81
Mean + 1.65s	6.02	197.63	5.76	188.86	5.30	173.94	5.67	186.09	6.08	199.60	5.42	177.80	6.00	196.76

MASS PER UNIT AREA														
POLYFELT TS 600														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	6.32	207.35	5.51	180.77	7.15	234.58	6.95	228.01	6.79	222.77	5.80	190.29	6.83	224.18
2	6.28	206.03	6.21	203.74	6.68	219.16	6.74	221.12	6.49	212.92	5.97	195.86	5.99	196.35
3	6.35	208.33	6.00	196.85	6.15	201.77	6.67	218.83	6.86	225.06	6.62	217.19	5.92	194.32
4	6.50	213.25	5.83	191.27	5.38	176.51	5.64	185.04	6.63	217.52	6.49	212.92	5.55	182.02
5	6.40	209.97	6.36	208.66	6.12	200.78	5.78	189.63	6.18	202.75	6.50	213.25	6.89	226.11
6	6.68	219.16	6.15	201.77									6.10	199.96
7	6.65	218.17	6.37	208.99									7.05	231.26
8	6.59	216.20	6.19	203.08									5.72	187.63
9	6.70	219.81	6.47	212.27									6.82	223.68
10	6.84	224.41	5.84	191.60									6.75	221.49
MEAN	6.53	214.27	6.09	199.90	6.30	206.56	6.36	208.53	6.59	216.20	6.28	205.90	6.36	208.70
S.D. (s)	0.19	6.21	0.30	9.77	0.66	21.81	0.60	19.71	0.27	8.87	0.37	11.99	0.60	19.55
C.V%	2.90	2.90	4.89	4.89	10.56	10.56	9.45	9.45	4.10	4.10	5.82	5.82	9.37	9.37
Mean - 1.65s	6.22	204.02	5.60	183.78	5.20	170.57	5.36	176.01	6.14	201.56	5.67	186.11	5.38	176.44
Mean + 1.65s	6.84	224.51	6.58	216.02	7.39	242.55	7.35	241.04	7.04	230.84	6.88	225.69	7.34	240.97

MASS PER UNIT AREA

POLYFELT TS 650

Specimen No.	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	6.99	229.33	6.99	229.33	6.75	221.45	7.12	233.59	6.97	228.67	6.93	227.36	7.73	253.64
2	7.08	232.28	7.17	235.23	7.07	231.95	7.26	238.18	7.17	235.23	7.33	240.48	7.18	235.56
3	6.77	222.11	6.92	227.03	7.05	231.30	7.44	244.09	7.13	233.92	6.97	228.67	7.52	246.71
4	6.90	226.37	7.23	237.20	7.16	234.90	7.72	253.28	6.59	216.20	7.91	259.51	6.75	221.45
5	7.75	254.26	6.92	227.03	6.71	220.14	6.45	211.61	6.70	219.81	7.03	230.64	6.96	228.28
6	6.98	229.00	6.43	210.95									7.45	244.35
7	7.75	254.26	7.06	231.62									7.15	234.67
8	6.86	225.06	6.78	222.44									7.37	241.93
9	7.75	254.26	6.45	211.61									7.35	241.27
10	7.85	257.54	7.48	245.40									7.52	246.71
MEAN	7.27	238.45	6.94	227.78	6.95	227.95	7.20	236.15	6.91	226.77	7.23	237.33	7.30	239.46
S.D. (s)	0.44	14.60	0.33	10.78	0.20	6.69	0.47	15.57	0.26	8.46	0.41	13.43	0.40	13.14
C.V%	6.12	6.12	4.73	4.73	2.93	2.93	6.59	6.59	3.73	3.73	5.66	5.66	5.49	5.49
Mean - 1.65s	6.53	214.37	6.40	209.99	6.61	216.92	6.42	210.47	6.49	212.81	6.56	215.18	6.64	217.77
Mean + 1.65s	8.00	262.53	7.49	245.57	7.28	238.98	7.98	261.84	7.34	240.73	7.91	259.49	7.96	261.14

MASS PER UNIT AREA														
POLYFELT TS 700														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	8.40	275.59	8.69	285.10	9.68	317.58	8.71	285.76	7.96	261.15	8.05	264.10	8.56	280.93
2	8.50	278.87	8.89	291.66	9.27	304.13	7.85	257.54	8.35	273.95	7.97	261.48	8.32	273.03
3	8.36	274.27	8.22	269.68	8.44	276.90	8.35	273.95	9.01	295.60	9.07	297.57	8.82	289.20
4	8.75	287.07	8.79	288.38	8.91	292.32	9.06	297.24	8.25	270.66	9.11	298.88	9.57	313.97
5	7.34	240.81	8.65	283.79	8.67	284.44	8.14	267.06	8.36	274.27	8.81	289.04	8.72	286.22
6	8.45	277.23	8.23	270.01									8.56	280.80
7	8.98	294.61	9.18	301.18									8.57	281.29
8	7.76	254.59	8.53	279.85									8.37	274.70
9	7.81	256.23	8.72	286.08									8.13	266.60
10	9.38	307.74	8.42	276.24									9.14	299.96
MEAN	8.37	274.70	8.63	283.20	8.99	295.07	8.42	276.31	8.39	275.13	8.60	282.21	8.68	284.67
S.D. (s)	0.61	19.89	0.30	9.72	0.49	16.12	0.47	15.58	0.38	12.61	0.55	18.15	0.47	15.42
C.V%	7.24	7.24	3.43	3.43	5.46	5.46	5.64	5.64	4.58	4.58	6.43	6.43	5.42	5.42
Mean - 1.65s	7.37	241.88	8.14	267.16	8.18	268.48	7.64	250.60	7.75	254.31	7.69	252.26	7.90	259.23
Mean + 1.65s	9.37	307.52	9.12	299.24	9.80	321.67	9.21	302.01	9.02	295.94	9.51	312.16	9.45	310.11

MASS PER UNIT AREA														
POLYFELT TS 750														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	10.75	352.68	11.02	361.54	10.88	356.95	11.18	366.79	10.98	360.23	10.28	337.26	11.33	371.71
2	11.30	370.73	10.93	358.59	11.73	384.84	10.81	354.65	10.90	357.61	10.59	347.44	11.82	387.82
3	10.85	355.97	10.24	335.95	11.00	360.89	10.28	337.26	11.64	381.88	11.24	368.76	11.16	366.17
4	10.45	342.84	10.79	354.00	10.65	349.40	11.84	388.44	10.82	354.98	10.66	349.73	10.70	351.18
5	10.65	349.40	10.69	350.72	10.48	343.83	12.40	406.82	10.97	359.90	12.20	400.26	10.82	355.08
6	10.31	338.25	10.38	340.55									10.66	349.60
7	10.77	353.34	10.51	344.81									11.80	387.20
8	10.85	355.97	11.13	365.15									10.97	359.90
9	9.72	318.89	11.28	370.07									11.22	367.94
10	10.64	349.08	10.96	359.57									10.88	357.08
MEAN	10.63	348.71	10.79	354.10	10.95	359.18	11.30	370.79	11.06	362.92	10.99	360.69	11.14	365.37
S.D. (s)	0.41	13.58	0.34	11.02	0.48	15.79	0.84	27.43	0.33	10.81	0.76	24.88	0.44	14.55
C.V%	3.90	3.90	3.11	3.11	4.40	4.40	7.40	7.40	2.98	2.98	6.90	6.90	3.98	3.98
Mean - 1.65s	9.95	326.30	10.24	335.91	10.15	333.12	9.92	325.53	10.52	345.09	9.74	319.65	10.40	341.36
Mean + 1.65s	11.31	371.13	11.35	372.28	11.74	385.24	12.68	416.06	11.61	380.75	12.25	401.73	11.87	389.38

MASS PER UNIT AREA														
POLYTRAC 155														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	4.73	155.18	4.71	154.52	4.59	150.59	4.69	153.87	4.70	154.20	4.73	155.18	4.80	157.31
2	4.78	156.82	4.71	154.52	4.76	156.17	4.69	153.87	4.79	157.15	4.74	155.51	4.77	156.36
3	4.72	154.85	4.70	154.20	4.75	155.84	4.68	153.54	4.64	152.23	4.78	156.82	4.76	156.26
4	4.71	154.52	4.73	155.18	4.76	156.17	4.66	152.88	4.75	155.84	4.75	155.84	4.71	154.59
5	4.72	154.85	4.70	154.20	4.72	154.85	4.64	152.23	4.73	155.18	4.74	155.51	4.72	154.89
6	4.73	155.18	4.74	155.51									4.77	156.62
7	4.74	155.51	4.73	155.18									4.78	156.69
8	4.72	154.85	4.75	155.84									4.76	156.13
9	4.83	158.46	4.74	155.51									4.80	157.61
10	4.80	157.48	4.78	156.82									4.73	155.05
MEAN	4.75	155.77	4.73	155.15	4.72	154.72	4.67	153.28	4.72	154.92	4.75	155.77	4.76	156.15
S.D. (s)	0.04	1.34	0.03	0.82	0.07	2.37	0.02	0.71	0.06	1.85	0.02	0.63	0.03	1.13
C.V%	0.86	0.86	0.53	0.53	1.53	1.53	0.46	0.46	1.19	1.19	0.41	0.41	0.72	0.72
Mean - 1.65s	4.68	153.56	4.69	153.79	4.60	150.81	4.64	152.10	4.63	151.87	4.72	154.73	4.70	154.29
Mean + 1.65s	4.82	157.98	4.77	156.51	4.84	158.64	4.71	154.45	4.81	157.97	4.78	156.81	4.82	158.01

MASS PER UNIT AREA														
POLYTRAC C (Woven side up)														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	10.77	353.34	10.29	337.59	10.87	356.62	11.11	364.50	11.41	374.34	10.80	354.32	11.53	378.27
2	10.53	345.47	10.98	360.23	10.38	340.55	10.40	341.20	11.07	363.18	11.63	381.56	10.57	346.65
3	10.77	353.34	10.81	354.65	10.61	348.09	10.11	331.69	11.05	362.53	10.43	342.19	10.38	340.41
4	10.84	355.64	10.44	342.51	10.17	333.66	10.70	351.04	9.96	326.77	10.23	335.62	11.04	362.30
5	11.05	362.53	10.51	344.81	11.10	364.17	10.44	342.51	9.27	304.13	10.25	336.28	10.53	345.60
6	10.76	353.01	10.61	348.09									10.52	345.20
7	10.74	352.36	10.10	331.36									10.39	340.87
8	10.37	340.22	10.61	348.09									10.73	352.13
9	10.30	337.92	10.68	350.39									10.81	354.52
10	10.29	337.59	9.50	311.67									10.84	355.64
MEAN	10.64	349.14	10.45	342.94	10.63	348.62	10.55	346.19	10.55	346.19	10.67	349.99	10.73	352.16
S.D. (s)	0.26	8.40	0.42	13.70	0.37	12.20	0.38	12.32	0.90	29.56	0.58	19.17	0.47	15.53
C.V%	2.40	2.40	3.99	3.99	3.50	3.50	3.56	3.56	8.54	8.54	5.48	5.48	4.41	4.41
Mean - 1.65s	10.22	335.29	9.76	320.34	10.01	328.49	9.93	325.86	9.07	297.42	9.70	318.36	9.95	326.53
Mean + 1.65s	11.06	362.99	11.14	365.54	11.24	368.74	11.17	366.52	12.04	394.96	11.63	381.63	11.52	377.79

MASS PER UNIT AREA														
POLYTRAC C (Woven side down)														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	10.16	333.33	11.10	364.17	9.87	323.81	10.60	347.76	10.46	343.17	10.46	343.17	9.46	310.43
2	10.24	335.95	11.53	378.27	10.57	346.78	11.46	375.98	9.98	327.42	10.68	350.39	10.03	329.16
3	9.97	327.09	10.52	345.14	10.62	348.42	10.34	339.23	9.55	313.31	10.62	348.42	9.71	318.56
4	10.43	342.19	11.26	369.42	10.86	356.29	10.10	331.36	10.96	359.57	11.12	364.82	10.53	345.47
5	11.03	361.87	10.73	352.03	10.35	339.56	10.56	346.45	10.24	335.95	11.15	365.81	9.66	316.89
6	10.61	348.09	10.73	352.03									10.35	339.43
7	10.85	355.97	11.30	370.73									9.92	325.42
8	11.03	361.87	10.50	344.48									10.57	346.78
9	10.48	343.83	10.49	344.15									10.53	345.43
10	11.88	389.76	10.42	341.86									10.47	343.47
MEAN	10.67	349.99	10.86	356.23	10.45	342.97	10.61	348.16	10.24	335.89	10.81	354.52	10.12	332.10
S.D. (s)	0.56	18.26	0.40	13.26	0.37	12.25	0.51	16.87	0.53	17.29	0.31	10.21	0.42	13.71
C.V%	5.22	5.22	3.72	3.72	3.57	3.57	4.85	4.85	5.15	5.15	2.88	2.88	4.13	4.13
Mean - 1.65s	9.75	319.87	10.19	334.35	9.84	322.76	9.76	320.32	9.37	307.36	10.29	337.68	9.43	309.48
Mean + 1.65s	11.59	380.12	11.52	378.10	11.07	363.19	11.46	376.00	11.11	364.41	11.32	371.36	10.81	354.72

MASS PER UNIT AREA														
POLYWEAVE R														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	2.96	97.11	2.88	94.49	2.95	96.78	2.94	96.46	2.95	96.78	2.92	95.80	2.90	95.18
2	2.90	95.14	2.90	95.14	2.90	95.14	2.85	93.50	2.87	94.16	2.91	95.47	2.90	95.04
3	2.93	96.13	2.92	95.80	2.92	95.80	2.89	94.81	2.74	89.89	2.86	93.83	2.87	93.99
4	2.90	95.14	2.86	93.83	2.90	95.14	2.88	94.49	2.92	95.80	2.93	96.13	2.94	96.32
5	2.90	95.14	2.88	94.49	2.90	95.14	2.88	94.49	2.90	95.14	2.87	94.16	2.82	92.42
6	2.87	94.16	2.89	94.81									2.92	95.67
7	2.91	95.47	2.90	95.14									2.88	94.42
8	2.89	94.81	2.97	97.44									2.92	95.73
9	2.96	97.11	2.88	94.49									2.85	93.40
10	2.93	96.13	2.90	95.14									2.87	94.09
MEAN	2.92	95.63	2.90	95.08	2.91	95.60	2.89	94.75	2.88	94.36	2.90	95.08	2.88	94.63
S.D. (s)	0.03	0.97	0.03	0.99	0.02	0.72	0.03	1.07	0.08	2.67	0.03	1.02	0.04	1.47
C.V%	1.01	1.01	1.04	1.04	0.75	0.75	1.13	1.13	2.83	2.83	1.07	1.07	1.55	1.55
Mean - 1.65s	2.87	94.04	2.85	93.45	2.88	94.42	2.83	92.98	2.74	89.95	2.85	93.39	2.81	92.21
Mean + 1.65s	2.96	97.23	2.95	96.71	2.95	96.79	2.94	96.52	3.01	98.76	2.95	96.76	2.96	97.05

MASS PER UNIT AREA														
POLYWEAVE F														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	4.97	163.05	5.00	164.04	4.93	161.74	5.12	167.98	5.06	166.01	5.01	164.37	4.99	163.55
2	5.02	164.70	5.02	164.70	4.87	159.77	4.92	161.41	4.95	162.40	4.88	160.10	4.97	162.92
3	5.00	164.04	4.97	163.05	4.96	162.73	4.99	163.71	5.06	166.01	4.86	159.45	4.96	162.63
4	4.92	161.41	4.94	162.07	5.06	166.01	4.94	162.07	5.08	166.66	4.89	160.43	5.09	167.02
5	4.96	162.73	4.96	162.73	5.00	164.04	5.04	165.35	5.07	166.34	5.09	166.99	4.95	162.53
6	4.94	162.07	4.99	163.71									5.08	166.63
7	5.07	166.34	5.01	164.37									4.87	159.81
8	4.90	160.76	4.95	162.40									5.01	164.40
9	4.90	160.76	4.92	161.41									5.07	166.20
10	4.90	160.76	4.97	163.05									4.99	163.81
MEAN	4.96	162.66	4.97	163.15	4.96	162.86	5.00	164.10	5.04	165.48	4.95	162.27	5.00	163.95
S.D. (s)	0.06	1.90	0.03	1.05	0.07	2.35	0.08	2.65	0.05	1.75	0.10	3.27	0.06	1.88
C.V%	1.17	1.17	0.64	0.64	1.44	1.44	1.61	1.61	1.05	1.05	2.01	2.01	1.15	1.15
Mean - 1.65s	4.86	159.53	4.92	161.42	4.85	158.98	4.87	159.73	4.96	162.60	4.78	156.87	4.90	160.84
Mean + 1.65s	5.05	165.79	5.03	164.89	5.08	166.74	5.14	168.48	5.13	168.36	5.11	167.66	5.09	167.06

MASS PER UNIT AREA														
POLYWEAVE HR														
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	6.18	202.75	6.15	201.77	6.19	203.08	6.11	200.46	6.18	202.75	6.23	204.39	6.49	212.92
2	6.12	200.78	6.24	204.72	6.19	203.08	6.09	199.80	6.28	206.03	6.29	206.36	6.44	211.28
3	6.13	201.11	6.07	199.14	6.30	206.69	6.12	200.78	6.24	204.72	6.36	208.66	6.48	212.59
4	6.16	202.10	6.21	203.74	6.07	199.14	6.16	202.10	6.14	201.44	6.17	202.42	6.42	210.63
5	6.08	199.47	6.16	202.10	6.18	202.75	6.13	201.11	6.25	205.05	6.30	206.69	6.41	210.30
6	6.24	204.72	6.23	204.39									6.34	208.00
7	6.21	203.74	6.31	207.02									6.39	209.64
8	6.22	204.06	6.20	203.41									6.45	211.61
9	6.25	205.05	6.18	202.75									6.45	211.61
10	6.28	206.03	6.34	208.00									6.41	210.30
MEAN	6.19	202.98	6.21	203.70	6.19	202.95	6.12	200.85	6.22	204.00	6.27	205.71	6.43	210.89
S.D. (s)	0.06	2.10	0.08	2.56	0.08	2.67	0.03	0.85	0.06	1.86	0.07	2.38	0.04	1.17
C.V%	1.04	1.04	1.26	1.26	1.32	1.32	0.42	0.42	0.91	0.91	1.16	1.16	0.55	0.55
Mean - 1.65s	6.08	199.51	6.08	199.48	6.05	198.54	6.08	199.45	6.12	200.93	6.15	201.78	6.37	208.96
Mean + 1.65s	6.29	206.45	6.34	207.93	6.32	207.36	6.16	202.25	6.31	207.07	6.39	209.63	6.49	212.82

MASS PER UNIT AREA

PROPEX 2002

	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	4.60	150.92	4.57	149.93	4.43	145.34	4.63	151.90	4.62	151.57	4.56	149.60	4.55	149.21
2	4.68	153.54	4.63	151.90	4.55	149.28	4.56	149.60	4.48	146.98	4.56	149.60	4.44	145.54
3	4.56	149.60	4.63	151.90	4.57	149.93	4.50	147.64	4.60	150.92	4.53	148.62	4.53	148.52
4	4.66	152.88	4.62	151.57	4.63	151.90	4.60	150.92	4.53	148.62	4.67	153.21	4.64	152.26
5	4.65	152.56	4.50	147.64	4.62	151.57	4.65	152.56	4.65	152.56	4.53	148.62	4.53	148.62
6	4.67	153.21	4.64	152.23									4.54	148.78
7	4.64	152.23	4.65	152.56									4.55	149.34
8	4.65	152.56	4.64	152.23									4.49	147.27
9	4.59	150.59	4.67	153.21									4.56	149.70
10	4.58	150.26	4.61	151.24									4.64	152.06
MEAN	4.63	151.83	4.62	151.44	4.56	149.60	4.59	150.52	4.58	150.13	4.57	149.93	4.55	149.13
S.D. (s)	0.04	1.37	0.05	1.59	0.08	2.62	0.06	1.96	0.07	2.28	0.06	1.90	0.07	2.39
C.V%	0.90	0.90	1.05	1.05	1.75	1.75	1.30	1.30	1.52	1.52	1.27	1.27	1.60	1.60
Mean - 1.65s	4.56	149.57	4.54	148.81	4.43	145.27	4.49	147.29	4.46	146.37	4.47	146.80	4.43	145.18
Mean + 1.65s	4.70	154.10	4.70	154.07	4.69	153.93	4.69	153.76	4.69	153.89	4.67	153.07	4.67	153.08

MASS PER UNIT AREA

TERRAFIX 310 R

	Standard CBR Test		750mm Drop Cone		Pyramid CBR Test		Round CBR Test		875mm Drop Cone		1000mm Drop Cone		TEST #1 1500mm Drop Cone		TEST #2 1500mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	9.19	301.50	9.32	305.77	9.41	308.72	9.00	295.27	10.26	336.61	8.85	290.35	10.06	330.01	9.43	309.41
2	9.27	304.13	9.90	324.80	9.44	309.71	9.12	299.21	9.84	322.83	8.64	283.46	8.19	268.53	8.47	277.75
3	9.13	299.54	10.12	332.02	9.17	300.85	8.66	284.12	10.12	332.02	8.79	288.38	10.00	328.08	8.76	287.53
4	9.86	323.49	9.62	315.61	9.54	312.99	9.08	297.90	9.11	298.88	8.71	285.76	10.17	333.69	9.27	304.16
5	9.89	324.47	9.45	310.03	9.33	306.10	9.10	298.55	9.71	318.56	8.92	292.65	9.82	322.17	9.18	301.14
6	10.04	329.39	10.13	332.34									9.97	326.96	9.90	324.70
7	9.84	322.83	10.28	337.26									9.59	314.59	9.10	298.68
8	10.49	344.15	9.20	301.83									9.58	314.30	9.64	316.10
9	9.66	316.92	8.70	285.43									9.03	296.09	8.63	283.10
10	9.29	304.78	8.83	289.69									9.44	309.54	8.29	272.01
MEAN	9.67	317.12	9.56	313.48	9.38	307.67	8.99	295.01	9.81	321.78	8.78	288.12	9.58	314.40	9.07	297.46
S.D. (s)	0.44	14.46	0.55	18.13	0.14	4.54	0.19	6.27	0.45	14.67	0.11	3.63	0.60	19.67	0.52	17.11
C.V%	4.56	4.56	5.78	5.78	1.48	1.48	2.13	2.13	4.56	4.56	1.26	1.26	6.26	6.26	5.75	5.75
Mean - 1.65s	8.94	293.26	8.64	283.57	9.15	300.18	8.68	284.66	9.07	297.58	8.60	282.12	8.59	281.93	8.21	269.23
Mean + 1.65s	10.39	340.98	10.47	343.39	9.61	315.17	9.31	305.35	10.55	345.98	8.96	294.11	10.57	346.86	9.93	325.68

MASS PER UNIT AREA																
	TERRAFIX 360 R												TEST #1		TEST #2	
	Standard CBR Test		750mm Drop Cone		Pyramid CBR Test		Round CBR Test		875mm Drop Cone		1000mm Drop Cone		1500mm Drop Cone		1500mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	11.46	375.98	11.48	376.63	11.15	365.81	10.33	338.91	12.15	398.62	10.84	355.64	11.53	378.37	11.36	372.80
2	12.46	408.79	12.28	402.88	11.76	385.82	11.24	368.76	12.08	396.32	10.48	343.83	12.97	425.52	10.40	341.07
3	11.40	374.01	11.63	381.56	11.98	393.04	11.45	375.65	11.55	378.93	11.68	383.20	11.60	380.64	10.95	359.25
4	11.91	390.74	13.80	452.75	11.58	379.91	11.65	382.21	11.53	378.27	11.65	382.21	12.39	406.52	11.26	369.48
5	10.84	355.64	11.00	360.89	10.55	346.12	11.49	376.96	11.22	368.10	10.69	350.72	11.77	386.18	11.98	393.07
6	12.00	393.69	10.82	354.98									12.16	398.84	11.44	375.32
7	12.40	406.82	11.67	382.87									11.30	370.86	11.68	383.26
8	11.54	378.60	11.94	391.73									12.05	395.17	11.33	371.84
9	11.31	371.06	11.37	373.03									11.11	364.56	12.44	408.13
10	12.65	415.02	11.81	387.46									12.95	424.70	11.55	378.86
MEAN	11.80	387.03	11.78	386.48	11.40	374.14	11.23	368.50	11.71	384.05	11.07	363.12	11.98	393.14	11.44	375.31
S.D. (s)	0.58	19.18	0.83	27.19	0.57	18.58	0.52	17.22	0.40	13.00	0.56	18.37	0.64	21.07	0.55	18.11
C.V%	4.95	4.95	7.03	7.03	4.97	4.97	4.67	4.67	3.39	3.39	5.06	5.06	5.36	5.36	4.82	4.82
Mean - 1.65s	10.83	355.39	10.41	341.62	10.47	343.48	10.37	340.08	11.05	362.59	10.14	332.81	10.92	358.37	10.53	345.43
Mean + 1.65s	12.76	418.68	13.15	431.33	12.34	404.80	12.10	396.92	12.36	405.51	11.99	393.43	13.04	427.90	12.35	405.19

MASS PER UNIT AREA

TERRAM 700 SUV

Specimen No.	Standard CBR Test: Specimen Weight (g)	Standard CBR Test: Mass per Unit area (g/m^2)	Drop Cone Test: Specimen Weight (g)	Drop Cone Test: Mass per Unit area (g/m^2)	Pyramid CBR Test: Specimen Weight (g)	Pyramid CBR Test: Mass per Unit area (g/m^2)	Round CBR Test: Specimen Weight (g)	Round CBR Test: Mass per Unit area (g/m^2)	250mm Drop Cone: Specimen Weight (g)	250mm Drop Cone: Mass per Unit area (g/m^2)	750mm Drop Cone: Specimen Weight (g)	750mm Drop Cone: Mass per Unit area (g/m^2)
1	3.40	111.55	3.48	114.17	3.56	116.80	3.34	109.58	3.54	116.14	3.32	108.92
2	3.39	111.22	3.43	112.53	3.77	123.69	3.34	109.58	3.74	122.70	3.32	108.92
3	3.38	110.89	3.44	112.86	3.54	116.14	3.25	106.63	3.57	117.12	3.15	103.34
4	3.18	104.33	3.40	111.55	3.60	118.11	3.35	109.91	3.65	119.75	3.65	119.75
5	3.20	104.99	3.58	117.45	3.68	120.73	3.14	103.02	3.68	120.73	3.73	122.37
6	3.09	101.38	3.44	112.86								
7	3.40	111.55	3.48	114.17								
8	3.57	117.12	3.53	115.81								
9	3.81	125.00	3.50	114.83								
10	3.62	118.76	3.74	122.70								
MEAN	3.40	111.68	3.50	114.89	3.63	119.09	3.28	107.74	3.64	119.29	3.43	112.66
S.D. (s)	0.22	7.17	0.10	3.24	0.09	3.11	0.09	2.96	0.08	2.67	0.25	8.05
C.V%	6.42	6.42	2.82	2.82	2.61	2.61	2.75	2.75	2.24	2.24	7.15	7.15
Mean - 1.65s	3.04	99.84	3.34	109.55	3.47	113.96	3.14	102.86	3.50	114.88	3.03	99.38
Mean + 1.65s	3.76	123.51	3.66	120.24	3.79	124.23	3.43	112.62	3.77	123.70	3.84	125.95

MASS PER UNIT AREA												
TERRAM 1000 SUV												
	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	4.41	144.68	4.50	147.64	4.72	154.85	4.91	161.09	4.57	149.93	4.49	147.31
2	4.74	155.51	4.36	143.04	4.67	153.21	4.28	140.42	4.48	146.98	4.48	146.98
3	4.64	152.23	4.52	148.29	4.72	154.85	4.71	154.52	4.56	149.60	4.43	145.34
4	4.44	145.67	4.62	151.57	4.37	143.37	4.86	159.45	4.57	149.93	4.37	143.37
5	4.41	144.68	4.31	141.40	4.97	163.05	4.74	155.51	4.67	153.21	4.56	149.60
6	4.63	151.90	4.44	145.67								
7	4.56	149.60	4.43	145.34								
8	4.38	143.70	4.60	150.92								
9	4.42	145.01	4.57	149.93								
10	4.35	142.71	4.76	156.17								
MEAN	4.50	147.57	4.51	148.00	4.69	153.87	4.70	154.20	4.57	149.93	4.47	146.52
S.D. (s)	0.13	4.38	0.13	4.38	0.21	7.02	0.25	8.17	0.07	2.21	0.07	2.33
C.V%	2.97	2.97	2.96	2.96	4.56	4.56	5.30	5.30	1.48	1.48	1.59	1.59
Mean - 1.65s	4.28	140.33	4.29	140.77	4.34	142.29	4.29	140.72	4.46	146.28	4.35	142.68
Mean + 1.65s	4.72	154.80	4.73	155.22	5.04	165.45	5.11	167.67	4.68	153.58	4.58	150.36

MASS PER UNIT AREA

TERRAM 3000 SUV

	Standard CBR Test		Drop Cone Test		Pyramid CBR Test		Round CBR Test		250mm Drop Cone		750mm Drop Cone		1000mm Drop Cone	
Specimen No.	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)	Specimen Weight (g)	Mass per Unit area (g/m^2)
1	8.87	291.01	9.00	295.27	8.72	286.08	8.90	291.99	8.58	281.49	8.80	288.71	8.29	272.01
2	8.72	286.08	8.76	287.40	8.77	287.72	8.49	278.54	8.66	284.12	8.69	285.10	8.69	285.10
3	9.00	295.27	8.43	276.57	8.71	285.76	8.38	274.93	8.52	279.52	8.70	285.43	8.81	289.04
4	8.63	283.13	8.93	292.97	8.32	272.96	8.76	287.40	8.77	287.72	8.76	287.40	9.13	299.47
5	8.44	276.90	8.67	284.44	8.83	289.69	8.72	286.08	8.85	290.35	8.72	286.08	8.49	278.60
6	8.94	293.30	8.83	289.69									8.24	270.37
7	9.04	296.58	8.63	283.13									8.78	287.99
8	8.45	277.23	8.56	280.84									9.25	303.47
9	8.76	287.40	8.21	269.35									8.89	291.56
10	8.61	282.48	7.92	259.84									8.57	281.03
MEAN	8.75	286.94	8.59	281.95	8.67	284.44	8.65	283.79	8.68	284.64	8.73	286.54	8.71	285.86
S.D. (s)	0.22	7.07	0.33	10.92	0.20	6.61	0.21	6.92	0.14	4.43	0.05	1.50	0.32	10.43
C.V%	2.46	2.46	3.87	3.87	2.32	2.32	2.44	2.44	1.56	1.56	0.52	0.52	3.65	3.65
Mean - 1.65s	8.39	275.27	8.04	263.93	8.34	273.54	8.30	272.37	8.45	277.33	8.66	284.07	8.19	268.65
Mean + 1.65s	9.10	298.60	9.14	299.98	9.00	295.34	9.00	295.21	8.90	291.95	8.81	289.01	9.24	303.08