**PROJECT ADMINISTRATION DATA SHEET**

**Project No./(Center No.)** E-20-654 (R6257-OA0)

**Project Director:** Dr. N. D. Williams

**Sponsor:** Various Sponsors*

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**Award Period:** From 10/15/86 To 4/14/88

**Sponsor Amount:**
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**Cost Sharing:** 

**Title:** Multi-Sponsor Program for Performance Evaluation of Improved Railroad Subgrades

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School of Civil Engineering

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**RESTRICTIONS**

See Attached N/A Supplemental Information Sheet for Additional Requirements.

**Travel:** Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

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*American Hoechst Corporation - $10,000 : 02.700.000.87.003
Exxon Chemical Americas - $ 5,000 : 02.700.000.87.005
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☒ Final Invoice or Copy of Last Invoice Serving as Final

☐ Release and Assignment

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Performance Evaluation of Railroad Track Embankment Using Geotextiles

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Hoechst Fibers Industries
Foss Manufacturing Company, Inc.
Exxon Chemical, Geotextile Fabrics
Norfolk - Southern

January 1988

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF CIVIL ENGINEERING
ATLANTA, GEORGIA 30332
Performance Evaluation of Improved Railroad Embankment Using Geotextiles

ABSTRACT
The purpose of this research project is to provide insight into the behavior of geotextiles in a railroad embankment. In-Situ testing as well as an extensive laboratory investigation on geosynthetic specimens from the embankment is summarized. The investigation leads to an isolation of the primary variables affecting performance. The performance of four geotextiles in a railroad embankment is discussed.
ACKNOWLEDGEMENTS

The success of this research project has, as many others, been only possible with the combined effort of many people. Here I wish to acknowledge their assistance and offer my thanks.

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To Mr. K. Thomas, engineering technician, who always was available when help was needed.

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To Dr. Neil Williams for offering so many opportunities to gain experience and knowledge in the laboratory and in the field, for his patience, time and thorough review of this report.

To Dr. Q. Robnett and Dr. R.C. Bachus for the review of the manuscript and many valuable suggestions.

Finally to my parents, without whose constant support my studies certainly would not have been as successful.
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1. INTRODUCTION

1.1 Background

During the late 1800's the railroads in the United States were in a period of rapid expansion. Communities lobbied to have the railroads pass through their towns. The track alignments were typically politically motivated and were seldom made with regard to geology. Indeed, the track was often installed in areas where the digging was easier and where the track could be installed more rapidly.

The previous decisions regarding track alignment have created a myriad of problems for railroad maintenance personnel. In areas where the track was installed over weak or compressible subgrade soils track alignment is a continual maintenance problem. In the past the most common remedy of misalignment of tracks was the placement of additional ballast and realignment of the track. In areas with very weak soils and particularly in wet areas, the placement of additional ballast and realignment of the track have been performed almost yearly. In many of these areas there are now more than 20 feet of ballast and the embankment has become so large that it threatens to exceed right-of-way limitations.

Clearly, alternative solutions to the problem had to be found. The most promising of the new technologies employs the use of geosynthetics for subgrade stabilization. The
geosynthetics work in conjunction with the embankment materials to increase stability and extend the life of the track.

The reasons for the improved track life where embankments are stabilized with single or multiple layers of geosynthetics are not well understood. It is believed that the primary benefits derived from the use of geosynthetics are:

1) Separation of embankment materials from subgrade soils. This prevents soft soils from coating the granular embankment materials and allows the embankment materials to remain intact.

2) Resistance to lateral spreading. High vertical and lateral stresses are placed on the embankment. Since granular soils cannot carry tension forces, the lateral stresses must be resisted by shear stresses at the interface between the ballast and the subgrade. In soft soils which have low shear strengths these lateral stresses result in lateral spreading of the embankment.

3) Resistance to differential settlement. In areas with heterogeneous subgrades the geosynthetics may redistribute stresses and provide more uniform vertical displacements.

4) Improved drainage. The thick nonwoven geotextiles commonly used in railroad applications may improve or enhance the longterm drainage capacity of the embankment and thereby reduce softening of the subgrade soils.
5) Filtration of fine grained soil particles. In areas where the subgrade soils are very wet and soft, the geotextile may induce the formation of a transitional filter in the subgrade soil which will promote long term drainage.

6) Dissipation of excess pore pressures induced by dynamic loads. In areas where the track has been placed directly over wet cohesive or cohesionless soils, the dynamic nature of the wheel loads of a train may induce the build-up of excess hydrostatic pressure. Such a build-up of hydrostatic pressure may induce a reduction in effective stress and hence a reduction in bearing capacity.

The relative importance of each of the benefits of the geosynthetics is primarily a function of the type of subgrade soil, drainage conditions, thickness of the embankment, embankment materials, and the type of geosynthetic.

In order to better understand the contributions to stability of geotextiles used in railroad embankments, a combined laboratory and field testing program was undertaken. The results of the program are discussed subsequently.
1.2 The Research Program

In October, 1985, in Wautubee, Clarke County, Mississippi, an in-track performance evaluation was initiated. Four geotextiles were installed during regular maintenance work on the track, 3 nonwovens and 1 stitchbonded geotextile. The track was undercut, the geotextiles placed on the existing subgrade and the track backfilled with new ballast material. A control section in the same area was constructed at the same time by undercutting the track and backfilling with new ballast.

The objective of the research project was twofold: First, to investigate the improvement of the stability of the railroad embankment afforded by the geotextiles; and second, to compare the performance of four geotextiles. To meet this objective the track behavior as well as geotextile properties and performance had to be observed over time.

The investigation was divided in a Laboratory Analysis Program and an In-Situ Testing Program. The Laboratory Analysis Program consisted of:

1. Ballast Testing;
2. Baseline Geotextile Testing; and
1.2.1. Ballast Testing Program

The ballast testing program consisted of the evaluation of the engineering properties of the existing "fouled" ballast and the "new" ballast that was to be installed with the geotextiles.

The testing performed on both new and fouled ballast was as follows:
- Grain Size Distribution
- Permeability
- Visual Classification

The testing performed only on the fouled ballast material was as follows:
- Water content
- Plastic Limit
- Liquid Limit
- Activity
- Consolidation

1.2.2 Baseline Geotextile Testing Program

This program consisted of index and design tests, which are defined in 1.3. The results provided a baseline for comparison with the in-service test results.
The index tests performed on the geotextiles were as follows:

- Wide Strip Tension in Machine Direction,
- Wide Strip Tension in Cross Direction,
- Puncture,
- Trapezoidal Tear,
- Permittivity, and
- Transmissivity.

The design tests performed on the geotextiles were as follows:

- Direct Shear Friction with new Ballast,
- Direct Shear Friction with fouled Ballast,
- Hydraulic Conductivity Ratio with fouled Ballast, and
- Transmissivity with fouled Ballast.
1.2.3 In-Service Geotextile Testing Program

The in-service testing methods were similar to the baseline testing procedures. Samples of each geotextile were obtained immediately after installation and at time intervals of 1, 2, 6 and 12 months.

The following index tests were performed on these samples:

- Wide Strip Tension (Machine Direction),
- Wide Strip Tension (Cross Direction),
- Permittivity,
- Transmissivity,
- Puncture, and
- Trapezoidal Tear.
1.3 Terminology

The application of a wide variety of testing, equipment and new or alternate methods requires the definition of the terminology used in this report. The following explanations are based on the most recent use in current literature.

Geotextiles are woven or nonwoven permeable textiles used in foundations, soil, rock, earth or any other geotechnical engineering related material as an integral part of a man-made project, structure or system [Christopher & Holtz, 1984].

There are three types of geotextiles:

Nonwoven geotextile is an arrangement of randomly oriented fibers, that are bonded with different mechanisms.

Woven geotextiles have an oriented structure and continuous yarn that are woven together to form the woven structure.

Stichbonded geotextiles consist of either type of geotextiles sown together.

Machine Direction is the production direction in the factory.

Cross Direction is the direction perpendicular to the machine direction.

Ballast is a uniformly graded, angular, coarse, hard-broken
rock which produces an elastic foundation.[22]

Fouled Ballast is commonly known as contaminated, dirty ballast material.

**Index Tests** are used to evaluate material properties under controlled laboratory conditions. The results may be used to compare the relative performance of geotextiles. Index test results are typically not appropriate for use in design.

**Design Tests** are used to evaluate design properties of geotextiles. Typically these tests are run using boundary conditions that simulate conditions in the field. Soil type, confining pressures, loading conditions and complex mechanisms are duplicated in these tests.
2. SITE DESCRIPTION

2.1 Location

The test sections are installed in an embankment of the Southern Railway Company, located in the northeastern part of Clarke County, Mississippi, near the Highway 11 overpass in an approximately 30 ft. deep cut. The location is shown in Figure [2.1].

2.2 Geologic Setting

The strata exposed at and below the test site are eocene deposits of tertiary age. A generalized section of strata exposed in Clarke County is depicted in Table [2.1]. Figure [2.2] shows a section of one of the cut faces near the site. The track itself lies in the uppermost part of the Potterchitto member, Cook Mountain Formation of the Claiborne group. The Potterchitto member is characterized as dark-greenish, silty clay. The log of a testhole drilled near the test site location is shown in Figure [2.3]. Groundwater is seasonal in the area and confined to joints and bedding planes in the formations following periods of precipitation. See Table [2.2]. The strata of the Cockfield formation are listed as a major aquifer. They are exposed in the upper part of the cut at the site location. Especially during rain periods, water drains out of the cut faces and causes a considerable accumulation of water along the track. This was observed during several site visits.
Fig. [2.1] Railroads and major highways of Clarke County, (after [38])
Fig. [2.2] Measured section of the Gordon Creek Shale Member of the Cook Mountain Formation at a railroad cut below Highway 11 in Clarke County, Mississippi. (after [33])
AN-4

Location: NW/4, NW/4, NW/4, NE/4, Sec. 10, T.3 N., R.14 E. On the east side of U.S. Highway 11, 300 feet south of the overpass.  

Elevation: 380 feet (Topographic map)  

Date: November 4, 1976

Purpose: Cored 36.5 feet at type locality of Gordon Creek Shale member for stratigraphic information. Electrical log from 2 to 35 feet.

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<td>Claiborne Group (Cockfield Formation)</td>
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<tr>
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<td>13.75</td>
<td>Clay, very pale-orange to grayish-orange; silty streaks, reddish- to dark-yellowish-orange; sand, pale-yellowish-orange, fine-grained.</td>
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<tr>
<td></td>
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<td>Claiborne Group (Cook Mountain Formation—Gordon Creek Shale member)</td>
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<tr>
<td>22</td>
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<td>Clay, greenish-black to dark-greenish-gray, shaly, micaceous; silt laminae, light-gray to greenish-gray.</td>
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<td>34.5</td>
<td>2.5</td>
<td>Clay, dark-greenish-gray, silty, laminated, micaceous.</td>
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<tr>
<td></td>
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<td>Claiborne Group (Cook Mountain Formation—Potterchitto member)</td>
</tr>
<tr>
<td>36</td>
<td>1.5</td>
<td>Clay, dark-greenish-gray, silty, glauconitic, calcareous, fossiliferous.</td>
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<tr>
<td>38.5</td>
<td>0.5</td>
<td>Clay, dark-greenish-gray to grayish-yellow-green, silty, glauconitic, calcareous, fossiliferous, partially indurated.</td>
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Fig. [2.3] Log of Testhole AN-4, (after [38])
Tab.[2.1] Generalized section of strata exposed in Clarke County
after [30]

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<tr>
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<th>LITHOLOGY</th>
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<tbody>
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<tr>
<td>Terrace deposits</td>
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<td>Metamorphic</td>
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<td>High Spring Formation</td>
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<td>Red Bluff Formation</td>
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<td>Pecosol (T)</td>
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Tab.[2.2] Stratigraphic Column and Water Resource Data of Clarke County, Mississippi
after [30]
2.3 Climate

The climate of Clarke county may be characterized as subtropical. It is influenced by its location between the mountainous area in the north and the warm waters of the Gulf to the south. Alternating dry polar winds and moist subtropical air result in rapid temperature changes during the winter. The summers are characterized by prevailing southerly winds and moist air. Occasionally northerly winds with hot, dry air from the continental landmass cause draught conditions. Precipitation and temperature data for a station near the test site, compiled from recordings 1966 through 1975 are given in Table [2.3]. The data for the same station are summarized for October, 1986, in Table [2.4].
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<tr>
<th>Month</th>
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<th>Average</th>
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Average temperature and precipitation based on a ten-year record; compiled from available recordings in U.S. Department of Commerce, Weather Bureau (Climatological Data) 1966 through 1975.

Tab.2.3 Normal Monthly, Seasonal, and Annual Temperature and Precipitation Quitman, Clarke County, Mississippi

After [301]
## MONTHLY SUMMARIZED STATION AND DIVISIONAL DATA

### Temperature (°F)

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<th>MONTHLY SUMMARIZED STATION AND DIVISIONAL DATA</th>
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<td>PRECIPITATION</td>
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<td>--- Divisional Data</td>
<td>--- Divisional Data</td>
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### Precipitation (in)

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<th>MONTHLY SUMMARIZED STATION AND DIVISIONAL DATA</th>
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<td>3.73</td>
</tr>
<tr>
<td>Pickens</td>
<td>7.47</td>
<td>4.66</td>
</tr>
<tr>
<td>Winona 5 E</td>
<td>7.47</td>
<td>4.66</td>
</tr>
</tbody>
</table>

Table [2.4] Summarized Precipitation and Temperature Data for Quitman, Clarke County, October, 1986; page, 1986.
2.4 Embankment Profile

The embankment was constructed in an exposed cut of the Potterchitto member, Cook Mountain formation of the Claiborne group. This member is a heavily overconsolidated clayey siltstone. The siltstone weathers into a low plasticity clayey silt or silty clay.

When the track was originally constructed a 12-in-thick layer of well graded sandy gravel was compacted above the siltstone. The embankment was then compacted above the gravel layer. The ballast consisted of fine to coarse, 2-in diameter, fragments of crushed granite and cinder. The cinder was black and very plastic, coating the granite ballast. The cinder was more prevalent in the lower sections of the embankment but had worked its way up into the upper layers of more recently placed granite ballast.

In areas below the railroad ties, there was a significant accumulation of wood fragments and rock flour. These rock flour and wood fragments resulted from abrasion between the ties and ballast and between ballast particles.
3. THE INSTALLATION

Five test sections including 4 geotextiles and 1 control section were constructed. The approach utilized for installation of the geotextiles consisted of track removal, embankment excavation, placement of track, placement of the geotextile and placement and compaction of the new ballast.

3.1 Geotextile Preparation

Prior to installation a grid was placed on each of the four geotextiles. A wooden frame template with inner dimensions of 30 inches by 30 inches was constructed. Strings were tensioned crosswise in a pattern of 3 inches by 3 inches. This configuration was believed to reveal the occurring strains on the geotextiles from the local to the global range and still be of practicable size. This template was placed over each geotextile and paint was sprayed along each string leaving an exact trace of the grid on the geotextile. Each crossing was permanently marked by punching short nails through the fabric. The nails were secured on the grid by placing epoxy glue around the tips. Two such grids were placed on each geotextile for redundancy purposes. The grids were located about 15 ft from the end of a roll directly under the anticipated location of the railroad ties.

3.2 Construction

Prior to construction, the drainage ditches parallel to the embankment were filled for access purposes. The track
was then cut and the track and ties were lifted off the embankment and placed along the west boundary at the cut slope. The fouled ballast material was excavated to a depth of approximately 18 inches below the ties. The exposed surface of the fouled ballast was trimmed and sloped. During this operation the track was repaired. Once the subbase had been constructed, the track was pulled back into its original position and connected to the existing track temporarily with bolts. The track was then lifted in sections of about 30 ft using mechanical jacks and front end loaders and the geotextiles rolled out beneath it. Some damage to the geotextiles occurred during this operation.

The jacks were placed on top of the geotextiles causing high load concentrations. The steel cable used to lift the track resulted in tearing of the fabrics. One of the grids was damaged when the geotextile was inadvertently hooked by one of the front end loaders. Once the geotextiles were placed, ramps were constructed by dumping new ballast material at each end of the construction section. The ballast in these ramps was compacted with tampers.

The remaining ballast material was brought in by ballast cars. The cars were moved slowly over the test section and dumped the ballast directly over the track. The track was then lifted and the ballast compacted using a track mounted ballast compactor. A plan, profile and the locations of grids and geotextiles are shown in Figure [3.1]
4. GEOTEXTILE PROPERTIES AFFECTING PERFORMANCE

The function of geotextiles in a railroad track embankment has been a subject of various research projects. In this chapter, a review of the current literature about ballast-subgrade interaction and the cause of track malfunction is given. Subsequent sections present previous research projects on geotextiles performed for railroad related applications.

4.1 Rail-Ballast-Subgrade Interaction

Railroad Tracks are subjected to high magnitude cyclic and vibratory loading. The loads are transferred from the steel rails resting on cross-ties into the ballast. This ballast improves bearing capacity as well as frost protection and track and subgrade drainage. The loads however, are not distributed equally. During construction and maintenance, the ballast is compacted beneath the ties and below each rail with little compaction between the rails. This method inhibits center-bounding and causes non-uniform loading of the ballast resulting in concentrated loads under each rail. (Newby,[22]). This load distribution obviously provides an increased stability.

As described previously, excessive settlements may occur in areas of silty or clayey subsoil and in the presence of water. Under such conditions, the high, dynamic, concentrated loads cause high pore pressure development in
the region of the interface between ballast and subgrade. These pore pressures build up very rapidly and tend to dissipate upwards into the more permeable ballast material. This causes relatively high water velocities, which may cause migration of small soil particles. (Newby,[22]). This is an irreversible process. The particles transported do not return when the load is released. Therefore repeated loading causes an increasing amount of particles to migrate into the ballast, translocating the ballast subgrade interface.[3,6]. The fines then reduce the hydraulic conductivity of the ballast resulting in a lower rate of dissipation of the excess pore pressures. The high pore pressures may cause the effective stresses in the subgrade to decrease, reducing their bearing capacity. Hence, the ballast, and with it the whole track structure may subside as shown in Figure [4.1]. Often a lateral spreading is found with this behavior. The plastic progressive deformations of this type are a common phenomenon known as "pumping track". If the fine materials propagate up to the top of the track the ballast is completely fouled. The penetration of fines into the ballast is often referred to as pollution or contamination.

To improve performance, several measures have to be taken. The ballast should be separated from the subsoil. Accumulated water or water generated from dissipation of excess pore pressures should pass across the interface with
Fig. 4.1] Typical Sections with and without Geotextiles

after [22]
as little interference as possible. The water should then be drained from the area. The lateral spreading should be resisted and the concentrated loads should be spread over a larger area.

4.1.1 Granular Filter Layer

A granular filter layer was placed between ballast and subgrade in the original construction. This layer improved performance of the embankment by separating the ballast from the subsoil, providing drainage and pore pressure dissipation during dynamic loading.

4.2 Function of Geotextiles in a Railroad Track Embankment

The use of geotextiles in a railroad track has proven to have certain advantages over a granular filter. These advantages are as follows:

1) A geotextile is more cost effective with regard to material and installation cost (Raymond,[24],Chrismer,[5]);

2) A geotextile, due to its planar structure, is capable of providing tension reinforcement and resistance to forces causing lateral spreading of the embankment;

3) A geotextile may reduce differential settlements and reduce maintenance intervals;
The longterm performance of geotextiles in a railroad embankment should be evaluated. It should improve the drainage capacity of the embankment and provide dissipation of excess pore pressures caused by high dynamic stresses, therefore reduce the softening of the subgrade soils.

It is important that the geotextile provide long term filtration and resistance to clogging. In addition, the geotextile should resist abrasion and should be resistant to creep deformations.

As stated previously a geotextile placed at the interface of ballast and subgrade has to provide (Fluet,[8]):

1) Reinforcement;
2) Separation;
3) Filtration; and
4) Drainage.

An overview over the functions and related properties is given in Figure [4.2].
<table>
<thead>
<tr>
<th>Classical function</th>
<th>Railroad function</th>
<th>Relevant geosynthetic properties*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>Transmits water from precipitation and/or pumping through plane of geosynthetic to edge of track</td>
<td>Transmissivity (the product of lateral permeability and thickness)</td>
</tr>
<tr>
<td>Filtration</td>
<td>Allows passage of water pumped from subgrade while retaining fines in subgrade</td>
<td>Permeability, Retention characteristics, Clogging resistance</td>
</tr>
<tr>
<td>Separation</td>
<td>Acts as a barrier and prevents intermixing of ballast and subballast/subgrade</td>
<td>Retention characteristics, Resistance to concentrated stresses (i.e. tear, puncture, burst)</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Reinforces ballast, may reinforce subgrade and track</td>
<td>Geosynthetic soil/ballast interaction, Tensile modulus, Tensile strength, Accommodation</td>
</tr>
</tbody>
</table>

*Durability properties are abrasion, puncture and cutting resistances.

**Fig. [4.2]** Functions and Related Properties of Geosynthetics, after [9]
4.2.1 Reinforcement

Especially over soft subsoil, the ballast in the interface region to the subgrade tends to spread laterally and causing vertical track subsidence. A geotextile as a tensile member in the track can reduce this spreading behavior and reduce settlements. The load is distributed over a larger area resulting in a more uniform loading of the subgrade. Tests run by Yasuhara et al. [37] using geotextiles over soft clays showed a significant reduction in total settlement. Figure [4.1] shows the reinforcing action that is provided by a geotextile. As the track subsides, the geotextile deforms with the ballast, forming a bulge under each rail. The geotextile is stretched resulting in an increase in the tension force mobilized in the geotextile.

Small scale laboratory analyses conducted by Saxena [29] and Friedli [10] were performed on various soil-ballast-geotextile composites. The soil used was a sandy clay with about 50% silt fraction. The samples were tested in triaxial cells. The setup and the results are shown in Figures [4.3]-[4.5]. The results show a clear increase in shear strength for a soil-geotextile-ballast sample as compared to tests performed on soil or on soil-ballast.

Dynamic Ko tests, performed by the same authors on similar samples, revealed smaller deformations and a smaller
decrease in resilient modulus for soil-geotextile-ballast samples than for soil-ballast samples.

Friedli [10] performed dynamic triaxial tests on similar samples. Results and setup are shown in Fig.[4.6]-[4.8]. It can be seen that as opposed to the soil-ballast tests, all tests incorporating geotextiles showed lower plastic strains and a flattening of the accumulated strain vs. load application curve over time. These tests, performed on relatively small samples, demonstrate the reinforcing action that is provided by a geotextile even over a short distance. Every grain of the ballast deforms the geotextiles resulting in high localized or micro strains. Reinforcement provides resistance to the spreading action of a track on soft ground.

4.2.2 Separation and Filtration

One of the most important functions of a geotextile in a subgrade is to separate the ballast from the subsoil. As explained previously, the main cause of track malfunction is contamination or fouling of the ballast. In addition to separation the geotextile must also promote the development of a transitional filter in the soil which reduces soil particle migration while allowing excess pore pressures to dissipate. Research has shown that conventional geometrical filter criteria do not apply to geotextiles. Bell et al.[3] show in Figure [4.14] that no clear relationship between
clay contamination and the $D_{50}$ opening size of a geotextile can be established.

When a geotextile is placed against a soil and water is forced to flow from the soil through the geotextile, a complex particle migration process is initiated. In the zone next to the geotextile, the very fine soil particles move with the water in and through the geotextile. Larger particles that do not fit through the geotextile openings are retained and reoriented. They bridge the openings of the geotextile creating a soil filter with smaller openings than the geotextile. This soil filter retains smaller soil particles which are slightly larger than the openings, which creates a soil filter with smaller openings. This action continues until a state of equilibrium is reached. The zone between the undisturbed soil and the geotextile is called transition-filter or filter-cake shown in Figure [4.10].

This process is influenced by many factors such as soil type, its state of stress and stress history, gradation, loading condition, geotextile geometry and clogging susceptibility. Once the filter-cake is formed and the equilibrium condition is established, the flow of water through the geotextile-soil composite continues without further reduction in hydraulic conductivity. In some cases, particularly for geotextiles with low porosity, the geotextile may become clogged. This phenomenon is called "blinding" and occurs when soil particles get trapped in the
geotextile structure, preventing the fine particles from moving through. A low permeability film builds up next to the fabric and water flow is inhibited. Previous research has shown a thin layer of very fine grained slurry built up adjacent to the geotextile. This phenomenon is called slurry formation. This was investigated by Dawson [6] and also Bell [3]. Figures [4.11] and [4.12] show the model of slurry initiation and migration.

During the dynamic tests performed by Saxena [29] and Friedli [10], the filtering behavior was also evaluated. This was quantified by measuring the contamination after each test. Their results are presented in Figures [4.3]-[4.8]. Migration of fines through the geotextiles occurred in all cases. The contamination was measured by comparing gradation curves before and after each test. The amount of contamination was reduced drastically after installation of a geotextile.

Dawson [6] examined the contamination of a ballast layer over a geotextile and a fine subbase. The amount of contamination was measured as the change in transmissivity of the ballast layer. The test setup is shown in Figure [4.13]. Bell et al. [3] also performed ballast contamination tests. Granular filters as well as geotextiles were used. The equipment and results from the analyses are shown in Figure [4.14]. The contamination was measured as an increase in weight of the ballast and filter layer after each test.
Both Dawson and Bell found that slurry buildup and passage through the geotextile occurred at points of high stress concentrations. Slurry collected and passed at areas which had an open structure.

The model of slurry formation is confirmed by Martinek [20] and Wehr [33]. Both performed in-situ analyses of geotextiles installed in a track. In sections where the geotextile was used below a protective layer of gravelly sand, absolutely no slurry formation or migration was found and no fine material passed the geotextile. At sections where the geotextile was placed directly against the coarse ballast material slurry buildup was found and soil particles passed through the geotextile. The thickness of the protective layer had no influence on the performance. When ballast is placed directly against a geotextile the open structure as well as the high pressures cause high velocity flow as well as an increase in pore pressures, reduction of strength and slurry formation. Bell [3] and Hoare [12] performed porewater pressure measurements during the dynamic loading tests close to the fabric. Figure [4.14] shows the results of Bell and indicates that a high amount of fouling is found with a short pore pressure dissipation rate, while low fouling was found with long dissipation rates. Short dissipation time means high water velocities causing more fouling. On the other hand, dissipation of pore pressures over time during a dynamic loading test and the dependence
of slurry migration on it suggests that the rate of migration is reduced with time, reaching an equilibrium condition as pore pressures dissipate totally. This is confirmed by the results of Hoare as shown in Figure [4.9].

These findings were also confirmed by an extensive testing program at Caldwell, Texas. A heavily instrumented geotextile reinforced railroad track embankment with soil-moisture gages, pore water pressure transducers and extensometers was built. Ballast contamination was measured as clay content in the ballast material vs. sampling depth. (Figure [4.15]). Transmissivity and permittivity tests were performed on samples retrieved from the track. Compared to tests on new samples, a significant decrease was found for both tests as shown in Figure [4.16]. It was found that even on a firm subsoil a geotextile provides reinforcement. Filtration and separation is provided, but not all soil can be retained by the fabrics. Moisture transport was not observed in the fabrics. The failure of a section containing a heatbonded fabric demonstrates the effect of clogging. Accumulation of water and excessive pore pressures caused a softening of the subgrade and excessive settlements. Werner [37] performed puncture tests using a modified CBR-device shown in Figure [4.21]. Different deformation geometries shown in Figures [4.17] to [4.19] are presented and are compared to the actual field situation. A chart relating the average grain diameter and surcharge to a
puncture resistance is shown in Figure [4.20].

4.2.3. Drainage

Precipitation which infiltrates through the embankment and ground water discharged from the subgrade soil should be drained from the ballast/subgrade soil interface or reduction in the shear strength of the soil will result. This drainage occurs directly by in-plane transport in the geotextile or indirectly by providing separation and inhibiting contamination, so maintaining hydraulic conductivity of the ballast layer over the geotextile. The drainage is therefore a function of the ability of a geotextile to conduct water in its plane and to provide sufficient contamination protection. Analyses simulating drainage through the ballast layer were performed by Dawson [6]. The equipment is shown in Figure [4.13]. The drainage of the geotextile was found to be important also on a smaller scale. Newby [22] found that a thick geotextile subjected to dynamic loads is squeezed cyclically, pressing out water from points of higher stress.
Procedure of Preparing Triaxial Soil-Fabric-Ballast Samples

(1) Compact soil portion.
(2) Remove split mold and membrane.
(3) Place fabric sheet.
(4) Reset membrane and split mold.
(5) Compact Ballast.
(6) Remove split mold, place second and third membranes and top platten.

Typical Soil-Fabric-Ballast Specimen

Fig.[4.3] Sample and Sample Preparation Procedure in [29]
Fig.[4.4] Results of triaxial tests conducted by [29]
Rebounds and Permanent Deformations of Soil-Ballast and Soil-Fabric-Ballast Samples after 300,000 Cyclic Loadings (t = 100 min)

Soil-Ballast
Soil-Fabric-Ballast (Monsanto C-34)
Soil-Fabric-Ballast (Celanese 600 X)

Fig. [4.5] Results dynamic tests performed by [29]
**TEST CASE SUMMARY**

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>TEST NO.</th>
<th>TEST CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>1</td>
<td>BASE COARSE/GEOTEXTILE 1/SAND/SILT</td>
</tr>
<tr>
<td>☐</td>
<td>2</td>
<td>BASE COARSE/GEOTEXTILE 2/SAND/SILT</td>
</tr>
<tr>
<td>O</td>
<td>3</td>
<td>BASE COARSE/GEOTEXTILE 1/SILT</td>
</tr>
<tr>
<td>☐</td>
<td>4</td>
<td>BASE COARSE/GEOTEXTILE 2/SILT</td>
</tr>
<tr>
<td>☐</td>
<td>5</td>
<td>BASE COARSE/GEOTEXTILE 2/SILT</td>
</tr>
<tr>
<td>△</td>
<td>6</td>
<td>BASE COARSE/SILT</td>
</tr>
</tbody>
</table>

**Fig.[4.6]** Test Setup Summary and Results presented in [10]
Fig. [4.7] Cross-section of triaxial test specimen in [10] used for dynamic tests.

Fig. [4.8] Typical Wave Form of Loading applied in [10].

Fig. [4.9] Test Setup and Results Presented in [7].

Dissipation of Mean Excess Pore Water Pressure with Time.
Fig.[4.10] Formation of Soil Filter. [1]

b. Road trafficked. Subgrade overstressed locally beneath stones. Slurry generated which moves to empty low stress areas between stones.

c. After several load cycles. Pore filled with slurry.

d. Road trafficked. Lateral stresses reduced due to tensile strains induced by loading. Pressure of slurry sufficient to allow it to pass upwards. When load removed, stones move together ejecting slurry.

e. After more load cycles. Stones coated with slurry. Pores filled.

Fig.[4.11] Mechanisms of Slurry Migration,[6]

a. Load spreading hinders slurry formation.

b. Filtering action hinders movements of fines.

c. Restraint of individual aggregate particles.

Fig.[4.12] Fabric Influence in Slurry Formation and Migration,[6]

Fig.[4.13] Test Setup in [6]
Fig. 5

Influence of subgrade moisture content on contamination

Fig. 4.14 Test Setup and Results by [3]
Fig. 4.15 Percentage of Clay in Total Weight vs. Sampling Depth in [5]
Permeability of Recovered Fabrics

In-Plane Permeability

In-Plane Permeability of Geotextiles Recovered From the Field and Tested at a Pressure of 3.4 psi, Applied Normal to the Surface.

Normal Permeability — Falling Head Test

In-Plane Permeability of Geotextiles Recovered From the Field and Tested at a Pressure of 10 psi, Applied Normal to the Surface.

Fig. [4.16] Test Results Presented in [5]
Fig. [4.17] Puncturing of Geotextiles after [34]

1) abgerundete, stumpfe Schüttmaterialien

Durchstanzebeanspruchung: nicht vorhanden

Berstbeanspruchung: \( d_B = d_m^2 - \frac{d_m}{n} \)

wobei

\( d_B = \) effektiver Berstdruckdurchmesser

\( d_m = \) mittlerer Gesteinsdurchmesser Rundkorn

II) scharfkantige, spitze Schüttmaterialien

Durchstanzebeanspruchung: \( d_B = d_m \)

Berstbeanspruchung: \( d_B = d_m \)

wobei

\( d_B = \) effektiver Durchstanzdurchmesser

\( d_m = \) mittlerer Gesteinsdurchmesser Kantkorn

Fig. [4.18] Perforating Action on a Geotextile after [34]

Fig. [4.20] Chart to Determine the Perforation Resistance after [34]

Fig. [4.21] Modified CBR-Test for Puncture Test after [34]
4.3 Geotextile Properties

As mentioned previously, the performance of a geotextile is a function of various properties shown in Figure [4.2]. Those that are believed to be relevant for the application in a railroad track are listed together with a description of the testing methods used in this research program.

The reinforcing performance of a geotextile can be evaluated by observing the track geometry over time. Laboratory tests performed on retrieved samples from the track provide a comparison of tensile strengths, moduli and elongations. Excavations show the amount of micro or localized strain. In-situ strain measurements allow to determine the amount of movement and provide an estimate of the tensile stress in the geotextiles. Direct shear tests allow the measurement of the frictional behavior of the geotextiles. The filtration/separation behavior can be determined by measuring the hydraulic properties of the geotextiles over time. Permittivity as well as transmissivity may provide an indication of the change in performance with time. The measurement of the hydraulic conductivity ratio may show the filtering and clogging characteristics of a geotextile. Resistance to mechanical attack or abrasion can be assessed by measuring the tensile, tearing and puncture resistance over time. Abrasion may also be evaluated visually.
The drainage may be evaluated by transmissivity tests and contamination control tests mentioned in the filtration/separation section.

1) The tensile properties like strength, elongation and modulus of a geotextile may be evaluated using a wide strip tensile test. The properties should be obtained in the machine and cross direction.

2) The resistance to concentrated stress and abrasion may be obtained with a puncture test and a trapezoidal tearing test. Visual inspection of exposed and retrieved samples may also be included.

3) The geosynthetic soil/ballast interaction may be evaluated using a direct shear test as design test, performed on geotextile samples between old and new ballast layers. Accommodation of geotextiles may be evaluated visually.

4) The permittivity of a geotextile may be evaluated using the constant head permittivity test.

5) The transmissivity of a geotextile may be evaluated using a transmissivity test. This transmissivity test can be performed as index test on a single geotextile sample and also as design test on a geotextile embedded in two layers of ballast.

6) The filtration, retention and clogging
characteristics of a geotextile may be evaluated using a hydraulic conductivity ratio test.

Index tests like the wide strip test, the puncture and trapezoid tearing tests, the permittivity and transmissivity tests should be performed on new and on old, retrieved geotextile samples. This provides a baseline for comparison of the properties over time.
5. THE TESTING PROGRAM

The testing program outlined in the introduction is presented in detail in this chapter. The geotextile testing procedures and equipment as well as the ballast tests and results are presented in this chapter.

5.1 Baseline and In-Service Geotextile Testing

A summary of the geotextile testing program for the research project is shown in Table [5.1]. Due to the large number of analyses and requirement for timely analyses, an automated data acquisition system was utilized. The data acquisition system consisted of a personal computer (PC) with an internal A/D board. Software was developed to obtain the digital output from the A/D board, store the data on diskettes, and plot the data in a format which could be utilized in the report. Descriptions of the methodology used for the analyses are described below.
Table [5.1] Summary of Geotextile Testing Program

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Baseline Testing</th>
<th>In-Service Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Strip Test</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Trapezoidal Tear</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Modified Direct Shear</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Puncture</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Permittivity</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Transmissivity</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hydraulic Conductivity Ratio</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>In-Situ Strain</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

5.1.1 The Wide Strip Tensile Test

The wide strip tensile test is used as a design or index test to evaluate the stress-strain behavior, tensile strength, modulus and elongation of geotextiles or other geosynthetics. A geotextile specimen is tensioned until failure occurs. The load and displacement between discrete points on the specimen are recorded as a function of the elapsed time. The load, divided by the initial width, and the displacement, divided by the initial distance between the discrete points on the specimen give the values of tensile stress and strain respectively. This transformation is performed by an EDAS, (Electronic Data Acquisition System) providing a continuous readout. The analysis is performed at a constant rate of deformation of about 10mm/min.
5.1.1.1 The Wide Strip Tension Device

The wide strip tension device consists of two wedge clamps as shown in Figure [5.1]. The clamps consist of a threaded rod (A), which is connected to the testing machine, a leveling plate (B), and 4 vertical rods (C) providing a fine leveling adjustment of the device. Two aluminum blocks (D), which are bolted with 4 threaded rods (E) contain the two steel wedges (F). These wedges may be tightened against the specimen by tightening the bolts (G). The device designed for this research project is capable of performing the clamping in different ways:

- Steel Wedges;
- Epoxy Wedges with the geotextile cast in them;
- Roller Wedges with the geotextile wrapped around them;
and
- Use without any wedges for low load applications.

In this research project, the required loads were relatively low. Therefore the steel clamps provided adequate support without risk of pullout from the clamp and the fastest sample installation. The upper threaded rod was connected to a load cell. Both clamping blocks were installed in a tension testing machine of sufficient capacity and displacement control. The strain measurement was performed directly on the geotextile
The On Sample Strain Measuring Device, OSSMD, consisted of two plexiglass bars, attached to the specimen by punching two small nails through the sample. The disturbance of the specimen by the nails was minimal and no failure due to these small holes in the specimen was observed during the testing program. These nails provide an exact and constant location of the discrete points on the sample throughout the course of the test. Figures [5.2] and [5.3] show the assembly of the plexiglass bars. LVDT's were attached to the ends of the bars to monitor the relative displacements between the bars.

5.5.5.2 Electronic Data Acquisition System

A schematic of the Electronic Data Acquisition System is shown in Figure [5.4]. The system consists of two regulated power supplies, a signal amplifier, Tecmar-Labpac and an IBM personal computer. The excitation for both the load cell and the LVDT's is provided by separate regulated power supplies. The voltage output of the LVDT's can be input directly into the TECMAR daughter-board, while the voltage from the load cell must be amplified prior to input. The daughter-board primarily consists of an A/D converter that converts the analog signal from the device into digital code which is appropriate for storage on a diskette. This digital signal is transported to the motherboard. The
program TESTWS.BAS accesses the digital data and converts the data to engineering units. (Appendix I.1).

The maximum sampling rate is about 10 readings per second, ensuring that peak values for the stress are obtained. The so obtained values of displacement and load, together with the initial test data input previously, are stored on an output file. These data are accessed later by the program REDUCWS.EXE which calculates the values of stress and strain, evaluates the maximum value of stress, reduces the number of data points and produces a printout. This program also creates a data file containing stress-strain data which may be accessed by the MICROSOFT-CHART program to produce a plot of the data.

5.1.1.3 Methodology

The geotextile specimens were trimmed to sample dimensions of about 9.25 inches by 20 inches. The edges which are parallel to the direction of elongation were very carefully trimmed to reduce the possibility of developing stress concentrations. Even small stress concentrations can induce premature failure. The specimens which were retrieved from the field were air dried and the soil was removed in the clamping areas. The clamps were positioned at an initial distance of 7 inches from each other and the specimen was placed between the clamps. Small pieces of geotextile were placed in the clamps between the test
specimen and the wedges to reduce the prospect of developing stress concentrations in the wedges. The 4 outer rods (E) and 6 inner bolts (G) were tightened so that the wedges were pressed against the specimen. The same procedure was repeated for the lower clamp.

Once the sample was placed, it was pretensioned to 5 lbs. This ensured sufficient stiffness to place the OSSMD. The two bars of the OSSMD were placed on the sample and fixed by punching the nails through the textile and securing them with a cork on the back side. The cores of the LVDT's were then placed in the OSSMD. Measurements of sample width, load and distance between the discrete points on the geotextile were obtained. The program TESTWS.BAS was invoked and the initial measurements of sample width and average distance of the discrete points was input. Then the analysis was started by starting the testing machine and setting the program on reading mode simultaneously. The analysis was continued until failure occurred. The testing machine and the program were stopped, the failure mode was recorded and the geotextile was removed from the clamps.
Fig. E5.13  Assembly of Clamp for the Wide Strip Tensile Test
Fig. 5.21  Installation of the
On-Sample-Strain-Measuring-Device
(OSSMD)
**Fig. [5.3] Upper and Lower Bars of the OSSMD**

- **Hose Clamp**
- **Plexiglass Bar**
- **Corks**
- **Nails**

**Upper Part**

**Lower Part**
**LVDT 1**  
**LVDT 2:** LINEAR VARIABLE DISPLACEMENT TRANSDUCER  

**LC:** LOAD CELL  
**PS:** POWER SUPPLY  
**SAMP:** SIGNAL AMPLIFIER  
**DB:** TECHMAK DAUGHTER BOARD  
**MB:** TECHMAK MOTHER BOARD  
**PC:** PERSONAL COMPUTER

*Fig. [5.4] Setup of the Electronic Data Acquisition System for the Wide Strip Tensile Test*
5.1.2 The Trapezoidal Tear Test

The trapezoidal tear test is an index test which is used to determine the tearing-extension behavior of geotextiles. The geotextile to be tested is placed in the clamps in a tensile testing machine. During the test tension is produced along a defined course, causing tear across the width of the specimen. The force and clamp separation are recorded. The peak force gives the trapezoid tearing resistance.

5.1.2.1 Equipment

The trapezoidal tear test is performed using the wide strip tension clamps and tension machine. The tearing force and clamp displacement were recorded via a load cell and an electronic data acquisition system. The general test configuration and data recording system are presented in Figures [5.5] and [5.6].

5.1.2.2 Methodology

The tests were run according to the ASTM D-4533 standard procedures with the following exceptions. A 3 inch by 8 inch sample was obtained and prepared. Soil was removed from the geotextile in the clamp areas, a 9/16 inch cut was made in the middle of one side of the sample and a template was used to mark the clamp locations (Figure [5.7]). The samples were air dried, the clamps were positioned 1 inch
apart and the geotextile was installed. The rate of displacement for the trapezoidal tear tests was adjusted to 11.5 cm/min.

The testing machine and the program TESTTRT.BAS were started simultaneously. The test was conducted until the tear propagated through the entire width of the sample. Upon rupture, the tension testing machine and the program were stopped and the sample was removed from the clamps.
Fig.[5.5]  Setup of the Electronic Data Acquisition System for the Trapezoidal Tear Test

LC: LOAD CELL
PS: POWER SUPPLY
SAMP: SIGNAL AMPLIFIER
DB: TEC MAR DAUGHTER BOARD
MB: TEC MAR MOTHER BOARD
PC: PERSONAL COMPUTER
Fig. 5.6 Clamping Method for the Trapezoid Tearing Test
Fig. [5.7] Trapezoid Template for the Trapezoid Tearing Test
5.1.3 Modified Direct Shear Test

The modified direct shear test is a design test used to evaluate the interface friction properties between soil and the geotextiles. The geotextile sample is placed between two layers of compacted soil. The top soil layer is displaced laterally relative to the geosynthetic at three confining stresses. The horizontal force and the horizontal displacement are recorded as a function of time.

5.1.3.1 Apparatus and Equipment

The modified direct shear device is shown in Figure [5.8]. The normal load is applied by a pneumatic piston mounted on linear ball bushings, a yoke and load cell. The horizontal shear force is applied by a horizontal piston and a loadframe guided by linear ball bushings. The shear box consists of two 2-inch high, 12 inch by 12 inch frames that accommodate the soil layers and the geotextile sample. The control mechanism makes it possible to run either stress control or displacement control tests. The signals from both horizontal and vertical load cells are input into an electronic data acquisition device that provides calibrated output. The horizontal movement of the shearbox is measured with a dial indicator.
5.1.3.2 Test Parameters

Parameters of this test are summarized as follows:

- Sample Size 12" x 12"
- Displacement rate 3 mm/min
- Normal Stresses 100, 250, 500 psf

5.1.3.3 Methodology

This test was only run during the baseline testing program on new geotextile samples against "new" and "fouled" ballast. Only the portion of ballast passing the 1/2 inch sieve was used. The soil was compacted at its optimum water content into a 2-inch-layer in the lower box. The geotextile was placed on top of the ballast, the upper box placed above the geotextile and the top ballast layer compacted on the geotextile. The upper box was then connected to the load frame, the normal load was applied and the horizontal displacement rate was adjusted using a needle valve. At certain time intervals, readings of horizontal displacement and shear force were recorded as a function of the elapsed time. Readings were taken until a significant peak in the shear force was detected.

5.1.3.4 Data Reduction and Presentation

The readings of time, displacement, shear and normal load were input into the program FRIC.FOR. The program calculated the values of shear and normal stress. These data
were stored on diskette and later accessed by the Microsoft Chart program. The peak shear stress was plot as a function of the corresponding normal stress. The slope of the shear stress versus normal stress curve was the interface friction angle and the intercept at zero normal stress was the adhesion as shown in a sample plot in Figure [5.8].
Fig. [5.8a] Direct Shear Device at GA-TECH

Fig. [5.8b] Shear Box with Soil Layers and Geosynthetic Specimen

Fig. [5.8c] Sample Plot of Results
5.1.4 Puncture Test

The Puncture test is an index test which is used to determine the puncture strength of geotextiles. A piston of specific size and shape is projected at a constant rate of deformation through a sample secured in a ring clamp attachment. The piston force required to induce puncture and elapsed time are recorded.

5.1.4.1 Equipment

The puncture device used for the testing program is shown in Figure [5.9]. The tip of the piston has a diameter of \( \frac{9}{16} \) inches and a \( \frac{1}{32} \)-inch x 45° chamfer. The ring clamp attachment consists of two circular plates with an inner opening of 1.75 inches. Six bolts are used to tighten the plates against the sample. The inner clamping surfaces consist of sandpaper bonded onto the steel to prevent sample slippage during the test. The ring clamps rest on a vertical cylinder secured in a loading apparatus. The loading apparatus displaces the piston at a constant rate of displacement relative to the geotextile.

The piston load is measured using a load cell attached to the piston. The test data are recorded using an electronic data acquisition system shown in Figure [5.10].
5.1.4.2 Data Acquisition

The voltage from the load cell is amplified and sampled by the daughter board at a specified rate. The program TESTPT.BAS converts the signal from volts to pounds, records the elapsed time, and stores these data in an output file on a diskette. The sampling rate which is used in these analyses is 15 samples per second.

5.1.4.3 Sample Preparation

To obtain a reliable estimate of the variation, four samples of each geotextile were tested during the baseline testing program and two samples were tested during the in-service testing program. The samples were cleaned by removing the soil from the sample surface. The samples were air dried and the bolt holes cut prior to testing.

5.1.4.4 Methodology

The sample was placed between the plates of the ring clamp attachment. The six bolts were tightened and the clamps with the specimen were placed on the cylinder in the testing machine. The piston was positioned adjacent to the center of the sample and the rate of deformation of the piston was adjusted to about 11.5 cm/min. The program TESTPT.BAS was installed on the computer and started simultaneously with the test. The test was terminated upon
rupture of the sample. The data were recorded on diskette and the sample was removed from the clamp.

5.1.4.5 Data Reduction

The output file created by the program TESTPT.BAS can be accessed by the REDUCPT.EXE program which reduces the number of datapoints to about 100, detects the peak value of the piston force, and produces a printout of the results. The data file created by the REDUCPT.EXE program containing the data is then accessed by the MICROSOFT.CHART software to plot the results.
Fig. [5.9] Ring Clamp Assembly and Detail of the Piston for the Puncture Test
Fig.[5.10] Setup of the Electronic Data Acquisition System for the Puncture Test.

LG: LOAD CELL
PS: POWER SUPPLY
SAMP: SIGNAL AMPLIFIER
DB: TECHMAR DAUGHTER BOARD
MB: TECHMAR MOTHER BOARD
PC: PERSONAL COMPUTER
5.1.5 The Permittivity Test

The permittivity test is an index test which is used to evaluate the permittivity of a geotextile. The permittivity is an expression of the volumetric flow rate of water, per unit cross sectional area, per unit head through a geotextile. After sampling and conditioning, a geotextile sample is placed in a column device and deaired water is percolated through the geotextile under a constant hydraulic head. These tests were performed according to ASTM D4491 procedures for constant head permittivity tests.

5.1.5.1 Apparatus and Equipment

The apparatus consists of the column device, a reservoir with appropriate connecting hoses, a vacuum pump and a deaired water supply. The column device consists of an upper part and a lower part installed in a larger diameter cylinder (Figure [5.11]).

A cylindrical weir is used to control the height of water above the geotextile. The lower column is filled with water up to the rim. The sample is placed between the flanges of the columns with an o-ring. As the bolts are tightened, the o-ring as well as the geotextile are compressed. The o-ring prevents leakage, and the compressed part of the geotextile prevents short-circuiting. The thickness of the o-ring has to match the geotextile thickness. The constant head is adjusted by regulating the flow from the reservoir. Deaired
water is used to eliminate the influence of air accumulating on the bottom sample surface.

5.1.5.2 Sample Preparation

In order to develop a statistical base for the permittivity analyses, five tests were performed on each of five samples. These analyses provided a baseline for the permittivity of the geotextiles. The in-service testing consisted of five tests performed on each of two samples of each geotextile. Samples of appropriate diameter were obtained and soaked 24 hours in deaired water. Special care was taken with the in-service samples to avoid removing the fine particles of soil in the geotextile structure.

5.1.5.3 Methodology

The lower column was filled to the rim with water. Then the geotextile sample with o-ring and the upper column were placed on top of the lower column and bolted into position. The sample was then inundated and the geotextile surface freed from any trapped air using the vacuum pump and a tube inserted into the column. The connecting hoses to the water reservoir were attached and the water flow adjusted so that a 50 mm head was maintained during the test. Measurements of the volumetric flow and temperature were obtained as a function of time. During the baseline testing the water was recycled, while during the in-service testing
new water was used for each analysis.

5.1.5.4 Data Reduction

The permittivity of the geotextile is calculated using the following equation:

\[ \bar{\varepsilon} = \frac{Q R_e}{h A t} \]

where:

- \( \bar{\varepsilon} \) = permittivity [sec\(^{-1}\)];
- \( Q \) = quantity of flow, [mm\(^3\)];
- \( h \) = head of water on the specimen, [mm];
- \( A \) = cross sectional area of specimen, [mm\(^2\)];
- \( t \) = time for flow \( Q \) [sec]; and,
- \( R_e \) = temperature correction factor.

\[ R_e = \frac{u_e}{u_{20\circ}} \]

where:

- \( u_e \) = water viscosity at test temperature, [millipoises];

and,

- \( u_{20\circ} \) = water viscosity at 20°C, [millipoises].

The permittivities were calculated using program PERM.BAS. The values for each test on the same specimen were averaged. The average of the values for each specimen was used to evaluate the permittivity of the geotextile.
Fig. [5.11] Schematic of the Permittivity Test Apparatus at Georgia TECH

- Reservoir
- Upper Part
- Sample
- Lower Part
- Outflow Cylinder
- O Rings
- Column Device
5.1.6 Transmissivity Test

The transmissivity test is used to evaluate the hydraulic transmissivity of geosynthetics. The hydraulic transmissivity is the measure of the inplane conductance of a geosynthetic per unit width. Under laminar flow conditions the hydraulic transmissivity may be evaluated using a modified form of the Darcy equation,

\[ q = K i B T \]

Where, \( q \) is the flowrate through the specimen [L^3t^{-1}], \( i \) is the hydraulic gradient [L/L], \( B \) is the width of the specimen [L], \( T \) is the thickness of the specimen [L] and \( K \) is the hydraulic conductivity for planar flow [Lt^{-1}]. The product of the hydraulic conductivity and saturated thickness of the specimen is the hydraulic transmissivity,

\[ \Theta = K T \]

Combining these two equations gives

\[ q = \Theta i B \]

The transmissivity test may be either an index test or a design test depending on the boundary conditions used in the analysis. When a sample is placed between two layers of soil the test can be considered a design test. For this research project the transmissivity of the geotextiles was measured between two aluminum plates. Since the boundary conditions from the test did not model field conditions, the transmissivity analyses for this research program should be
considered index test values.

The hydraulic transmissivity of thick nonwoven geotextiles is primarily a function of the confining stress, the hydraulic gradient and the duration of the load. Increasing the confining stress decreases the porosity of the geotextile which results in a decrease in hydraulic transmissivity.

5.1.6.2 Apparatus and Equipment

The hydraulic transmissivity of a geosynthetic is measured in a transmissivity device, as shown in Figure [5.12]. It consists of a horizontal flow channel, a loading box and a inflow reservoir. An outflow reservoir with a pump and water storage tanks close the flow loop. A loading apparatus is used to apply loads perpendicular to the direction of flow.

5.1.6.3 Methodology

The geotextile sample was placed into the horizontal flow channel and the edges parallel to the direction of flow were sealed with silicon RTV sealant. The load box was inserted and sealed against the vertical column and the sides of the flow channel using silicon sealant. This ensured that no leakage occurred and the water only flowed through the sample.

After letting the sealant set for about 4 hours and
saturating the sample the test was started. The device was connected to the storage tanks and the vertical load was applied. The inflow reservoir was filled to an initial height $H_1$, and readings of the height as a function of time were obtained. The temperature, height of the water in the outflow and the sample deformation were also recorded. Following completion of a test at a given confining stress, the confining stress was increased, the inflow reservoir refilled, and another test initiated.

The water used in the analyses was pretreated with chlorox to prevent biological growth in the samples which may influence the test results.

5.1.6.4 Data Reduction and Interpretation

The mathematical expression for the hydraulic transmissivity at a temperature $T$ is:

$$
\Theta_T = \frac{A_o L}{B(t_2-t_1)} \ln \left( \frac{H_1 - H_o}{H_2 - H_o} \right)
$$

Where $\Theta_T$ is the hydraulic transmissivity at temperature $T$ [L^2T^{-1}], $A_o$ is the cross-directional area of the inflow reservoir [L^2], $L$ is the sample length [L], $B$ is the sample width [L], $t_1$ and $t_2$ are the times at which water levels are measured [t], $H_1$ and $H_2$ are the water levels in the inflow reservoir at times $t_1$ and $t_2$ respectively [L], and $H_o$ is the water level at the outfall weir [L].

The hydraulic transmissivity of the drainage layer is
typically normalized to water at a temperature of 20 °C using the following equation:

\[
\Theta_{20} = \frac{\rho_{20}}{\rho_T} \frac{\mu_T}{\mu_{20}} \Theta_T
\]

Where \( \rho_{20} \) is the equivalent hydraulic transmissivity at a temperature of 20 °C \([\text{L}^2\text{t}^{-1}]\), \( \rho_{20} \) is the fluid density at 20 °C \([\text{ML}^{-3}]\), \( \rho_T \) is the fluid density at a temperature \( T \) \([\text{ML}^{-3}]\), \( \mu_{20} \) is the fluid viscosity at 20 °C \([\text{L}^2\text{t}^{-1}]\) and \( \mu_T \) is the fluid viscosity at a temperature \( T \) \([\text{L}^2\text{t}^{-1}]\).

The results of the transmissivity analyses are typically presented graphically as normalized transmissivity, \( \Theta_{20} \) versus hydraulic gradient, \( i \) for the different confining stresses.

5.1.6.5 Test Parameters

The parameters used in this test program are summarized below.

- Sample Size: 12 inches by 12 inches
- Normal Stress: 1000 psf and 5000 psf
- Hydraulic Gradients: 1.0, 0.5, and 0.25
Fig. 5.12: Schematic of the Transmissivity Test Apparatus at Georgia Tech
5.1.7 Hydraulic Conductivity Ratio Test

The hydraulic conductivity ratio test (HCR-test) is a test to evaluate the filtering and clogging behavior of a geotextile. The filtering behavior of a geotextile is governed by the properties of both the geotextile and the soil. The hydraulic conductivities of the "fouled" ballast alone and of the "fouled" ballast/geotextile composite are compared. The ratio of these values is the hydraulic conductivity ratio. The tests are performed in triaxial permeability devices which provide control of the state of stress, stress history, void ratio and drainage conditions of the composite.

5.1.7.1 Equipment

The triaxial permeability apparatus used for the research is shown schematically in Figure [5.13]. The device is identical to conventional triaxial devices utilized in many soil testing laboratories.

5.1.7.2 Methodology

A 7.3-cm diameter by 7.5-cm high sample of fouled ballast was prepared by compacting the portion of ballast passing the 1/2 inch sieve at the optimum water content to the maximum dry density (ASTM D1557). The sample was placed in the triaxial cell, sealed inside using double latex membranes and saturated. The soil was the consolidated under
isotropic condition for 24 hours. When 100% consolidation for the given isotropic pressure was reached, the permeability tests were begun. The hydraulic conductivity of the soil was measured several times until about 1 to 2 pore volumes of water were passed through the sample. (A pore volume represents the volume of the pore space in a sample). The triaxial cell was then opened and a geotextile was placed at the downgradient end of the soil. The composite sample was again saturated and consolidated at an effective stress of 10 psi. Following consolidation, the hydraulic conductivity of the composite was measured several times until the hydraulic conductivity did not change as a function of the volume of flow. The analyses were performed at a hydraulic gradient of 20.

5.1.7.3 Data Reduction and Presentation

The hydraulic conductivity is calculated as follows:

\[ k = \frac{a L}{2 A t} \ln \left( \frac{H_1}{H_2} \right) \]

where:

- \( k \) = Hydraulic conductivity [cm/sec];
- \( a \) = cross sectional area of reservoirs [cm²];
- \( L \) = sample length [cm];
- \( A \) = cross sectional area of sample [cm²];
- \( t \) = time [sec]; and,
- \( H_1, H_2 \) = Inflow and Outflow heights [cm].
Fig. 3.13: Schematic of Permeability Test Apparatus used for the Research

Mercury Manometer

Influent Reservoir

Effluent Reservoir

3-Way Valve
Plug Valve
Needle Valve

Fig. 31: a Schematic of Permeability Test Apparatus Used in the Research

CFM: Cell Pressure Regulator
HPM: Back Pressure Regulator
HPM: High Pressure Meter

Main Cell Recharge Reservoir

Dial Guage

Cell Pressure Regulator
Back Pressure Regulator
High Pressure Regulator
5.1.8 In-Situ Strain Measurements

As part of the in-service testing program, strain measurements were carried out directly on the geotextiles. The measurements were obtained at intervals of 0, 1, 2 months after installation. Prior to installation, a strain measurement grid was installed on each geotextile. The grid consisted of tacks pushed through the geotextile and secured with epoxy on the opposite side. These tacks were installed on 3-inch centers over an area of 30 inches by 30 inches.

5.1.8.1 Methodology

The grids were located on the geotextiles below the rails. The grids were uncovered by removing four crossties. The crossties were pushed to one side of the track. The ballast above the geotextile was excavated using a backhoe. To prevent damage of the grids the last few inches of ballast were removed using a shovel and later a brush. A string template, used for the installation of the tacks, was placed over the grid and aligned at one corner and one side. Using millimeter paper, the displacement of selected points relative to original position was obtained. After the readings were obtained the template was removed, the ballast backfilled over the geotextile, the crossties attached to the rails and the ballast compacted using hand tampers.
5.1.8.2 Data Reduction and Presentation

The measurements were transferred to a lower scale grid for overview purposes. The relative displacement of 2 points divided by the initial distance yielded the strain occurring between these two points. Measurements in the Track Direction (TD) and in the Cross Direction (CD) were taken. The results were divided up into three categories.

- **Global Strain:** Over an initial distance of 21" - 30"
  
  Category G

- **Intermediate**
  
  Strain: Over an initial distance of 12" - 18"
  
  Category I

- **Local Strain:** Over an initial distance of 3" - 9"
  
  Category L
5.2 Ballast Testing

A summary of the ballast tests performed for the research project is given in Table [5.2]. The ballast soil tests were performed using standard procedures. Descriptions of the methodologies and summaries of the results of the analyses are presented in subsequent sections of the report.

Table [5.2] Summary of Ballast Testing Program

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Number of Tests Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Situ Density Measurement</td>
<td>2</td>
</tr>
<tr>
<td>Water Content Evaluation</td>
<td>3</td>
</tr>
<tr>
<td>Gradation Analysis</td>
<td>6</td>
</tr>
<tr>
<td>Proctor Analysis</td>
<td>2</td>
</tr>
<tr>
<td>Consolidation Test</td>
<td>1</td>
</tr>
</tbody>
</table>
5.2.1 In-Situ Density Measurements

The sand cone method was used to obtain the in-situ density of the ballast at depths of about 18 inches below the bottom of the crossties. The calibration, tests and calculations were performed following the procedures outlined in ASTM D1556. The results are summarized below.

<table>
<thead>
<tr>
<th>Location</th>
<th>Wet Density</th>
<th>Water Content</th>
<th>Dry density</th>
</tr>
</thead>
<tbody>
<tr>
<td>6+28</td>
<td>121.8</td>
<td>0.0983</td>
<td>110.9</td>
</tr>
<tr>
<td>7+22</td>
<td>129.1</td>
<td>0.1793</td>
<td>109.4</td>
</tr>
</tbody>
</table>

Table [5.3] In-Situ Densities and Water Contents

5.2.2 Water Contents

Ballast samples were obtained and placed in plastic bags. The samples were then oven dried in order to measure the in-situ water content. The laboratory analyses were performed according to ASTM-D2216. The results are shown below:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture Content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>16.7</td>
</tr>
<tr>
<td>#2</td>
<td>19.8</td>
</tr>
<tr>
<td>#3</td>
<td>17.1</td>
</tr>
</tbody>
</table>

Table [5.4] Water Contents of Fouled Ballast Samples
5.2.3 Gradation Analyses

The sieve analyses were performed according to ASTM D422. One sieve analysis was performed on new ballast material. The sample was taken from a stockpile of material which was later placed in the embankment. One sieve analysis was also performed on 1 month old ballast material. The sample was taken at the 1 month sampling period. Four sieve analyses and one hydrometer analysis were performed on samples of "fouled" ballast. The samples were taken at depths of about 18 inches below the bottom of the crosstie. The gradation curves are shown in Figures [5.14]-[5.16].

5.2.4 Proctor Analyses

Proctor tests were performed on the ballast. The tests were performed according to ASTM-D698 Method A. The portion passing the 1/2 inch sieve of 1 month old ballast and fouled ballast material was used in the analyses. The results are shown in Figures [5.17] and [5.18]. The optimum dry density and optimum water content were 124.2 pcf and 11.2% for the 1 month old ballast, and 99.8 pcf and 18.8% for the fouled ballast, respectively.

5.2.5 Atterberg Limit Analyses

Liquid limits were evaluated using the mechanical method of ASTM D423. The plastic limits were evaluated using ASTM procedure D424. The portion of the ballast passing the
#40 sieve resulted to be non-plastic. The results of tests performed on ballast material passing the #200 sieve are shown in Figure [5.19]. The material had a plasticity index of 24%.

The activity of a soil is defined as:

\[
A = \frac{\text{PI}}{\% < 0.002 \text{ mm}}
\]

Where, \(A\) = Activity, and \(\text{PI}\) = Plasticity of a soil.

The hydrometer analyses gave .8% passing at 0.002 mm which gives an activity of 30 for the portion passing the #200 sieve.

5.2.6 Consolidation Test

A one dimensional consolidation test was performed on fouled ballast material passing the 1/4-inch sieve. The test was run according to ASTM procedure D2435. The sample dimensions were 4.8 cm in diameter by 5.4 cm in height. The soil was compacted at a water content of 18.5% to a dry density of 99.3 ocf. The time vs. deflection and compression curves are shown in Figures [5.20] and [5.21]. Based on these analyses the preconsolidation pressure was estimated to be about 1200 psf, the compression index, \(C_v\), = 0.075 and the recompression index was estimated to be about \(C_r\) = 0.0017.
Fig. (5.14) Gradation Curves of New Ballast Material
Fig. 5.151 Gradation Curves of 1 Month old Ballast Material
Fig. 15.161 Gradation Curves of Fouled Ballast Material
PROCTOR ANALYSIS
STANDARD EFFORT
ON NEW BALLAST MATERIAL PASSING 1/2" SIEVE

Max. Dry Density = 124.2pcf
Opt. Moisture Cont. = 11.2%

Fig. 5.17 Proctor Compaction Results new Ballast
PROCTOR ANALYSIS
STANDARD EFFORT
ON FOULED BALLAST MATERIAL PASSING 1/2" SIEVE

Max. Dry Density = 99.8 pcf
Opt. Moisture Cont. = 18.8%
**Fig. [5.19] Results of Atterbergs Limits Test**

<table>
<thead>
<tr>
<th>#blocks</th>
<th>Value</th>
<th>mean</th>
<th>mean</th>
<th>mean</th>
<th>w%</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>13</td>
<td>5.26</td>
<td>14.34</td>
<td>11.61</td>
<td>0.92</td>
</tr>
<tr>
<td>30</td>
<td>16</td>
<td>5.7</td>
<td>15.32</td>
<td>11.99</td>
<td>1.25</td>
</tr>
<tr>
<td>18</td>
<td>14</td>
<td>5.66</td>
<td>13.38</td>
<td>14.72</td>
<td>1.48</td>
</tr>
<tr>
<td>11</td>
<td>13</td>
<td>4.43</td>
<td>14.59</td>
<td>14.72</td>
<td>2.02</td>
</tr>
<tr>
<td>Wp</td>
<td>15</td>
<td>12.85</td>
<td>12.72</td>
<td>11.87</td>
<td>3.11</td>
</tr>
</tbody>
</table>

\[ \omega_p = 13.4\% \]

\[ \omega_v = 37.5\% \]

\[ I_p = 24.1\% \]
CONSOLIDATION CURVE
FOULED BALLAST MATERIAL PASS. 1/2 " SIEVE

Fig. 25.20  Consolidation Test Results
CONSOLIDATION TEST RESULTS
FOULED BALLAST MATERIAL PASS. 1/2 " SIEVE
TIME [HRS]

DEFLECTION [IN]

0.001 0.01 0.1 1 10 100

- 500 psf
+ 1000 psf
* 2000 psf
o 5000 psf
x 10000 psf
- 20000 psf
+ UNL. 500 psf

Fig 19.211: Time Compression Curves of the Consolidation Test
6. RESULTS OF ANALYSES

The results of the geotextile testing program are discussed in detail in this chapter.

6.1 Test Excavations

Two excavations were made above each geotextile just after the geotextiles were installed (initial excavation), then after elapsed times of 1, 2, 6, and 12 months. One excavation was made above the grid to perform strain measurements, the remaining excavations were made in new areas each time for sample retrieval. Each excavation was made by first removing 4 crossties, then excavating the ballast to a depth about 2 inches above the geotextile using a backhoe. The remaining material was excavated by hand. A template was used to measure the global strains in the grid.

At the other locations, 2 ft. by 4 ft. specimens were cut out of the geotextiles, placed in plastic bags, and returned to the laboratory. New ballast was then placed in the excavations and the ballast was compacted.

Observations

Initial excavation (10-30-86):

The geotextiles were undamaged and in relatively good condition. Soil beneath the fabrics appeared damp, but no fine material or slurry formation could be seen. Water was observed to be draining out of the track.
1 Month Excavations (12-2-86):

Substantial rainfall had occurred during the days prior to excavation. The eastern ditch showed significant erosion but was functioning well. The western ditch was still not completed and had filled with eroded material. The standing water was above geotextiles A and C. The material in the western ditch was too soft to allow backhoe operations.

Geotextile A:

Standing water was above geotextile A. Tamper damage was apparent. The laboratory sample was obtained between two holes caused by tamper damage. The damage to the fabric was in isolated areas between the ties at the locations where the tamper feet were extended below the rail. Global deformations appeared to be caused by tamping.

Geotextile B:

Excessive tamper damage was observed. The geotextile specimen was taken from below the east rail due to tamper damage. Global deformations appeared to have been caused by tamping. Fine grained particles had accumulated at the lower surface of the geotextile.
Geotextile C:

Due to excessive tamper damage under the west rail, the laboratory sample was taken from below the east rail. Global deformations appeared to have been caused by tamping. Standing water was above the fabric at the location where the sample was obtained. The soil below the fabric was wet and a thin layer of fine particles had accumulated beneath the geotextile.

Geotextile D:

The fabric was in relatively good condition with no apparent damage. The soil beneath the textile was damp, but there was little or no accumulation of fines.

2 Months excavations (1-23-87):

A substantial amount of rainfall had occurred prior to the 2 month excavation. The eastern ditch was still in excellent condition, however eroded material from the side slopes was observed. The western ditch was still filled with erosion debris. The water level was still higher than the elevations of geotextiles A and C. In sections B and D the geotextiles and the subgrade were in a slightly moist condition, despite of the amount of precipitation.
Geotextile A:

A minor amount of standing water was present making it possible to obtain strain measurement at the grid. A substantial quantity of fine grained particles had accumulated above and below the fabric. No further damage was noticed.

Geotextile B:

The fabric was damp and a thin film of fine grained particles had accumulated above and below the geotextile. No further damage to the geotextile was observed.

Geotextile C:

A minor amount of standing water was present, making it possible to obtain strain measurements at the grid. Fine grained particles had accumulated in thin layers above and below the geotextile. No further damage to the geotextiles was observed.

Geotextile D:

The fabric and ballast were in a slightly moist condition. No further damage to the geotextile was observed.

6 Months excavation (5-28-87):

A substantial amount of rainfall had occurred prior to the 6 month excavation. The western ditch had been excavated from the 106+50 Station on northbound. Water was present in
both ditches. The water level however was lower than all geotextile elevations.

Geotextile A:

The geotextile and subgrade were in a damp condition. No apparent damage was observed. A significantly increased amount of clay size particles had accumulated on the geotextiles in the grid excavations. Below the geotextiles an increased amount of silt and clay size particles could be observed.

Geotextile B:

The geotextile was in a wet condition. An increased amount of clay, silt and fine sand size particles was found on the geotextiles at the grid locations. Below the geotextiles an increased amount of silt and clay size particles was found.

Geotextile C:

The geotextile was in a wet condition. Local tamper damage could be observed. A 1 cm thick layer of clay, silt and fine sand size particles was found on the geotextiles at the grid locations. Below the geotextile clay and silt size particles were found. Tamper deformation and damage was observed.
Geotextile B:

The geotextile was damp, fine sand, silt and clay had accumulated on the top surface at the grid locations. Below the geotextile clay and silt size particle accumulation was observed. Tamper damage and was not observed.

6.2 Visual Inspection of Retrieved Samples

2 ft. by 4 ft. specimens of each geotextile were obtained at elapsed times of 0, 1, 2, 6, and 12 months after installation. The retrieved samples from 0 to 6 months in-service time were inspected visually. The observations for each textile are discussed below.

Geotextile A:

The samples from the 0, 1 and 2 month sampling interval were in a wet condition. A progressive amount of grain accommodation could be observed. Sandy material was trapped in the surface fibers. A fine slurry was observed on the fabric surfaces from the 1 and 2 month samples. Under the microscope silt and clay size particle penetration of the fabric was observed. This penetration extended to about half the thickness of the fabric for the samples taken immediately after installation. For later samples the fine grained particles penetrated through the entire fabric. Tamper damage was noted for all samples. On the 1 month sample pen-size perforations at points of inter grain
contact were observed. The 6 month sample appeared in a relatively dry condition. The extent of local straining was not increasing. Various perforations similar to the 1 month sample were observed. A slightly increasing amount of fine grained particles on the surface and in the structure of the geotextile were observed.

Geotextile B:

While the 0 month sample was relatively dry, the other samples were wet. The samples showed an increasing amount of silty fines collected at the bottom surface. A microscopic inspection showed only minor accumulation of fine sandy particles in the structure. Clay and silt size particles had accumulated through the entire thickness of all of the specimens. Puncturing caused by sharp-edged stones was observed, including 4-5 holes of about 1-2 mm in diameter. Heavy tamper damage could be seen on the 1 and 2 months samples. The 6 month samples appeared in a similar condition except for local high accumulation of clay and silt size particles. These local accumulations with an area of about 2 inches in diameter were observed all over the entire sample.

Geotextile C:

The geotextile samples were very wet from the 0, 1 and 2 month sampling periods. Fine sand, clay and silt size particles had penetrated the entire thickness of the geotextile. This geotextile had accumulated more fine
grained particles than any of the other samples. Two or three 1 cm diameter holes were observed. Tamper damage was also evident in all of the samples. The 6 month sample was in a slightly dryer condition and an increased amount of particles was found on the sample.

Geotextile D:

These samples were in dry condition throughout the testing program. No fines had collected in the 0 month sample. The one and two month samples showed a progressive amount of accumulation of fine grained particles, but only on the bottom surface. A small amount of fines had accumulated on the top surface of the 2 month sample. Four to six 1 cm diameter punctures were observed in the samples. Some surface abrasion could be observed on the 2 month sample. The six month sample showed a significantly increased amount of fines on the top surface. Less punctures and about the same extent of surface abrasion was observed.

6.3 Wide Strip Tensile Test Results

The wide strip tensile test results are shown in Appendix A. The tensile strength, maximum strain and secant modulus vs. in-service time of each geotextile are presented in Figures [6.1] to [6.6]. The results are also summarized in Table [6.1]. The maximum strain is the strain at maximum tensile stress. The secant modulus was evaluated by
determining the slope of a line through the origin and a point at 0.05 strain on the stress-strain curve.

**Sample A:**

The baseline tests show a significantly higher tensile strength and secant modulus in the machine direction. The elongation for the cross direction is clearly larger. The tensile strength changes only slightly over in-service time. The results show the same tendency for each test direction. The tensile strength difference stays constant with time. No significant trend can therefore be found.

The elongation however, shows a drastic decrease in value at the 0 month period and stays approximately constant after that. In machine direction the elongation decreases from 0.69 [-] to a value around 0.35 [-] and in cross direction from 0.97 [-] to about 0.5 [-]. This represents for both directions a decrease to nearly 50% of the baseline elongation value.

The secant moduli show an increase for both directions. Both curves indicate a rapid increase after installation and less changes after 1, 2 and 6 months. The increase in machine direction is much higher. The secant modulus increases from 1604.9 [lbs/ft] to about 6000 [lbs/ft] for the machine direction, and from 1080.5 [lbs/ft] to about 3000 [lbs/ft] for the cross direction. This represents an increase by 310% for the machine direction and by 200% in the cross direction.
Sample B:

The baseline tests show a slightly larger tensile strength and a larger secant modulus in the machine direction. The elongation in the cross direction is larger. The results for sample B show a sudden decrease in tensile strength after installation and stay approximately constant over time after the 0 months test. A decrease from 2533.7 [lbs/ft] to about 1500 [lbs/ft] in machine direction is found, representing a decrease to about 70% of the baseline value. For the cross direction a decrease from 2310.3 [lbs/ft] to about 1500 [lbs/ft] is observed, representing a decrease to about 65% of the baseline value.

The elongation decreases immediately after installation to approximately the same value for both test directions. In machine direction a decrease from 0.52 [-] to about 0.36 [-] is observed, representing a decrease to about 69%. A decrease from 0.66 [-] to 0.36 [-] can be seen for the cross direction, representing a decrease to about 55% of the baseline value.

The secant modulus shows the same, steadily increasing trend for both test directions.

Sample C:

The baseline tests show a larger tensile strength and secant modulus in the cross direction. The elongation in the machine direction is larger. A decrease in tensile strength
after installation for both test directions can be observed. The further trend is not clear. In machine direction the tensile strength decreases from 1292.1 [lbs/ft] to about 800 [lbs/ft] after 1 month. This represents a decrease to 66% of the baseline value.

In the cross direction a decrease from 1611.95 [lbs/ft] to about 1100 [lbs/ft] with a still decreasing trend can be observed. This represents a decrease to 75% of the baseline value.

The elongation values show a less pronounced decrease versus in-service time. A decrease from 0.90 [-] to about 0.44 [-] for the machine direction can be observed, representing a decrease to about 49% of the baseline value. In the cross direction a decrease from 0.58 [-] to about 0.30 [-], representing a decrease to about 50% of the baseline value.

The secant moduli for both directions show a steady, almost linear increase versus in-service time from the baseline tests to the one month test. Both decrease after that. The maximum increase was from 866.5 [lbs/ft] to 3300.4 [lbs/ft] representing a 380% increase of the baseline value for the machine direction. For the cross direction an increase from 1208.7 [lbs/ft] to 3501.9 [lbs/ft] can be observed. This represents an increase by 290% of the baseline value.
Sample D:

The baseline tests show a higher tensile strength and secant modulus in the cross direction. The elongation does not show any significant difference. No significant change in tensile strength versus time can be observed. The scatter of data is only due to sample variations. The trend of higher tensile strengths in the cross direction appears to be consistent.

The tensile strength in the machine direction varies from 2330.4 [lbs/ft] to 2689 [lbs/ft], and from 2368.4 [lbs/ft] to 2896.8 [lbs/ft] in the cross direction.

The elongations show a steady decreasing trend in both test directions. In the machine direction a decrease from 0.163 [-] to 0.127 [-], and in the cross direction from 0.150 [-] to 0.113 [-] can be observed.

The secant moduli have a steady trend. In the machine direction they range from 16952.2 [lbs/ft] to 21746.5 [lbs/ft]. In the cross direction an increase from 22684.2 [lbs/ft] to 31177.2 [lbs/ft] can be observed.

Geotextile D, as compared to all the other geotextiles, has the highest tensile strength and shows no decrease in elongation and change in secant modulus.
WIDE STRIP TENSILE TESTS
COMPARISON OF RESULTS
MACHINE DIRECTION

Fig. 6.1) Comparison of Wide Strip Tensile Strengths
Machine Direction
WIDE STRIP TENSILE TESTS
COMPARISON OF RESULTS
CROSS DIRECTION

TENSILE STRENGTH 1500 [lbs/ft]

TIME AFTER INSTALLATION [d]

Fig.[6.2] Comparison of Wide Strip Tensile Strengths
Cross Direction
Fig.[6.3] Comparison of Elongation
Machine Direction
WIDE STRIP TENSILE TESTS
COMPARISON OF RESULTS
CROSS DIRECTION

Fig. 6.4 Comparison of Elongation
Cross Direction
Fig. 6.5] Comparison of Secant Moduli
Machine Direction
WIDE STRIP TENSILE TESTS
COMPARISON OF RESULTS
CROSS DIRECTION

Fig.[6.6] Comparison of Secant Moduli
Cross Direction
6.4 Trapezoidal Tear Test Results

The trapezoidal tear strengths are summarized in Table [6.2]. Trapezoidal tear strengths as a function of the in-service time are presented in Figures [6.7] and [6.8]. The load vs. extension curves are shown in Appendix B. These curves typically show a flat part during the first inch of extension. The load then increases subsequently until it reaches a plateau. The sample extends and several peaks develop in this plateau. After a certain amount of extension, the load drops off quickly. This plateau region can be seen as the portion where the sample starts to develop a tear and this tear propagates through the entire sample. When the tear is about to reach the other sample side the load drops off.

Geotextiles A:

The load versus extension curve was relatively flat for the first inch of extension. For the next two inches of extension, the load increased linearly. A plateau showing several peaks was then encountered. The plateau extended over approximately two inches. This was the range over which tearing occurred. Once the tear propagated through the entire sample, the load dropped off rapidly. With the existing data no relationship between machine direction and cross direction could be seen. A decrease to an average value of 130.1 [lbs] for the subsequent tests reflects a
decrease to 67% of the initial average value for both directions. The failure extension decreased from about 4.5 inches for the baseline tests to about 2.5 inches for the subsequent tests.

Geotextile B:

The load versus extension curve was relatively flat for the first inch of extension. A subsequent increase in load was observed until the plateau was reached at about a 2 inch extension. The load stayed at about the same amount with several small peaks until it dropped off after about a 4 inch extension. The peaks became less pronounced with increasing sample age. The cross directional strength was smaller than the machine direction strength. This difference became less pronounced during subsequent tests. The baseline trapezoidal tear strength in the machine direction was 162.9 [lbs] while in the cross direction the trapezoidal tear strength was 227.3. A decrease to an average value of 139.4 [lbs] for the subsequent tests reflects a decrease to 74% of the initial average for both directions. The failure extension decreased from about 4.5 inches for the baseline tests in both directions to about 3.5 inches for the subsequent tests.

Geotextile C:

A large difference in the trapezoidal tear strength for
the two test directions was observed here. The difference decreased after installation. Common to all curves is the flat portion up to 1 inch extension and an increase to a plateau at about 3 inch extension. The failure extension decreased from about 5 inches to 4 inches after installation. The baseline trapezoidal tear strengths in the machine and cross direction were 89.6 [lbs] and 160.0 [lbs], respectively. A decrease to an average of the subsequent tests of 71.8 [lbs] reflects a decrease to 57% of the average baseline strength. The peak values became less pronounced with in-service time.

Geotextiles D:

The trapezoidal tear strength decreased by about 51% in the machine direction and by 60% in the cross direction after installation. The differences between the machine and cross direction became less pronounced with in-service time. The reduction in the average trapezoidal tear strength appeared to have been caused by tamping during installation. The decrease in strength occurred immediately after installation. No further decrease in strength was observed.

A comparison of the trapezoidal tear test results revealed a significantly lower strength for geotextile C. Geotextile D, with initially high strengths, decreased to similar values as B and A.
TRAPEZOIDAL TEAR TESTS
COMPARISON OF RESULTS
MACH NE DIRECTION

Fig.[6.7] Trapezoidal Tear Tests
Comparison of Results. Machine Direction
TRAPEZOIDAL TEAR TESTS
COMPARISON OF RESULTS
CROSS DIRECTION

Fig. [6.8] Trapezoidal Tear Tests
Comparison of Results, Cross Direction
6.5 Direct Shear Test Results

The direct shear tests were performed on the geotextiles prior to installation. These analyses were performed against both the new and the fouled ballast. The interface friction angles and the adhesion intercepts are summarized in Table [6.3]. A comparison of the direct shear test results is given in Figures [6.9] and [6.10]. The individual results are given in Appendix C.

Table [6.3] Summary of Direct Shear Test Results

<table>
<thead>
<tr>
<th>Geotextile</th>
<th>Used soil</th>
<th>Interface Friction</th>
<th>Adhesion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle [°]</td>
<td>[°]</td>
<td>a, [psf]</td>
</tr>
<tr>
<td>A</td>
<td>New Bal.</td>
<td>36.4</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Foul. Bal.</td>
<td>35.0</td>
<td>55</td>
</tr>
<tr>
<td>B</td>
<td>New Bal.</td>
<td>42.5</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Foul. Bal.</td>
<td>39.5</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>New Bal.</td>
<td>41.9</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Foul. Bal.</td>
<td>42.0</td>
<td>37</td>
</tr>
<tr>
<td>D</td>
<td>New Bal.</td>
<td>38.1</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Foul. Bal.</td>
<td>38.0</td>
<td>16</td>
</tr>
</tbody>
</table>

The interface friction angles for all of the geotextiles and for both of the ballast materials lie within a narrow range of 35° to 42.5°. The adhesion values vary considerably, largely due to the interaction between the coarse aggregates and the mold used to contain the ballast.
DIRECT SHEAR TEST RESULTS
COMPARISON OF RESULTS

Fig. [6.9] Direct Shear Test Results
Comparison of Interface Friction Angles
Fig.[6.10] Direct Shear Test Results
Comparison of Adhesion Values
6.6 Puncture Test Results

The puncture strengths versus in-service time are shown in Figure [6.11]. Piston force vs. elapsed time graphs are presented in Appendix D. The puncture strengths are summarized in Table [6.4]. A discussion of the results of the analyses for each geotextile follows:

Geotextile sample A initially had the second highest puncture strength of 247.1 [lbs]. The puncture strength decreased by about 16% to 207 [lbs] after 6 months service.

Geotextile sample B had the second lowest initial puncture strength of 208.8 [lbs]. The puncture strength decreased by about 30% to 147.3 [lbs] after 2 months service.

Geotextile sample C had the lowest initial puncture strength of 203.6 [lbs]. The puncture strength decreased by about 45% to 105.6 [lbs] after 6 months service.

Geotextile sample D had the highest initial puncture strength of 318.1 [lbs]. The puncture strength decreased by about 26% to 237.1 [lbs] after 6 months service.

All of the geotextiles showed a large decrease in puncture strength immediately after installation. It is believed that the reduction in puncture strength is due primarily to the damage sustained by the fabric during the tamping of the ballast. Subsequent decreases were small by comparison.
<table>
<thead>
<tr>
<th>Geotextile</th>
<th>Period</th>
<th>Strength</th>
<th>Average Strength</th>
<th>% Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>New</td>
<td>239.4</td>
<td>253.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>255.4</td>
<td>247.1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0 Months</td>
<td>221.4</td>
<td>236.2</td>
<td>228.8</td>
</tr>
<tr>
<td></td>
<td>1 Month</td>
<td>227.3</td>
<td>226.6</td>
<td>91.7</td>
</tr>
<tr>
<td></td>
<td>2 Months</td>
<td>231.7</td>
<td>212.9</td>
<td>86.2</td>
</tr>
<tr>
<td></td>
<td>6 Months</td>
<td>210.4</td>
<td>206.9</td>
<td>83.7</td>
</tr>
<tr>
<td></td>
<td>12 Months</td>
<td>216.6</td>
<td>208.9</td>
<td>84.5</td>
</tr>
<tr>
<td>B</td>
<td>New</td>
<td>219.9</td>
<td>201.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>211.8</td>
<td>208.8</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0 Months</td>
<td>142.9</td>
<td>145.9</td>
<td>144.4</td>
</tr>
<tr>
<td></td>
<td>1 Month</td>
<td>152.5</td>
<td>152.5</td>
<td>73.0</td>
</tr>
<tr>
<td></td>
<td>2 Months</td>
<td>151.8</td>
<td>147.3</td>
<td>70.5</td>
</tr>
<tr>
<td></td>
<td>6 Months</td>
<td>186.4</td>
<td>170.9</td>
<td>85.6</td>
</tr>
<tr>
<td></td>
<td>12 Months</td>
<td>117.3</td>
<td>137.7</td>
<td>65.9</td>
</tr>
<tr>
<td>C</td>
<td>New</td>
<td>191.0</td>
<td>202.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>196.2</td>
<td>203.6</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0 Months</td>
<td>114.8</td>
<td>132.5</td>
<td>123.6</td>
</tr>
<tr>
<td></td>
<td>1 Month</td>
<td>135.5</td>
<td>140.7</td>
<td>138.1</td>
</tr>
<tr>
<td></td>
<td>2 Months</td>
<td>138.5</td>
<td>140.8</td>
<td>69.2</td>
</tr>
<tr>
<td></td>
<td>6 Months</td>
<td>105.9</td>
<td>105.2</td>
<td>51.9</td>
</tr>
<tr>
<td></td>
<td>12 Months</td>
<td>111.8</td>
<td>119.0</td>
<td>58.4</td>
</tr>
<tr>
<td>D</td>
<td>New</td>
<td>341.9</td>
<td>333.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>336.9</td>
<td>318.1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0 Months</td>
<td>236.9</td>
<td>259.9</td>
<td>248.4</td>
</tr>
<tr>
<td></td>
<td>1 Month</td>
<td>252.5</td>
<td>260.6</td>
<td>256.5</td>
</tr>
<tr>
<td></td>
<td>2 Months</td>
<td>276.9</td>
<td>213.9</td>
<td>245.4</td>
</tr>
<tr>
<td></td>
<td>6 Months</td>
<td>251.4</td>
<td>222.8</td>
<td>237.1</td>
</tr>
<tr>
<td></td>
<td>12 Months</td>
<td>232.0</td>
<td>265.8</td>
<td>248.9</td>
</tr>
</tbody>
</table>
Fig. [6.11] Comparison of Puncture Test Results
6.7 Transmissivity Test Results

The results of the transmissivity tests are shown graphically in Appendix E. A comparison of the results versus time is given in Figure [6.12]. The transmissivity is a function of both the hydraulic gradient and the confining stress. In all cases the transmissivity decreased as a function of in-service time. The decrease in transmissivity was likely due to the accumulation of fine grained particles in the geotextiles. At a gradient of 0.25 and a confining stress of 1000 psf the transmissivity decreased by 83%, 76%, 67% and ? in geotextile samples A, B, C, and D, respectively. The highest initial and final transmissivities were measured in geotextile C.
TRANSMISSIVITY TESTS
COMPARISON OF RESULTS

TRANSMISSIVITY
T20 [m^2/sec]
AT 1000 psf AND
GRADIENT 0.25

Fig. [6.12] Transmissivity Test
Comparison of Selected Results
6.3 Permittivity Test Results

The permittivity test results are shown vs. in-service time in Figure [6.13]. The results of the transmissivity analyses are summarized in Table [6.5]. The permittivity test results are shown in Appendix F. After an initial high value the permittivity decreased to low values at 0 and 1 months and increased for the 2 months test. The initial values however were not reached. A slight decrease was found after 6 months. The increase in values for all the geotextiles at the 2 months testing may have been due to an increased abrasion and perforation.

The permittivity of geotextile A decreased from an initial permittivity of 0.5973 [1/sec] to about .1 [1/sec], 17.0% of the initial value.

The permittivity of geotextile B decreased from 0.5992 [1/sec] to about .4 [1/sec], 66% of the initial value. This geotextile had the highest permittivity after 1 month and the smallest decrease.

The permittivity of geotextile C decreased from 1.3056 [1/sec] to about .3 [1/sec], 23% of the initial value. This geotextile had the highest initial permittivity.

The permittivity of geotextile D decreased from 0.1115 [1/sec] to 0.03 [1/sec], 27% of the initial value. This geotextile had the lowest permittivity through the whole testing program. Geotextile D showed a significantly lower permittivity, geotextile B showed the lowest decrease.
Table [6.5b] RESULTS OF PERMITTIVITY TESTS

<table>
<thead>
<tr>
<th>GEOTEXTILE</th>
<th>TIME PERIOD</th>
<th>PERMITTIVITY [$sec^{-1}$]</th>
<th>AVERAGE [$sec^{-1}$]</th>
<th>PERCENTAGE OF BASELINE VALUE [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>new (baseline)</td>
<td>1.195 1.192 1.332 1.448 1.361</td>
<td>1.3056</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0 months</td>
<td>0.2409 0.2273</td>
<td>0.2341</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>1 months</td>
<td>0.2008 0.2231</td>
<td>0.2119</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td>2 months</td>
<td>0.5167 0.4932</td>
<td>0.5049</td>
<td>38.7</td>
</tr>
<tr>
<td></td>
<td>6 months</td>
<td>0.3123 0.3989</td>
<td>0.3556</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>0.377 0.195</td>
<td>0.286</td>
<td>21.9</td>
</tr>
<tr>
<td>D</td>
<td>new (baseline)</td>
<td>0.1115 0.1057 0.0841 0.1281 0.1280</td>
<td>0.1115</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0 months</td>
<td>0.0244 0.0284</td>
<td>0.0264</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>1 month</td>
<td>0.0315 0.0267</td>
<td>0.0291</td>
<td>26.1</td>
</tr>
<tr>
<td></td>
<td>2 months</td>
<td>0.0394 0.0310</td>
<td>0.0352</td>
<td>31.5</td>
</tr>
<tr>
<td></td>
<td>6 months</td>
<td>0.0260 0.0296</td>
<td>0.0278</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>0.0320 0.0370</td>
<td>0.0350</td>
<td>31.4</td>
</tr>
</tbody>
</table>
PERMITTIVITY TEST
COMPARISON OF RESULTS

TIME AFTER INSTALLATION, [days]

PERMITTIVITY [sec^−1]

GEOTEXTILE A
GEOTEXTILE B
GEOTEXTILE C
GEOTEXTILE D

Fig. (6.13) Permittivity Test Comparison of Results
6.9 Hydraulic Conductivity Ratio (HCR) Test Results

The results of the analyses are presented as hydraulic conductivity versus volume of flow in pore volumes. One pore volume is the amount of water that is contained in the pores of the soil or ballast sample. The curves are presented in Appendix G. The hydraulic conductivity of the fouled ballast/geotextile sample was lower than the hydraulic conductivity of the fouled ballast in all cases.

The ratio of the hydraulic conductivity of the ballast geotextile composite to that of the ballast is the hydraulic conductivity ratio (HCR). The initial hydraulic conductivity of the ballast was about the same in all of the analyses except in test #1, where soil of a slightly lower density was used. A summary of parameters and results for the HCR analyses is given in Table [6.6].

Table [6.6] Summary of HCR Test Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Wet Density [lbs/ft³]</th>
<th>k(soil) [cm/sec]</th>
<th>Fabric # of pore V.</th>
<th>k(soil,fabric) [cm/sec]</th>
<th>HCR [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110</td>
<td>4.2x10⁻⁵</td>
<td>D</td>
<td>6.5</td>
<td>1.2x10⁻⁵</td>
</tr>
<tr>
<td>2</td>
<td>119</td>
<td>3.4x10⁻⁶</td>
<td>B</td>
<td>6.4</td>
<td>1.7x10⁻⁶</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
<td>1.7x10⁻⁶</td>
<td>C</td>
<td>3.7</td>
<td>8.0x10⁻⁷</td>
</tr>
<tr>
<td>4</td>
<td>112</td>
<td>3.3x10⁻⁷</td>
<td>A</td>
<td>2.1</td>
<td>8.3x10⁻⁷</td>
</tr>
</tbody>
</table>
Both geotextiles B and C show about the same HCR value, which is about twice as large as those for geotextiles A and D.

6.10 In-Situ Strain Measurements

A summary of all strain measurements taken is given in Appendix H. Tables (6.7)-(6.10) give a summary of index and maximum local strain values. Figures (6.14) and (6.15) show the index strain values vs. in-service time.

All of the grids showed an increase in strain with increasing in-service time. Geotextile A showed no clear trend. Geotextiles C and D showed strain after installation with a flattening of the strain versus in-service time curve after 40 days. The initial negative values for geotextile A and D are probably caused by tamping during installation. On straight track sections the geotextiles typically do not strain in the direction of the track. This is confirmed by the results for B, C and D, where the strains in the track direction are much smaller than in cross direction. Geotextile A was installed in a curved section of the track where strains in the cross direction developed.
### Table [6.7] Index and Maximum Local Strain Values

#### Geotextile A

**Index Strain Values**

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
<th>TD</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Months</td>
<td>.0083</td>
<td>-.0011</td>
<td></td>
</tr>
<tr>
<td>1 Month</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>2 Month</td>
<td>.0197</td>
<td>.0024</td>
<td></td>
</tr>
</tbody>
</table>

**Maximum Local Strain Values**

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
<th>TD</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Months</td>
<td>.2296</td>
<td>-.0459</td>
<td></td>
</tr>
<tr>
<td>1 Month</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>2 Months</td>
<td>.0153</td>
<td>.0098</td>
<td></td>
</tr>
</tbody>
</table>

### Table [6.8] Index and Maximum Local Strain Values

#### Geotextile B

**Index Strain Values**

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
<th>TD</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Months</td>
<td>-.01265</td>
<td>0.0088</td>
<td></td>
</tr>
<tr>
<td>1 Month</td>
<td>-.0036</td>
<td>0.0219</td>
<td></td>
</tr>
<tr>
<td>2 Month</td>
<td>-.000534</td>
<td>0.0198</td>
<td></td>
</tr>
</tbody>
</table>

**Maximum Local Strain Values**

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
<th>TD</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Months</td>
<td>-0.0131</td>
<td>0.1214</td>
<td></td>
</tr>
<tr>
<td>1 Month</td>
<td>0.157</td>
<td>0.0437</td>
<td></td>
</tr>
<tr>
<td>2 Months</td>
<td>0.0197</td>
<td>0.07874</td>
<td></td>
</tr>
</tbody>
</table>
Table C6.9: Index and Maximum Local Strain Values
Geotextile C

Index Strain Values

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
</tr>
<tr>
<td>0 Months</td>
<td>0.0029</td>
</tr>
<tr>
<td>1 Month</td>
<td>0.0082</td>
</tr>
<tr>
<td>2 Month</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

Maximum Local Strain Values

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
</tr>
<tr>
<td>0 Months</td>
<td>0.01312</td>
</tr>
<tr>
<td>1 Month</td>
<td>0.105</td>
</tr>
<tr>
<td>2 Months</td>
<td>0.105</td>
</tr>
</tbody>
</table>

Table C6.10: Index and Maximum Local Strain Values
Geotextile D

Index Strain Values

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
</tr>
<tr>
<td>0 Months</td>
<td>-0.0078</td>
</tr>
<tr>
<td>1 Month</td>
<td>-0.0114</td>
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<tr>
<td>2 Month</td>
<td>0.0053</td>
</tr>
</tbody>
</table>

Maximum Local Strain Values

<table>
<thead>
<tr>
<th>Period</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD</td>
</tr>
<tr>
<td>0 Months</td>
<td>*</td>
</tr>
<tr>
<td>1 Month</td>
<td>-0.00656</td>
</tr>
<tr>
<td>2 Month</td>
<td>0.0153</td>
</tr>
</tbody>
</table>
COMPARISON OF STRAIN INDEX VALUES
TRACK DIRECTION

Fig. [6.14] Comparison of Strain Index Values
Track Direction
COMPARISON OF STRAIN INDEX VALUES
CROSS DIRECTION

Fig. (6.15) Comparison of Strain Index Values
7. CONCLUSIONS

Previous research on geotextiles in railroad tracks, geotextile-soil composites subjected to dynamic loading and various other testing methods related to the subject have been reviewed. Models and theories of the function of geotextiles in railroad track embankments were compared to large scale and in-situ investigation programs and this research program. The models of slurry formation and the reinforcing function of geotextiles have been confirmed. Four 100-foot long geotextile sections and one 100-foot long control section were installed in an existing section of the track. Geotextile specimens were obtained prior to installation, immediately after installation and at elapsed times of 1, 2, 6 and 12 months. The geotextile specimens were analyzed using a variety of index and performance tests. After a service period of approximately 3 months the track profiles indicated no significant change or difference between the sections. The laboratory analyses indicated that most of the change in properties of the geotextiles occurred immediately after installation and up to 1 month service time. The results showed a significant decrease in wide strip tensile strength, trapezoidal tear strength and puncture resistance, water transmissivity and permittivity immediately after installation. Further decreases with time were small by comparison. The geotextiles showed some
abrasion with time. It is believed that most of these changes are caused by compaction of the ballast during installation and by initial loading. Conclusions relating to the main functions of geotextiles in a railroad track embankment are given below.

7.1 Reinforcement

Geosynthetics provide tensile reinforcement of embankments primarily by preventing lateral spreading under imposed dynamic loads. The strain measurements in the track indicate, that the tensile forces are fully mobilized only in the local range where high localized strains occur. The global strain measurements lie in a range of 2 to 4%. The largest localized strains were observed in those textiles with low modulus. Geotextile D did not undergo large localized strains due to the high modulus of the geotextile. Also, larger strains were measured in geotextiles with larger interface friction angles. Geotextile C, exhibiting the highest interface friction angles in the direct shear test, showed about twice as much strain as geotextiles B and D. Geotextile A, with the lowest friction angles, showed the lowest strain values. It is therefore believed that the direct shear test is an important test to evaluate the reinforcing action of a geotextile, especially its ability to take up tensile stress by ballast-geotextile interaction. The wide strip tensile test was found to be very valuable in
determining the tensile properties of a geotextile.

7.2 Filtration/Separation

The function of geotextiles as filters or separators in a railroad embankment have been evaluated. Dynamic laboratory tests were compared to findings in large scale tests and laboratory investigations. The model of slurry formation and migration has been found to be valid. Excavations and sample retrievals however show that slurry formation occurred only at sections were the water level was above the geotextile due to the drainage ditch malfunction. The permittivity test results show a significant effect versus in-service time. All samples show a drop of about 10 to 20% of the initial value, except for geotextile B. Geotextiles B and C, which have the highest values of HCR, also show the largest drops in permittivity. The sample inspections indicate two different modes of geotextile damage. If the geotextile has a low modulus, large localized strains occur and damage results primarily from abrasion. For high modulus fabrics puncturing damage can be observed.

7.3 Drainage

The transmissivity and permittivity analyses show a large decrease in flow capacity immediately after placement in the soil, slight decreases thereafter, and then in some cases increases after long periods of time. The differences
are likely due to the differences in hydrology between the different test sections. Some test sections, A and C, were submerged for prolonged periods of time. Additionally, the dynamic nature of the loads may induce changes in the direction of flow which may disrupt the formation of the "filter cake" and induce changes in hydraulic conductivity with time.

7.4 Ballast

The gradation analyses performed, show a steep gradation of the new ballast material in the 10 to 100 mm range. The 1 month old sample shows the gradation curve beginning to flatten out due to abrasion and wear. As time progresses, fine grained particles accumulate in the ballast either due to abrasion or transport from external sources by wind and rain.

7.5 Recommendations for Future Research

The track profile has not shown any differences between the geotextile sections and the control section. This may also be due to repeated work on the track after installation. It is recommended that the analyses be performed for a sufficient period of time to evaluate the influence of the geotextiles in the subgrade.
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Appendix A  Wide Strip Tensile Test Results
WIDE STRIP TENSION TESTS
SAMPLES A, NEW
TEST#: AWSMD2 AWSCD2

Stress [lbs/ft]

Strain [-]

Stress-Strain Curves

-- MD
-. CD

Fig. [A.1] Wide Strip Tensile Test
Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLES A, 1 MONTH AFTER INST.
TEST#: AWSCD22  AWSMD22

Stress [lbs/ft]

Strain [-]

Fig. 5A-21  Wide Strip Tensile Test
WIDE STRIP TENSION TESTS
SAMPLES A, AFTER INST.
TEST#: AWS CD11 AWS MD11

Fig. [A.3] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLES A, 2 MONTHS AFTER INST.
TEST#: AWSCD33 AWSMD33
WIDE STRIP TENSION TESTS
SAMPLES B, NEW
TEST#: BWSMD2  BWSCD2

Fig. [A.51] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLES B, AFTER INST.
TEST#: BWSCD11  BWSMD11

Stress [lbs/ft] 1500

Strain [-] 0.1 0.2 0.3 0.4 0.5 0.6 0.7

MD
CD

Fig. [A.6]  Wide Strip Tensile Test
WIDE STRIP TENSION TESTS
SAMPLES B, 1 MONTH AFTER INST.
TEST#: BWSCD22  BWSMD22

Fig. [A.71] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLES B, 2 MONTHS AFTER INST.
TEST#: BWSCD33  BWSMD33

![Graph showing wide strip tension test results with stress and strain on the axes.](image-url)
WIDE STRIP TENSION TESTS
SAMPLES C, NEW
TEST#: CWSCD1  CWSMD2

Stress [lbs/ft]

Strain [\textit{L}-1]

Fig. [A.9] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLES C, AFTER INST.
TEST#: CWSCD11 CWSDM11

Stress (lbf/ft)

Strain [-]

- MD
- CD
WIDE STRIP TENSION TESTS
SAMPLES C, 1 MONTH AFTER INST.
TEST#: CWSCD22  CWSMD22

Stress [lbs/ft]

Strain [-]

Fig. [A.11] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLES C, 2 MONTHS AFTER INST.
TEST#: CWSCH33 CWSMD33
Fig. [A.13] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLE D AFTER INST.
TEST#: DWSCD11 DWSMD11

![Stress vs. Strain Graph](image)
WIDE STRIP TENSION TESTS
SAMPLE D 1 MONTH AFTER INST.
TEST#:DWSCD22 DWSMD22

Fig. [A.15] Wide Strip Tensile Test Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLE D  2 MONTHS AFTER INST.
TEST#:  DWSCD33  DWSMD33

Stress [lbs/ft]

Strain [1-1]
WIDE STRIP TENSILE TEST
SAMPLE: GEOTEXTILE A
6 MONTHS AFTER INST.

![Graph showing stress-strain curves with labels](image-url)
WIDE STRIP TENSILE TEST
GEOTEXTILE B
6 MONTHS AFTER INST.

Fig. FA.181  Wide Strip Tensile Test
Stress Strain Curves
WIDE STRIP TENSILE TEST
SAMPLE: GEOTEXTILE C6 MONTHS AFTER INST.

Fig. 7A.17) Wide Strip Tensile Test: Stress Strain Curves
WIDE STRIP TENSILE TEST
SAMPLE: GEOTEXTILE D
6 MONTHS AFTER INST.

Fig. EA.201  Wide Strip Tensile Test
Stress-Strain Curves
WIDE STRIP TENSION TESTS
SAMPLE HOECHST STAPLE (12 MONTHS)

(A)

Stress [-] vs. Strain [-]

Stress Levels:
- 0 to 2500
- 0 to 2000
- 0 to 1500

Strain Levels:
- 0 to 0.35
WIDE STRIP TENSION TESTS
SAMPLES HOECHST, 12 MONTH AFTER INST.

(B)

Stress (lbs/ft) vs Strain ([-])

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
WIDE STRIP TENSION TESTS
SAMPLES FOSS, 12 MONTH AFTER INST.

(c)
WIDE STRIP TENSION TESTS
SAMPLES EXXON, 12 MONTH AFTER INST.

(D)

Stress (lfs/ft)
3000
2500
2000
1500
1000
500
0

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35
Strain [-]

CD
MD
Appendix B  Trapezoidal Tear Test Results
TRAPEZOIDAL TEAR TESTS
SAMPLE A NEW
TEST#: ATSMD00 ATSCD00

FORCE [lbs]

EXTENSION [in]

--- MD
--- CD
TRAPEZOIDAL TEAR TESTS
SAMPLE A AFTER INST.
TEST#: ATSMD11 ATSCD11

Fig. 10.21 Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLE A  1 MONTH AFTER INST.
TEST#:  ATSND22

FORCE [lbs]

EXTENSION (in)
TRAPEZOIDAL TEAR TESTS
SAMPLE A 2 MONTH AFTER INST.
TEST#: ATS MD33 ATSCD33

Fig. [8.4] Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLE B  NEW
TEST#: BTSMD00  BTSCD00

FORCE
[lbs]

EXTENSION [in]

MD
CD
TRAPEZOIDAL TEAR TESTS
SAMPLE B AFTER INST.
TEST#: BTSND11

Fig. [B.6] Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLES 2 1 MONTH AFTER INST.
TEST#: BITSHDZ22

FORCE [lbs]

EXTENSION [in.]
TRAPEZOIDAL TEAR TESTS
SAMPLE B  2 MONTHS AFTER INST.
TEST#:  BTSND33

Fig. [8.8] Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLE C NEW
TEST#: CTSMD00 CTSCD08
TRAPEZOIDAL TEAR TESTS
SAMPLE C AFTER INST.
TEST#: CTSMD11  CTSD11

Fig. FB.103 Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLE C 2 MONTHS AFTER INST.
TEST#: CTSND33

Fig. [B.12] Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLE D  NEW
TEST#:  DTSM000  DTSCD00

FORCE [lbs]

350
300
250
200
150
100
50
0

EXTENSION [in]

0  1  2  3  4  5  6
TRAPEZOIDAL TEAR TESTS
SAMPLE D AFTER INST.
TEST#: DTSMD11 DTSCD11

Fig. [B.14] Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TESTS
SAMPLE D  1 MONTH AFTER INST.
TEST#:  DTSMD22  DTSCS22

FORCE [lbs]

EXTENSION [in]
TRAPEZOIDAL TEAR TESTS
SAMPLE D L23209 2 MONTHS AFTER INST.
TEST#: DTSMD33 DTSCD33

Fig. [B.16] Trapezoidal Tear Test Results
Load-Extension Curves
TRAPEZOIDAL TEAR TEST
SAMPLE: GEOTEXTILE A
6 MONTHS AFTER INST.

Fig. [B.17] Trapezoidal Tear Test
Load Extension Curves
TRAPEZOIDAL TEAR TEST
SAMPLE: GEOTEXTILE B
6 MONTHS AFTER INST.

Fig.[B.18]  Trapezoidal Tear Test
Load Extension Curves
TRAPEZOIDAL TEAR TEST
SAMPLE: GEOTEXTILE C
6 MONTHS AFTER INST.

Fig. [B.19]  Trapezoidal Tear Test
Load Extension Curves
TRAPEZOIDAL TEAR TEST
SAMPLE: GEOTEXTILE D
6 MONTHS AFTER INST.

Fig.[B.20] Trapezoidal Tear Test
Load Extension Curves
TRAPEZOIDAL TEAR TEST
SAMPLES HOECHST STAPLE, 12 MONTHS AFTER INST.

(A)
TRAPEZOIDAL TEAR TEST
SAMPLES HOECHST, 12 MONTHS AFTER INST.

(B)
TRAPEZOIDAL TEAR TEST
SAMPLES FOSS, 12 MONTHS AFTER INST.
(c)
TRAPEZOIDAL TEAR TEST
SAMPLES EXXON, 12 MONTHS AFTER INST.

(D)

FORCE [lbs]

CLAMP DISPLACEMENT [in.]
Appendix C Direct Shear Test Data
DIRECT SHEAR TEST DATA
SAMPLE: GEOTEXTILE A  TEST#: ADSN1, 2, 5
NEW BALLAST/GEOTEXTILE A/NEW BALLAST

DELTA= 36.4 DEG.
A= 95 PSF

Fig. [C.11] Direct Shear Test Data
Geotextile A  New Ballast
DIRECT SHEAR TEST DATA
SAMPLE: GEOTEXTILE B  TEST#: DDSN1,2,5
NEW BALLAST/GEOTEXTILE B/NEW BALLAST

DELTA = 42.5 DEG.
γ = 27 PSF
DIRECT SHEAR TEST DATA
SAMPLE: GEOTEXTILE C TEST#: CDSN1,2,5
NEW BALLAST/GEOTEXTILE C/NEW BALLAST

Fig. [C.3] Direct Shear Test Data
Geotextile C  New Ballast
DIRECT SHEAR TEST DATA
SAMPLE: GEOTEXTILE D TEST#: DXDSM1,2,5
NEW BALLAST/GEOTEXTILE D/NEW BALLAST

\[
\text{DELT}A = 38.1 \, \text{DEG.} \\
\text{R} = 34 \, \text{PSF}
\]
FRICTION DATA
SOUTHERN RAILWAY

SAMPLE: GEOTEXTILE A  TEST#: ADSF1, 2, 5
FOULED BALLAST/GEOTEXTILE A/FOULED BALLAST

INTERFACE FRICTION ANGLE = 35 DEGREES
ADHESION = 55 PSF

Fig. [C.5] Direct Shear Test Data
Geotextile A  Fouled Ballast
FRICTION DATA
SOUTHERN RAILWAY

SAMPLE: GEOTEXTILE B  TEST#: BDSF1,2,5
FOULED BALLAST/GEOTEXTILE B/FOULED BALLAST

INTERFACE FRICTION ANGLE = 39.5 DEGREES
ADHESION = 8 PSF
Friction Data
Southern Railway

Sample: Geotextile C Test#: CDSF1,2,5
Fouled Ballast/Geotextile C/Fouled Ballast

Interface Friction Angle = 42 degrees
Adhesion = 37 PSF

Fig. 10.71 Direct Shear Test Data
Geotextile C Fouled Ballast
FRICITION DATA
SOUTHERN RAILWAY

SAMPLE: GEOTEXTILE D  TEST#: DLSF1,2,5
FOULED BALLAST/GEOTEXTILE D/FOULED BALLAST

INTERFACE FRICTION ANGLE = 38 DEGREES
ADHESION = 16 PSF
Appendix D Puncture Test Results
PUNCTURE TEST
SAMPLE A NEW
TEST#: APT1 APT2 APT3 APT4
PUNCTURE TEST
SAMPLE A AFTER INST.
TEST#: APT111 APT211

Fig. [10.2] Puncture Test Results
PUNCTURE TEST
SAMPLE A 1 MONTH AFTER INST.
TEST#: APT122 APT222

Graph showing the piston force in pounds as a function of elapsed time in seconds.
PUNCTURE TEST
SAMPLE A 2 MONTHS AFTER INST.
TEST#: APT133 APT233

Fig. [D.4] Puncture Test Results
PUNCTURE TEST
SAMPLE B NEW
TEST #: BPT1 BPT2 BPT3 BPT4

Piston Force [lfs]
0  50  100  150  200  250

0  1  2  3  4  5  6  7  8  9  10

B speed Time [sec]
PUNCTURE TEST
SAMPLE B AFTER INST.
TEST#: BPT111 BPT211

Fig. [D.6] Puncture Test Results
PUNCTURE TEST
SAMPLE B 1 MONTH AFTER INST.
TEST#: BPT122  BPT222
Figure D.8: Puncture Test Results
PUNCTURE TEST
SAMPLE C NEW
TEST#: CPT001 CPT002 CPT003 CPT004
PUNCTURE TEST
SAMPLE C AFTER INST.
TEST#: CPT111  CPT211

Fig. (D.10) Puncture Test Results
PUNCTURE TEST
SAMPLE C 1 MONTH AFTER INST.
TEST#: CPT122 CPT222

Piston Force [lbs]

Elapsed Time [sec]
PUNCTURE TEST
SAMPLE C  2 MONTHS AFTER INST.
TEST#: CPT133   CPT233

Fig. (D.12) Puncture Test Results
PUNCTURE TEST
SAMPLE D NEW
SAMPLES: D001 D002 D003 D004

Force (lbs)

Time (sec)
PUNCTURE TEST
SAMPLE D AFTER INST.
SAMPLES: DPT111 DPT211

Fig. [D.14] Puncture Test Results
PUNCTURE TEST
SAMPLE D 1 MONTH AFTER INST.
SAMPLES: DPT122  DPT222
PUNCTURE TEST
SAMPLE D 2 MONTHS AFTER INST.
SAMPLES: DPT133  DPT233

Fig. [D.16] Puncture Test Results
PUNCTURE TESTS
SAMPLES: GEOTEXTILE A
6 MONTHS AFTER INST.

FORCE [lbs]

ELAPSED TIME [sec]
PUNCTURE TESTS
SAMPLES: GEOTEXTILE B
6 MONTHS AFTER INST.
PUNCTURE TESTS
SAMPLES: GEOTEXTILE C
6 MONTHS AFTER INST.
PUNCTURE TESTS
SAMPLES: EXXON L23209
6 MONTHS AFTER INST.

FORCE [lbs]

CLAPSED TIME [sec]
PUNCTURE TEST
SAMPLE HOECHST STAPLE, 12 MONTHS AFTER INST.

(A)

Piston Force [lbs]

0 2 4 6 8 10 12 14

ELAPSED TIME [sec.]

250
200
150
100
50
0
PUNCTURE TEST
SAMPLE HOECHST, 12 MONTHS AFTER INST.

(P)

Piston Force [lbs]

ELAPSED TIME [sec.]
PUNCTURE TEST
SAMPLE FOSS, 12 MONTHS AFTER INST.

ELAPSED TIME [sec.]

Piston Force [lbs.]

0 2 4 6 8 10 12 14
0 20 40 60 80 100 120 140

(c)
PUNCTURE TEST
SAMPLE EXXON, 12 MONTHS AFTER INST.

(D)

Piston Force [lbs]

ELAPSED TIME [sec.]
Appendix E Transmissivity Test Results
GEOTEXTILE A (TREVIRA 2185)

NORMAL STRESS = 1000 psf

<table>
<thead>
<tr>
<th>hydraulic gradient</th>
<th>baseline</th>
<th>after installed</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
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</thead>
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<td>0.25</td>
<td>8.2E-04</td>
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NORMAL STRESS = 5000 psf

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<th>1 month</th>
<th>2 months</th>
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<th>1 year</th>
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TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD at 1000 psf
ALPL/geotextile A (TREVIRA 2185)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

PERIOD OF INSTALLATION
- baseline
- after installed
- 1 month
- 2 months
- 6 months
- 1 year

HYDRAULIC GRADIENT, i (-)
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD at 5000 psf
ALPL/geotextile A (TREVIRA 2185)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

0.000001

0.0000001

PERIOD OF INSTALLATION

baseline
after installed
1 month
2 months
6 months
1 year

HYDRAULIC GRADIENT, i (-)

0 0.25 0.5 0.75 1 1.25
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 101
ALPL/TREVIRA 2185 (baseline)/ALPL

HYDRAULIC TRANSMISSIVITY
$T_{20}$
$m^2/s$

NORMAL STRESS

- 1000 psf
- 5000 psf

HYDRAULIC GRADIENT, $i$ (-)
HYDRAULIC GRADIENT FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 101
ALPL/TREVIRA 2185 (baseline)/ALPL

FLOW RATE (gpm/ft)

NORMAL STRESS, [psf]

HYDRAULIC GRADIENT

--- i = 0.25
+- i = 0.5
*- i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 161
ALPL/TREVIRA 2185 (after installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRES
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 161
ALPL/TREVIRA 2185 (after installation)/ALPL

FLOWRATE
(gpm/ft)

HYDRAULIC
GRADIENT

- - i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psf]
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 169
ALPL/TREVIRA 2185 (1 month installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

0.000001

NORMAL STRESS

- - 1000 psf
- - 5000 psf

HYDRAULIC GRADIENT, i (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 169
ALPL/TREVIRA 2185 (1 month installation)/ALPL

FLOWRATE (gpm/ft)

0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001

NORMAL STRESS, [psf]

1000
10000

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 110
ALPL/TREVIRA 2185 (2 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 110
ALPL/TREVIRA 2185 (2 months installation)/ALPL

FLOWRATE
(gpm/ft)

NORMAL STRESS, [psf]

0.009

0.008

0.007

0.006

0.005

0.004

0.003

0.002

0.001

0.000

1000

10000

HYDRAULIC
GRADIENT

i = 0.25

i = 0.5

i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 174
ALPL/TREVIRA 2185 (6 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
($m^2/s$)

NORMAL STRESS

- 1000 psf
- 5000 psf

HYDRAULIC GRADIENT, $i$ (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 174
ALPL/TREVIA 2185 (6 months installation)/ALPL

FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 174
ALPL/TREVIA 2185 (6 months installation)/ALPL

FLOWRATE (gpm/ft)

0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001

NORMAL STRESS, [psf]

1000 10000

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00

ALPL/TREVIA 2185 (6 months installation)/ALPL
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 155
ALPL/TREVIRA 2185 (1 year installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

0.000001

0.0000001

0.00000001

0
0.25
0.5
0.75
1
1.25

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 155
ALPL/TREVIRA 2185 (1 year installation)/ALPL

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
*-- i = 1.00

FLOWRATE (gpm/ft)
0.012
0.01
0.008
0.006
0.004
0.002

NORMAL STRESS, [psf]
1000
10000
### GEOTEXTILE B (TREVIRA 1155)

### NORMAL STRESS = 1000 psf

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<tr>
<th>hydraulic gradient</th>
<th>baseline</th>
<th>after installed</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
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### NORMAL STRESS = 5000 psf

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<th>after installed</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
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</table>
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD AT 1000 psf
ALPL/geotextile B (TREVIRA 1155)/ALPL

HYDRAULIC TRANSMISSIVITY
T20 (m^2/s)

0.00001

PERIOD OF INSTALLATION

- baseline
- after installed
- 1 month
- 2 months
- 6 months
- 1 year

0.000001

0.0000001

0.00000001

0.25 0.5 0.75 1 1.25

HYDRAULIC GRADIENT, i (-)
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD AT 5000 psf
ALPL/geotextile B (TREVIRA 1155)/ALPL

PERIOD OF INSTALLATION
- baseline
- after installed
- 1 month
- 2 months
- 6 months
- 1 year

HYDRAULIC GRADIENT, $i$ (-)

HYDRAULIC TRANSMISSIVITY $T_{20}$ ($m^2/s$)
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 104
ALPL/TREVIRA 1155 (baseline)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

NORMAL STRESSES
- 1000 psf
- 5000 psf

HYDRAULIC GRADIENT, i (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 104
ALPL/TREVIRA 1155 (baseline)/ALPL

FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 104
ALPL/TREVIRA 1155 (baseline)/ALPL

HYDRAULIC
GRADIENT

--- i = 0.25
+ i = 0.5
* i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 156
ALPL/TREVIRA 1155 (after installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS

- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 156
ALPL/TREVIRA 1155 (after installation)/ALPL

HYDRAULIC GRADIENT

- $i = 0.25$
- $i = 0.5$
- $i = 1.00$

FLOWRATE (gpm/ft)

NORMAL STRESS, (psf)
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 162
ALPL/TREVIRA 1155 (1 month installation)/ALPL

HYDRAULIC TRANSMISSIVITY T20 (m^2/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 162
ALPL/TREVIIRA 1155 (1 month installation)/ALPL

FLOWRATE (gpm/ft)

0.012
0.01
0.008
0.006
0.004
0.002

NORMAL STRESS, [psf]

1000
10000

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 113
ALPL/TREVIRA 1155 (2 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

0.000001

0.000001

0.000001

0 0.25 0.5 0.75 1 1.25
HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 113
ALPL/TREVIRA 1155 (2 months installed)/ALPL

FLOWRATE
(gpm/ft)

HYDRAULIC
GRADIENT

-- i = 0.25
+- i = 0.5
*- i = 1.00

NORMAL STRESS, [psf]

0.007
0.006
0.005
0.004
0.003
0.002
0.001
0

10000
10000
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 173
ALPL/TREVIRA 1155 (6 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
$T_{20}$
($m^2/s$)

NORMAL STRESS
- 1000 psf
- 5000 psf
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 159
ALPL/TREVIRA 1155 (1 year installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 159
ALPL/TREVIRA 1155 (1 year installation)/ALPL

FLOWRATE (gpm/ft) 0.015
0.025
0.03

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psi]
0
1000
10000
### GEOTEXTILE C (FOSS Z6AF3)

**NORMAL STRESS = 1000 psf**

<table>
<thead>
<tr>
<th>hydraulic gradient</th>
<th>baseline (installed)</th>
<th>after</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>2.1E-03 (0.024)</td>
<td>3.1E-04 (0.0037)</td>
<td>2.7E-04 (0.0033)</td>
<td>6.9E-05 (8.0E-02)</td>
<td>2.8E-05 (3.6E-02)</td>
<td>6.5E-04 (0.0079)</td>
</tr>
<tr>
<td>0.50</td>
<td>2.2E-03 (0.052)</td>
<td>2.5E-04 (0.0060)</td>
<td>3.0E-04 (0.0073)</td>
<td>2.2E-04</td>
<td>4.6E-05 (8.4E-04)</td>
<td>8.6E-04 (0.020)</td>
</tr>
<tr>
<td>1.00</td>
<td>2.3E-04 (0.110)</td>
<td>9.2E-04 (0.044)</td>
<td>2.8E-04 (0.0095)</td>
<td>2.0E-04</td>
<td>4.5E-05</td>
<td>8.6E-04</td>
</tr>
</tbody>
</table>

**NORMAL STRESS = 5000 psf**

<table>
<thead>
<tr>
<th>hydraulic gradient</th>
<th>baseline (installed)</th>
<th>after</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>3.2E-04 (0.037)</td>
<td>1.0E-04 (0.0013)</td>
<td>5.3E-05 (6.4E-02)</td>
<td>9.8E-05 (0.0011)</td>
<td>—</td>
<td>3.6E-04</td>
</tr>
<tr>
<td>0.50</td>
<td>3.3E-04 (0.0979)</td>
<td>1.3E-04 (0.0031)</td>
<td>8.0E-05 (0.0035)</td>
<td>1.5E-04 (4.5E-04)</td>
<td>1.6E-06</td>
<td>3.9E-04</td>
</tr>
<tr>
<td>1.00</td>
<td>3.3E-04 (0.160)</td>
<td>1.5E-04 (0.0070)</td>
<td>4.1E-05 (0.0020)</td>
<td>6.5E-05 (0.0031)</td>
<td>3.0E-06</td>
<td>2.7E-04</td>
</tr>
</tbody>
</table>

Transmissivity 20°C, (m²/s) (Flowrate, (qpm/ft))
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD at 1000 psf
ALPL/geotextile C (FOSS Z6AF3)/ALPL

HYDRAULIC TRANSMISSIVITY
T20 (m²/s)

HYDRAULIC GRADIENT, i (−)

PERIOD OF INSTALLATION

- baseline
- after installed
- 1 month
- 2 months
- 6 months
- 1 year
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD at 5000 psf
ALPL/geotextile C (FOSS Z6AF3)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

0.000001

0.000001

0.000001

0.000001

0 0.25 0.5 0.75 1 1.25

HYDRAULIC GRADIENT, i (-)

PERIOD OF INSTALLATION

– baseline
– after installed
* 1 month
* 2 months
– 6 months
– 1 year
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 103
ALPL/FOSS Z6AF3 (baseline)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
($m^2/s$)

HYDRAULIC GRADIENT, $i$ (-)

NORMAL STRESS
- - 1000 psf
- - 5000 psf
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 203
ALPL/FOSS Z6AF3 (after installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 203
ALPL/FOSS Z6AF3 (after installation)/ALPL

FLOWRATE (gpm/ft)

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psf]
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 167
ALPL/FOSS Z6AF3 (1 month installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

0.00001

NORMAL STRESS
• - 1000 psf
• - 5000 psf

HYDRAULIC GRADIENT, i (-)

0 0.25 0.5 0.75 1 1.25
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 167
ALPL/FOSS Z6AF3 (1 month installation)/ALPL

FLOWRATE (gpm/ft)

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psf]
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 112
ALPL/FOSS Z6AF3 (2 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

0.000001

0.000001

0.000001

NORMAL STRESS

- 1000 psf
- 5000 psf

0 0.25 0.5 0.75 1 1.25

HYDRAULIC GRADIENT, i (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 112
ALPL/FOSS Z6AF3 (2 months installation)/ALPL

FLOWRATE (gpm/ft)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001

NORMAL STRESS, [psf]

10000
100000

HYDRAULIC GRADIENT

- i = 0.25
+ i = 0.5
* i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 202
ALPL/FOSS Z6AF3 (6 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

0.0000001

0.0000001

0.0000001

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 202
ALPL/FOSS Z6AF3 (6 months installation)/ALPL

FLOWRATE (gpm/ft)

0.0025
0.002
0.0015
0.001
0.0005
0
1000
10000

NORMAL STRESS, (psf)

HYDRAULIC GRADIENT

-- i = 0.5
+ i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 158
ALPL/FOSS Z6AF3 (after 1 year installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

NORMAL STRESS
- 1000 psf
- 5000 psf

HYDRAULIC GRADIENT, i (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 158
ALPL/FOSS Z6AF3 (after 1 year installation)/ALPL

FLOW RATE (gpm/ft)

0.05

0.04

0.03

0.02

0.01

0

100

1000

10000

NORMAL STRESS, [psf]

HYDRAULIC
GRADIENT

-- i = 0.25
+

i = 0.5

*-- i = 1.00
### GEOTEXTILE D (EXXON L23205)

#### NORMAL STRESS = 1000 psf

<table>
<thead>
<tr>
<th>hydraulic gradient</th>
<th>baseline</th>
<th>after installed</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>1.8E-04</td>
<td>4.9E-04</td>
<td>3.4E-04</td>
<td>1.6E-04</td>
<td>1.8E-03</td>
<td>1.4E-02</td>
</tr>
<tr>
<td></td>
<td>(0.0022)</td>
<td>(0.0059)</td>
<td>(0.0042)</td>
<td>(0.0018)</td>
<td>(0.0022)</td>
<td>(0.017)</td>
</tr>
<tr>
<td>0.50</td>
<td>2.0E-04</td>
<td>8.5E-04</td>
<td>4.7E-04</td>
<td>1.9E-04</td>
<td>2.5E-03</td>
<td>1.2E-02</td>
</tr>
<tr>
<td></td>
<td>(0.0049)</td>
<td>(0.021)</td>
<td>(0.011)</td>
<td>(0.0047)</td>
<td>(0.0061)</td>
<td>(0.030)</td>
</tr>
<tr>
<td>1.00</td>
<td>2.7E-04</td>
<td>1.1E-03</td>
<td>5.0E-04</td>
<td>2.0E-04</td>
<td>4.0E-03</td>
<td>1.2E-02</td>
</tr>
<tr>
<td></td>
<td>(0.013)</td>
<td>(0.052)</td>
<td>(0.024)</td>
<td>(0.0095)</td>
<td>(0.019)</td>
<td>(0.052)</td>
</tr>
</tbody>
</table>

#### NORMAL STRESS = 5000 psf

<table>
<thead>
<tr>
<th>hydraulic gradient</th>
<th>baseline</th>
<th>after installed</th>
<th>1 month</th>
<th>2 months</th>
<th>6 months</th>
<th>1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>4.9E-05</td>
<td>8.1E-05</td>
<td>1.2E-04</td>
<td>3.5E-05</td>
<td>1.9E-04</td>
<td>6.2E-03</td>
</tr>
<tr>
<td></td>
<td>(6.3E-02)</td>
<td>(9.8E-02)</td>
<td>(0.0014)</td>
<td>(4.5E-02)</td>
<td>(0.0022)</td>
<td>(0.0750)</td>
</tr>
<tr>
<td>0.50</td>
<td>7.2E-05</td>
<td>1.1E-04</td>
<td>1.5E-04</td>
<td>4.9E-05</td>
<td>2.6E-04</td>
<td>7.9E-03</td>
</tr>
<tr>
<td></td>
<td>(0.0017)</td>
<td>(0.0026)</td>
<td>(0.0036)</td>
<td>(0.0012)</td>
<td>(0.0063)</td>
<td>(0.019)</td>
</tr>
<tr>
<td>1.00</td>
<td>4.1E-05</td>
<td>1.4E-04</td>
<td>1.9E-04</td>
<td>5.3E-05</td>
<td>3.0E-04</td>
<td>6.7E-03</td>
</tr>
<tr>
<td></td>
<td>(0.0019)</td>
<td>(0.0069)</td>
<td>(0.0093)</td>
<td>(0.0026)</td>
<td>(0.014)</td>
<td>(0.033)</td>
</tr>
</tbody>
</table>
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD at 1000 psf
ALPL/geotextile D (EXXON L23205)/ALPL

HYDRAULIC
TRANSMISSIVITY
T20
(m^2/s)

0.001

0.0001

0.00001

0.000001

0 0.25 0.5 0.75 1 1.25

HYDRAULIC GRADIENT, i (-)

PERIOD OF
INSTALLATION

baseline
after installed
1 month
2 months
6 months
1 year
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
NORMAL LOAD at 5000 psf
ALPL/geotextile D (EXXON L23205)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

PERIOD OF INSTALLATION
- baseline
- after installed
- 1 month
- 2 months
- 6 months
- 1 year

HYDRAULIC GRADIENT, i (–)
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 100
ALPL/EXXON L23205 (baseline)/ALPL

HYDRAULIC TRANSMISSIVITY $T_{20}$ ($m^2/s$)

0.000001

0.00001

0.0001

HYDRAULIC GRADIENT, $i$ (-)

0

0.25

0.5

0.75

1

1.25

NORMA1 STRESS

- 1000 psf

- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 100
ALPL/EXXON L23205 (baseline)/ALPL

FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 100
ALPL/EXXON L23205 (baseline)/ALPL

FLOWRATE (gpm/ft)

HYDRAULIC GRADIENT

- i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psf]
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 154
ALPL/EXXON L23205 (after installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m^2/s)

NORMAL STRESS
- 1000 psf
- 5000 psf

HYDRAULIC GRADIENT, i (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 154
ALPL/EXXON L23205 (after installation)/ALPL

FLOWRATE vs. NORMAL STRESS
FLOWRATE (gpm/ft)
N O R M A L S T R E S S, [psi]

HYDRAULIC GRADIENT
- i = 0.25
+ i = 0.5
* i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 171
ALPL/EXXON L23205 (1 month installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20
(m²/s)

HYDRAULIC GRADIENT, i (–)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 171
ALPL/EXXON L23205 (1 month installation)/ALPL

FLOWRATE (gpm/ft)

HYDRAULIC GRADIENT

- i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psf]
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 201
ALPL/EXXON L23205 (2 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20 (m²/s)

HYDRAULIC GRADIENT, i (-)

NORMAL STRESS
- 1000 psf
- 5000 psf
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 201
ALPL/EXXON L23205 (2 months installation)/ALPL

FLOWRATE (gpm/ft)

NORMAL STRESS, [psf]

HYDRAULIC GRADIENT

-- i = 0.25
+ i = 0.5
* i = 1.00
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 172
ALPL/EXXON L23205 (6 months installation)/ALPL

HYDRAULIC TRANSMISSIVITY

\[ T_{20} (m^2/s) \]

NOMINAL STRESS

- 1000 psf
- 5000 psf

HYDRAULIC GRADIENT, \( i (-) \)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 172
ALPL/EXXON L23205 (6 months installation)/ALPL

FLOWRATE (gpm/ft)

HYDRAULIC GRADIENT

- i = 0.25
+ i = 0.5
* i = 1.00

NORMAL STRESS, [psf]
TRANSMISSIVITY DATA
SOUTHERN RAILWAY
TEST NO.: 157
ALPL/EXXON L23205 (after 1 year installation)/ALPL

HYDRAULIC TRANSMISSIVITY
T20 (m^2/s)

NORMAL STRESS
- ○ 1000 psf
- □ 5000 psf

HYDRAULIC GRADIENT, i (-)
FLOWRATE DATA
SOUTHERN RAILWAY
TEST NO.: 157
ALPL/EXXON L23205 (after 1 year installation)/ALPL

FLOWRATE (gpm/ft)

0.6
0.5
0.4
0.3
0.2
0.1
0
1000
10000

NORMAL STRESS, [psf]

HYDRAULIC GRADIENT

-- i = 0.25
+- i = 0.5
-* i = 1.00
Appendix F Permittivity Test Results
PERMITTIVITY TEST

| SAMPLE: | HOECHST S11551 NEW |
| TEST#:   | H1PT100           |
| DATE:    | 02-07-1987        |
| TEMPERATURE= | 23.6°C           |
| FLOW VOLUME= | 814003.6 mm³      |
| TIME READ. | PERMITTIVITY | FLOWRATE |
| [sec] | [1/sec] | [mm/sec] |
| 8.4   | 56.40E-02 | 30.60E+00 |
| 8.7   | 54.45E-02 | 29.54E+00 |
| 8.8   | 53.83E-02 | 29.21E+00 |
| 9.8   | 48.34E-02 | 26.23E+00 |
| 10.3  | 45.99E-02 | 24.95E+00 |
| AVERAGE PERMITTIVITY= | 51.80E-02 [1/sec] |
| AVERAGE FLOWRATE= | 28.11E+00 [mm/sec] |

<p>| SAMPLE: | HOECHST S11551 NEW |
| TEST#:   | H1PT200           |
| DATE:    | 02-07-1987        |
| TEMPERATURE= | 23.6°C           |
| FLOW VOLUME= | 814003.6 mm³      |
| TIME READ. | PERMITTIVITY | FLOWRATE |
| [sec] | [1/sec] | [mm/sec] |
| 7.5   | 63.33E-02 | 34.36E+00 |
| 7.2   | 65.61E-02 | 35.60E+00 |
| 7.0   | 67.67E-02 | 36.72E+00 |
| 7.5   | 63.16E-02 | 34.27E+00 |
| 7.7   | 61.52E-02 | 33.38E+00 |
| AVERAGE PERMITTIVITY= | 64.26E-02 [1/sec] |
| AVERAGE FLOWRATE= | 34.87E+00 [mm/sec] |</p>
<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>sec</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>8.8</td>
<td>53.59E-02</td>
<td>29.08E+00</td>
</tr>
<tr>
<td>8.6</td>
<td>55.28E-02</td>
<td>29.99E+00</td>
</tr>
<tr>
<td>8.8</td>
<td>53.89E-02</td>
<td>29.64E+00</td>
</tr>
<tr>
<td>8.9</td>
<td>53.23E-02</td>
<td>28.88E+00</td>
</tr>
<tr>
<td>8.8</td>
<td>53.83E-02</td>
<td>29.21E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 53.96E-02 [1/sec]
AVERAGE FLOWRATE= 29.28E+00 [mm/sec]
### PERMITTIVITY TEST

**SAMPLE:** HOECHST S11551  
**TEST#:** H1PT500  
**DATE:** 02-07-1987

**TEMPERATURE:** 23.6 °C  
**FLOW VOLUME:** 81403.6 [cm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY (1/sec)</th>
<th>FLOWRATE (cm³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>66.63E-02</td>
<td>36.15E+00</td>
</tr>
<tr>
<td>7.2</td>
<td>65.89E-02</td>
<td>35.75E+00</td>
</tr>
<tr>
<td>7.1</td>
<td>66.72E-02</td>
<td>36.20E+00</td>
</tr>
<tr>
<td>7.4</td>
<td>64.02E-02</td>
<td>34.73E+00</td>
</tr>
<tr>
<td>7.2</td>
<td>65.79E-02</td>
<td>35.70E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY:** 65.81E-02 [1/sec]  
**AVERAGE FLOWRATE:** 35.71E+00 [cm³/sec]

---

**SAMPLE:** HOECHST S11551  
**TEST#:** H1PT111  
**DATE:** 02-07-1987

**TEMPERATURE:** 20.6 °C  
**FLOW VOLUME:** 407001.8 [cm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY (1/sec)</th>
<th>FLOWRATE (cm³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>31.51E-02</td>
<td>15.96E+00</td>
</tr>
<tr>
<td>7.8</td>
<td>32.31E-02</td>
<td>16.37E+00</td>
</tr>
<tr>
<td>7.9</td>
<td>32.11E-02</td>
<td>16.27E+00</td>
</tr>
<tr>
<td>8.4</td>
<td>30.20E-02</td>
<td>15.30E+00</td>
</tr>
<tr>
<td>7.8</td>
<td>32.52E-02</td>
<td>16.48E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY:** 31.73E-02 [1/sec]  
**AVERAGE FLOWRATE:** 16.08E+00 [cm³/sec]
PERMITTIVITY TEST

SAMPLE: HOECHST S11551 AFTER INST.

TEST#: H1PT211 DATE: 02-07-1987

TEMPERATURE= 21.7 [°C]
FLOW VOLUME= 407001.8 [mm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>39.04E-02</td>
<td>20.27E+00</td>
</tr>
<tr>
<td>5.9</td>
<td>41.67E-02</td>
<td>21.64E+00</td>
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<td>41.46E-02</td>
<td>21.53E+00</td>
</tr>
<tr>
<td>6.4</td>
<td>38.98E-02</td>
<td>20.24E+00</td>
</tr>
<tr>
<td>6.3</td>
<td>39.29E-02</td>
<td>20.40E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 40.09E-02 [1/sec]
AVERAGE FLOWRATE= 20.81E+00 [mm/sec]

SAMPLE: HOECHST S11551 1 MONTH AFTER INST.

TEST#: H1PT122 DATE: 02-07-1987

TEMPERATURE= 21.7 [°C]
FLOW VOLUME= 407001.8 [mm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>35.36E-02</td>
<td>18.36E+00</td>
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<td>7.5</td>
<td>33.00E-02</td>
<td>17.14E+00</td>
</tr>
<tr>
<td>6.5</td>
<td>38.37E-02</td>
<td>19.93E+00</td>
</tr>
<tr>
<td>7.3</td>
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</tr>
<tr>
<td>7.0</td>
<td>35.36E-02</td>
<td>18.36E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 35.25E-02 [1/sec]
AVERAGE FLOWRATE= 18.30E+00 [mm/sec]
Tab. [F.5]
PERMITTIVITY TEST

SAMPLE: HOECHST S11551 1 MONTH AFTER INST.
TEST#: H1PT222 DATE: 02-07-1997

<table>
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<th>TIME READ</th>
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<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>38.55E-02</td>
<td>20.02E+00</td>
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<tr>
<td>7.2</td>
<td>34.47E-02</td>
<td>17.90E+00</td>
</tr>
<tr>
<td>6.4</td>
<td>38.37E-02</td>
<td>19.93E+00</td>
</tr>
<tr>
<td>7.5</td>
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<td>17.25E+00</td>
</tr>
<tr>
<td>6.1</td>
<td>40.57E-02</td>
<td>21.07E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 37.04E-02 [1/sec]
AVERAGE FLOWRATE = 19.23E+00 [mm/sec]

SAMPLE: HOECHST S11551 2 MONTHS AFTER INST.
TEST#: H1PT133 DATE: 02-07-1987

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
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</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>52.26E-02</td>
<td>28.56E+00</td>
</tr>
<tr>
<td>10.0</td>
<td>47.04E-02</td>
<td>25.70E+00</td>
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<tr>
<td>10.0</td>
<td>47.04E-02</td>
<td>25.70E+00</td>
</tr>
<tr>
<td>11.0</td>
<td>42.76E-02</td>
<td>23.37E+00</td>
</tr>
<tr>
<td>12.0</td>
<td>39.20E-02</td>
<td>21.42E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 45.66E-02 [1/sec]
AVERAGE FLOWRATE = 24.95E+00 [mm/sec]
PERMITTIVITY TEST

SAMPLE: HOECHST S11551 2 MONTHS AFTER INST.

TEST#: H1PT233   DATE: 02-07-1987

TEMPERATURE= 23.9 °C
FLOW VOLUME= 814003.6 mm³

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>42.76E-02</td>
<td>23.37E+00</td>
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<tr>
<td>11.0</td>
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<td>23.37E+00</td>
</tr>
<tr>
<td>11.0</td>
<td>42.76E-02</td>
<td>23.37E+00</td>
</tr>
<tr>
<td>12.0</td>
<td>39.20E-02</td>
<td>21.42E+00</td>
</tr>
<tr>
<td>11.0</td>
<td>42.76E-02</td>
<td>23.37E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 42.05E-02 [1/sec]
AVERAGE FLOWRATE= 22.98E+00 [mm/sec]
### Tab. EF.7

PERMITTIVITY TEST

<table>
<thead>
<tr>
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<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
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</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>8.7</td>
<td>54.20E-02</td>
<td>29.41E+00</td>
</tr>
<tr>
<td>8.8</td>
<td>54.08E-02</td>
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<td>8.7</td>
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<tr>
<td>9.3</td>
<td>50.94E-02</td>
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</tr>
<tr>
<td>9.1</td>
<td>52.06E-02</td>
<td>28.25E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 53.41E-02 [1/sec]
AVERAGE FLOWRATE = 28.84E+00 [mm/sec]

---

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>7.3</td>
<td>64.89E-02</td>
<td>35.21E+00</td>
</tr>
<tr>
<td>7.8</td>
<td>60.73E-02</td>
<td>32.95E+00</td>
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<td>6.2</td>
<td>76.41E-02</td>
<td>41.46E+00</td>
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<tr>
<td>7.5</td>
<td>63.16E-02</td>
<td>34.27E+00</td>
</tr>
<tr>
<td>7.3</td>
<td>64.89E-02</td>
<td>35.21E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 66.02E-02 [1/sec]
AVERAGE FLOWRATE = 35.82E+00 [mm/sec]
PERMITTIVITY TEST

SAMPLE: HOECHST S21850 NEW

TEST#: H2PT300       DATE: 02-07-1987

TEMPERATURE= 23.6°C
FLOW VOLUME= 814003.6 mm³

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>49.87E-02</td>
<td>27.06E+00</td>
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<tr>
<td>9.2</td>
<td>51.49E-02</td>
<td>27.94E+00</td>
</tr>
<tr>
<td>9.4</td>
<td>50.40E-02</td>
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<tr>
<td>9.6</td>
<td>49.35E-02</td>
<td>26.77E+00</td>
</tr>
<tr>
<td>9.9</td>
<td>47.85E-02</td>
<td>25.96E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 49.79E-02 [1/sec]
AVERAGE FLOWRATE= 27.02E+00 [mm/sec]

SAMPLE: HOECHST S21850 NEW

TEST#: H2PT400       DATE: 02-07-1987

TEMPERATURE= 23.6°C
FLOW VOLUME= 814003.6 mm³

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.8</td>
<td>69.67E-02</td>
<td>37.80E+00</td>
</tr>
<tr>
<td>7.1</td>
<td>66.72E-02</td>
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<tr>
<td>7.3</td>
<td>64.89E-02</td>
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</tr>
<tr>
<td>7.6</td>
<td>62.33E-02</td>
<td>33.82E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 65.70E-02 [1/sec]
AVERAGE FLOWRATE= 35.65E+00 [mm/sec]
Tab. [F.9]

PERMITTIVITY TEST

SAMPLE: HOECHST 521850 NEW
TEST#: H2PT500 DATE: 02-07-1987

TEMPERATURE= 23.6 [C]
FLOW VOLUME= 814003.6 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
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<tr>
<td>7.7</td>
<td>61.52E-02</td>
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<td>7.2</td>
<td>65.79E-02</td>
<td>35.70E+00</td>
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<tr>
<td>7.5</td>
<td>63.16E-02</td>
<td>34.27E+00</td>
</tr>
<tr>
<td>7.8</td>
<td>60.73E-02</td>
<td>32.95E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 63.97E-02 [1/sec]
AVERAGE FLOWRATE= 34.71E+00 [mm/sec]

SAMPLE: HOECHST S21850 AFTER INST.
TEST#: H2PT111 DATE: 02-07-1987

TEMPERATURE= 21.1 [C]
FLOW VOLUME= 814003.6 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.2</td>
<td>29.10E-02</td>
<td>14.91E+00</td>
</tr>
<tr>
<td>18.0</td>
<td>27.87E-02</td>
<td>14.28E+00</td>
</tr>
<tr>
<td>20.1</td>
<td>24.99E-02</td>
<td>12.80E+00</td>
</tr>
<tr>
<td>21.8</td>
<td>23.04E-02</td>
<td>11.80E+00</td>
</tr>
<tr>
<td>21.0</td>
<td>23.89E-02</td>
<td>12.24E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 25.78E-02 [1/sec]
AVERAGE FLOWRATE= 13.21E+00 [mm/sec]
### PERMITTIVITY TEST

**SAMPLE:** HOECHST S21850  
**TEST#:** H2PT211  
**DATE:** 02-07-1987

**TEMPERATURE =** 21.9°C  
**FLOW VOLUME =** 81403.6 mm³

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [C/µsec]</th>
<th>FLOWRATE [mm/sec]</th>
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</thead>
<tbody>
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<td>31.19E-02</td>
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</tr>
<tr>
<td>19.4</td>
<td>25.40E-02</td>
<td>13.25E+00</td>
</tr>
<tr>
<td>14.7</td>
<td>33.52E-02</td>
<td>17.49E+00</td>
</tr>
<tr>
<td>17.7</td>
<td>27.84E-02</td>
<td>14.52E+00</td>
</tr>
<tr>
<td>18.0</td>
<td>27.38E-02</td>
<td>14.28E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY =** 29.07E-02 [C/µsec]  
**AVERAGE FLOWRATE =** 15.16E+00 [mm/sec]

---

**SAMPLE:** HOECHST S21850  
**TEST#:** H2PT122  
**DATE:** 02-07-1987

**TEMPERATURE =** 22.5°C  
**FLOW VOLUME =** 203500.9 mm³

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [C/µsec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.5</td>
<td>62.31E-03</td>
<td>32.95E-01</td>
</tr>
<tr>
<td>17.6</td>
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<td>36.51E-01</td>
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<tr>
<td>17.7</td>
<td>68.65E-03</td>
<td>36.30E-01</td>
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<td>21.7</td>
<td>56.00E-03</td>
<td>29.61E-01</td>
</tr>
<tr>
<td>25.2</td>
<td>52.38E-03</td>
<td>27.70E-01</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY =** 61.68E-03 [C/µsec]  
**AVERAGE FLOWRATE =** 32.62E-01 [mm/sec]
Tab. [F.11]
PERMITTIVITY TEST

SAMPLE: HOECHST S21860 1 MONTH AFTER INST.
TEST#: H2PT222 DATE: 02-07-1987

<table>
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<tr>
<th>TEMPERATURE</th>
<th>FLOW VOLUME</th>
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</thead>
<tbody>
<tr>
<td>23.9 [°C]</td>
<td>203500.9 [mm³]</td>
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<table>
<thead>
<tr>
<th>TIME READ. PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec] [1/sec] [mm/sec]</td>
<td></td>
</tr>
<tr>
<td>15.0 78.39E-03 42.84E-01</td>
<td></td>
</tr>
<tr>
<td>15.0 78.39E-03 42.84E-01</td>
<td></td>
</tr>
<tr>
<td>15.0 78.39E-03 42.84E-01</td>
<td></td>
</tr>
<tr>
<td>20.0 58.80E-03 32.13E-01</td>
<td></td>
</tr>
<tr>
<td>15.0 78.39E-03 42.84E-01</td>
<td></td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 74.47E-03 [1/sec]
AVERAGE FLOWRATE= 40.70E-01 [mm/sec]

SAMPLE: HOECHST S21850 2 MONTHS AFTER INST.
TEST#: H2PT133 DATE: 02-07-1987

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>FLOW VOLUME</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.9 [°C]</td>
<td>407001.8 [mm³]</td>
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</tbody>
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<table>
<thead>
<tr>
<th>TIME READ. PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec] [1/sec] [mm/sec]</td>
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</tr>
<tr>
<td>10.8 21.78E-02 11.90E+00</td>
<td></td>
</tr>
<tr>
<td>11.8 19.93E-02 10.89E+00</td>
<td></td>
</tr>
<tr>
<td>11.4 20.63E-02 11.27E+00</td>
<td></td>
</tr>
<tr>
<td>12.0 19.60E-02 10.71E+00</td>
<td></td>
</tr>
<tr>
<td>12.0 19.60E-02 10.71E+00</td>
<td></td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 20.31E-02 [1/sec]
AVERAGE FLOWRATE= 11.10E+00 [mm/sec]
### Tab. [F.12]

**PERMITTIVITY TEST**

**SAMPLE:** HOECHST 21850 2 MONTHS AFTER INST.  
**TEST#:** H2PT233  
**DATE:** 02-07-1987

**TEMPERATURE=** 23.9 [°C]  
**FLOW VOLUME=** 407001.8 [mm^3]

<table>
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<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
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<td>16.80E-02</td>
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<tr>
<td>13.0</td>
<td>18.09E-02</td>
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<tr>
<td>14.0</td>
<td>16.80E-02</td>
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</tr>
<tr>
<td>14.0</td>
<td>16.80E-02</td>
<td>91.80E-01</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY=** 17.06E-02 [1/sec]  
**AVERAGE FLOWRATE=** 93.21E-01 [mm/sec]

---

**SAMPLE:** FOSS Z6AF7 NEW  
**TEST#:** FOPT100  
**DATE:** 02-07-1987

**TEMPERATURE=** 23.6 [°C]  
**FLOW VOLUME=** 1628007 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ. [sec]</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>12.24E-01</td>
<td>66.42E+00</td>
</tr>
<tr>
<td>7.5</td>
<td>12.70E-01</td>
<td>68.91E+00</td>
</tr>
<tr>
<td>8.1</td>
<td>11.77E-01</td>
<td>63.86E+00</td>
</tr>
<tr>
<td>7.8</td>
<td>12.12E-01</td>
<td>65.74E+00</td>
</tr>
<tr>
<td>8.7</td>
<td>10.92E-01</td>
<td>59.22E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY=** 11.95E-01 [1/sec]  
**AVERAGE FLOWRATE=** 64.83E+00 [mm/sec]
Tab. [F.13]
PERMITTIVITY TEST

SAMPLE: FOSS Z6AF3 NEW
TEST#: FOPT200 DATE: 02-07-1987
TEMPERATURE= 23.6 [C]
FLOW VOLUME= 1628007 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>7.0</td>
<td>13.53E-01</td>
<td>73.44E+00</td>
</tr>
<tr>
<td>7.6</td>
<td>12.47E-01</td>
<td>67.64E+00</td>
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<tr>
<td>7.8</td>
<td>12.15E-01</td>
<td>65.91E+00</td>
</tr>
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<td>8.5</td>
<td>11.15E-01</td>
<td>60.48E+00</td>
</tr>
<tr>
<td>9.2</td>
<td>10.30E-01</td>
<td>55.88E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 11.92E-01 [1/sec]
AVERAGE FLOWRATE= 64.67E+00 [mm/sec]

SAMPLE: FOSS Z6AF3 NEW
TEST#: FOPT300 DATE: 02-07-1987
TEMPERATURE= 23.6 [C]
FLOW VOLUME= 1628007 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ.</th>
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<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>6.6</td>
<td>14.36E-01</td>
<td>77.89E+00</td>
</tr>
<tr>
<td>6.7</td>
<td>14.14E-01</td>
<td>76.73E+00</td>
</tr>
<tr>
<td>7.2</td>
<td>13.16E-01</td>
<td>71.40E+00</td>
</tr>
<tr>
<td>7.8</td>
<td>12.15E-01</td>
<td>65.91E+00</td>
</tr>
<tr>
<td>7.4</td>
<td>12.80E-01</td>
<td>69.47E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 13.32E-01 [1/sec]
AVERAGE FLOWRATE= 72.28E+00 [mm/sec]
### PERMITTIVITY TEST

**SAMPLE:** FOSS Z6AF3 NEW  
**TEST #:** FOPT400  
**DATE:** 02-07-1987

**TEMPERATURE:** 23.6 [°C]  
**FLOW VOLUME:** 1628007 [mm³]

**TIME READ.**  
**PERMITTIVITY**  
**FLOWRATE**  
<table>
<thead>
<tr>
<th>[sec]</th>
<th>[1/sec]</th>
<th>[mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>14.80E-01</td>
<td>80.32E+00</td>
</tr>
<tr>
<td>6.1</td>
<td>15.53E-01</td>
<td>84.27E+00</td>
</tr>
<tr>
<td>7.0</td>
<td>13.53E-01</td>
<td>73.44E+00</td>
</tr>
<tr>
<td>5.9</td>
<td>16.06E-01</td>
<td>87.13E+00</td>
</tr>
<tr>
<td>7.6</td>
<td>12.47E-01</td>
<td>67.64E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY =** 14.48E-01 [1/sec]  
**AVERAGE FLOWRATE =** 73.86E+00 [mm/sec]

---

**SAMPLE:** FOSS Z6AF3 NEW  
**TEST #:** FOPT500  
**DATE:** 02-07-1987

**TEMPERATURE:** 23.6 [°C]  
**FLOW VOLUME:** 1628007 [mm³]

**TIME READ.**  
**PERMITTIVITY**  
**FLOWRATE**  
<table>
<thead>
<tr>
<th>[sec]</th>
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<th>[mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>13.34E-01</td>
<td>72.40E+00</td>
</tr>
<tr>
<td>6.3</td>
<td>15.04E-01</td>
<td>81.60E+00</td>
</tr>
<tr>
<td>6.5</td>
<td>14.58E-01</td>
<td>79.09E+00</td>
</tr>
<tr>
<td>7.4</td>
<td>12.80E-01</td>
<td>69.47E+00</td>
</tr>
<tr>
<td>7.7</td>
<td>12.30E-01</td>
<td>66.76E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY =** 13.61E-01 [1/sec]  
**AVERAGE FLOWRATE =** 73.86E+00 [mm/sec]
<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
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<td>[mm/sec]</td>
</tr>
<tr>
<td>5.2</td>
<td>23.66E-02</td>
<td>12.29E+00</td>
</tr>
<tr>
<td>5.3</td>
<td>23.31E-02</td>
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<td>4.6</td>
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<td>14.09E+00</td>
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<tr>
<td>5.1</td>
<td>24.27E-02</td>
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</tr>
<tr>
<td>5.6</td>
<td>22.10E-02</td>
<td>11.47E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 24.09E-02 [1/sec]
AVERAGE FLOWRATE = 12.51E+00 [mm/sec]
Tab. [F.16]

PERMITTIVITY TEST

SAMPLE: FOSS Z6AF3 1 MONTH AFTER INST.

TEST#: FOPT122 DATE: 02-07-1987

TEMPERATURE= 23.9 [°C]
FLOW VOLUME= 407001.8 [mm³]

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>10.0</td>
<td>23.52E-02</td>
<td>12.85E+00</td>
</tr>
<tr>
<td>10.0</td>
<td>23.52E-02</td>
<td>12.85E+00</td>
</tr>
<tr>
<td>12.0</td>
<td>19.60E-02</td>
<td>10.71E+00</td>
</tr>
<tr>
<td>13.0</td>
<td>18.09E-02</td>
<td>98.36E-01</td>
</tr>
<tr>
<td>15.0</td>
<td>15.68E-02</td>
<td>85.68E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 20.08E-02 [1/sec]
AVERAGE FLOWRATE= 10.97E+00 [mm/sec]

SAMPLE: FOSS Z6AF3 1 MONTH AFTER INST.

TEST#: FOPT222 DATE: 02-07-1987

TEMPERATURE= 23.9 [°C]
FLOW VOLUME= 407001.8 [mm³]

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>10.0</td>
<td>23.52E-02</td>
<td>12.85E+00</td>
</tr>
<tr>
<td>10.0</td>
<td>23.52E-02</td>
<td>12.85E+00</td>
</tr>
<tr>
<td>12.0</td>
<td>19.60E-02</td>
<td>10.71E+00</td>
</tr>
<tr>
<td>10.0</td>
<td>27.52E-02</td>
<td>12.85E+00</td>
</tr>
<tr>
<td>11.0</td>
<td>21.38E-02</td>
<td>11.68E+00</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 22.31E-02 [1/sec]
AVERAGE FLOWRATE= 12.19E+00 [mm/sec]
### PERMITTIVITY TEST

**Sample:** FOSS Z6AF3 2 MONTHS AFTER INST.

**Test #:** FOPT133  
**Date:** 02-07-1987

**Temperature:** 23.9 °C

**Flow Volume:** 814003.6 mm³

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Permittivity (1/sec)</th>
<th>Flowrate (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>52.26E-02</td>
<td>28.56E+00</td>
</tr>
<tr>
<td>8.0</td>
<td>58.80E-02</td>
<td>32.13E+00</td>
</tr>
<tr>
<td>9.0</td>
<td>52.26E-02</td>
<td>28.56E+00</td>
</tr>
<tr>
<td>11.0</td>
<td>42.76E-02</td>
<td>23.37E+00</td>
</tr>
</tbody>
</table>

**Average Permittivity:** 51.67E-02 [1/sec]

**Average Flowrate:** 28.23E+00 [mm/sec]

---

**Sample:** FOSS Z6AF3 2 MONTHS AFTER INST.

**Test #:** FOPT233  
**Date:** 02-07-1987

**Temperature:** 23.9 °C

**Flow Volume:** 814003.6 mm³

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Permittivity (1/sec)</th>
<th>Flowrate (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>52.26E-02</td>
<td>28.56E+00</td>
</tr>
<tr>
<td>9.0</td>
<td>52.26E-02</td>
<td>28.56E+00</td>
</tr>
<tr>
<td>9.0</td>
<td>52.26E-02</td>
<td>28.56E+00</td>
</tr>
<tr>
<td>10.0</td>
<td>47.04E-02</td>
<td>25.70E+00</td>
</tr>
<tr>
<td>11.0</td>
<td>42.76E-02</td>
<td>23.37E+00</td>
</tr>
</tbody>
</table>

**Average Permittivity:** 49.32E-02 [1/sec]

**Average Flowrate:** 26.95E+00 [mm/sec]
Tab. [F.18]

PERMITTIVITY TEST

SAMPLE: EXXON L23209

TEST#: EXPT100 DATE: 02-07-1987

TEMPERATURE = 23.6 [C]
FLOW VOLUME = 407001.8 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ [sec]</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.4</td>
<td>10.56E-02</td>
<td>57.27E-01</td>
</tr>
<tr>
<td>18.5</td>
<td>12.81E-02</td>
<td>69.51E-01</td>
</tr>
<tr>
<td>22.8</td>
<td>10.41E-02</td>
<td>56.47E-01</td>
</tr>
<tr>
<td>21.6</td>
<td>10.96E-02</td>
<td>59.44E-01</td>
</tr>
<tr>
<td>21.5</td>
<td>11.02E-02</td>
<td>59.78E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 11.15E-02 [1/sec]
AVERAGE FLOWRATE = 60.49E-01 [mm/sec]

---

SAMPLE: EXXON L23209 NEW

TEST#: EXPT200 DATE: 02-07-1987

TEMPERATURE = 23.6 [C]
FLOW VOLUME = 407001.8 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ [sec]</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.6</td>
<td>10.95E-02</td>
<td>59.39E-01</td>
</tr>
<tr>
<td>22.0</td>
<td>10.77E-02</td>
<td>58.42E-01</td>
</tr>
<tr>
<td>23.0</td>
<td>10.30E-02</td>
<td>55.88E-01</td>
</tr>
<tr>
<td>22.1</td>
<td>10.71E-02</td>
<td>58.13E-01</td>
</tr>
<tr>
<td>23.4</td>
<td>10.12E-02</td>
<td>54.90E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 10.57E-02 [1/sec]
AVERAGE FLOWRATE = 57.34E-01 [mm/sec]
Tab. [F.19]  
PERMITTIVITY TEST

SAMPLE: EXXON L23209 NEW  
TEST#: EXPT300  DATE: 02-07-1987

TEMPERATURE= 23.6 [°C]
FLOW VOLUME= 407001.8 [mm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.0</td>
<td>87.73E-03</td>
<td>47.60E-01</td>
</tr>
<tr>
<td>28.7</td>
<td>87.53E-03</td>
<td>44.78E-01</td>
</tr>
<tr>
<td>27.1</td>
<td>87.40E-03</td>
<td>47.42E-01</td>
</tr>
<tr>
<td>27.9</td>
<td>84.84E-03</td>
<td>46.03E-01</td>
</tr>
<tr>
<td>30.4</td>
<td>78.04E-03</td>
<td>42.34E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 84.11E-03 [1/sec]  
AVERAGE FLOWRATE= 45.64E-01 [mm/sec]

SAMPLE: EXXON L23209 NEW  
TEST#: EXPT400  DATE: 02-07-1987

TEMPERATURE= 23.6 [°C]
FLOW VOLUME= 407001.8 [mm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.5</td>
<td>13.51E-02</td>
<td>73.31E-01</td>
</tr>
<tr>
<td>18.7</td>
<td>12.67E-02</td>
<td>68.73E-01</td>
</tr>
<tr>
<td>18.7</td>
<td>12.67E-02</td>
<td>68.73E-01</td>
</tr>
<tr>
<td>19.0</td>
<td>12.49E-02</td>
<td>67.75E-01</td>
</tr>
<tr>
<td>18.6</td>
<td>12.73E-02</td>
<td>69.09E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 12.81E-02 [1/sec]  
AVERAGE FLOWRATE= 69.52E-01 [mm/sec]
PERMITTIVITY TEST

SAMPLE: EXXDN L23209 NEW

TEST#: EXPT500 DATE: 02-07-1987

TEMPERATURE= 23.6 [C]
FLOW VOLUME= 407001.8 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
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</thead>
<tbody>
<tr>
<td>17.9</td>
<td>13.23E-02</td>
<td>71.80E-01</td>
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<tr>
<td>18.4</td>
<td>12.87E-02</td>
<td>69.85E-01</td>
</tr>
<tr>
<td>17.9</td>
<td>13.23E-02</td>
<td>71.80E-01</td>
</tr>
<tr>
<td>18.3</td>
<td>12.94E-02</td>
<td>70.23E-01</td>
</tr>
<tr>
<td>20.2</td>
<td>11.73E-02</td>
<td>63.62E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 12.80E-02 [1/sec]
AVERAGE FLOWRATE= 69.46E-01 [mm/sec]
Tab. [F.21]
PERMITTIVITY TEST

SAMPLE: EXXON L23209 AFTER INST.
TEST#: . EXPT111 DATE: 02-07-1987

TEMPERATURE= 21.9 [C]
FLOW VOLUME= 203500.9 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.2</td>
<td>24.54E-03</td>
<td>12.80E-01</td>
</tr>
<tr>
<td>49.1</td>
<td>25.09E-03</td>
<td>13.09E-01</td>
</tr>
<tr>
<td>53.6</td>
<td>22.98E-03</td>
<td>11.99E-01</td>
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<tr>
<td>50.9</td>
<td>24.20E-03</td>
<td>12.62E-01</td>
</tr>
<tr>
<td>49.4</td>
<td>24.94E-03</td>
<td>13.01E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 24.35E-03 [1/sec]
AVERAGE FLOWRATE= 12.70E-01 [mm/sec]

SAMPLE: EXXON Z6AF3 AFTER INST.
TEST#: EXPT211 DATE: 02-07-1987

TEMPERATURE= 21.9 [C]
FLOW VOLUME= 407001.8 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOWRATE [mm/sec]</th>
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</thead>
<tbody>
<tr>
<td>75.6</td>
<td>32.59E-03</td>
<td>17.00E-01</td>
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<td>85.2</td>
<td>28.92E-03</td>
<td>15.08E-01</td>
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<tr>
<td>80.1</td>
<td>30.76E-03</td>
<td>16.04E-01</td>
</tr>
<tr>
<td>99.3</td>
<td>24.81E-03</td>
<td>12.94E-01</td>
</tr>
<tr>
<td>98.3</td>
<td>25.06E-03</td>
<td>13.07E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 28.43E-03 [1/sec]
AVERAGE FLOWRATE= 14.93E-01 [mm/sec]
PERMITTIVITY TEST

SAMPLE: EXXON L23209 1 MONTH AFTER INST.
TEST#: EXPT122 DATE: 02-07-1987

TEMPERATURE = 21.7°C
FLOW VOLUME = 407001.8 mm³

<table>
<thead>
<tr>
<th>TIME READ (sec)</th>
<th>PERMITTIVITY (1/sec)</th>
<th>FLOW RATE (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>77.4</td>
<td>31.98E-03</td>
<td>16.60E-01</td>
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<tr>
<td>76.1</td>
<td>32.52E-03</td>
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<td>77.4</td>
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<td>16.60E-01</td>
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<td>79.6</td>
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</tr>
<tr>
<td>82.9</td>
<td>29.86E-03</td>
<td>15.50E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 31.49E-03 [1/sec]
AVERAGE FLOW RATE = 16.75E-01 [mm/sec]

---

SAMPLE: EXXON L23209 1 MONTH AFTER INST.
TEST#: EXPT222 DATE: 02-07-1987

TEMPERATURE = 21.7°C
FLOW VOLUME = 203500.9 mm³

<table>
<thead>
<tr>
<th>TIME READ (sec)</th>
<th>PERMITTIVITY (1/sec)</th>
<th>FLOW RATE (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3</td>
<td>29.96E-03</td>
<td>15.56E-01</td>
</tr>
<tr>
<td>46.2</td>
<td>26.79E-03</td>
<td>13.91E-01</td>
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<tr>
<td>48.6</td>
<td>25.46E-03</td>
<td>13.22E-01</td>
</tr>
<tr>
<td>52.2</td>
<td>23.71E-03</td>
<td>12.31E-01</td>
</tr>
<tr>
<td>44.7</td>
<td>27.69E-03</td>
<td>14.38E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY = 26.72E-03 [1/sec]
AVERAGE FLOW RATE = 13.87E-01 [mm/sec]
PERMITTIVITY TEST

SAMPLE: EXXON L23209 2 MONTHS AFTER INST.

TEST#: EXPT133 DATE: 02-07-1987

TEMPERATURE= 23.9 [C]
FLOW VOLUME= 203500.9 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>30.0</td>
<td>39.20E-03</td>
<td>21.42E-01</td>
</tr>
<tr>
<td>26.0</td>
<td>45.23E-03</td>
<td>24.71E-01</td>
</tr>
<tr>
<td>31.0</td>
<td>37.93E-03</td>
<td>20.73E-01</td>
</tr>
<tr>
<td>31.0</td>
<td>37.93E-03</td>
<td>20.73E-01</td>
</tr>
<tr>
<td>32.0</td>
<td>36.75E-03</td>
<td>20.08E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 39.41E-03 [1/sec]
AVERAGE FLOWRATE= 21.53E-01 [mm/sec]

---

SAMPLE: EXXON L23209 2 MONTHS AFTER INST.

TEST#: EXPT233 DATE: 02-07-1987

TEMPERATURE= 23.9 [C]
FLOW VOLUME= 203500.9 [mm^3]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
</tr>
<tr>
<td>32.0</td>
<td>36.75E-03</td>
<td>20.08E-01</td>
</tr>
<tr>
<td>35.0</td>
<td>33.60E-03</td>
<td>18.36E-01</td>
</tr>
<tr>
<td>40.0</td>
<td>29.40E-03</td>
<td>16.06E-01</td>
</tr>
<tr>
<td>47.0</td>
<td>25.02E-03</td>
<td>13.67E-01</td>
</tr>
<tr>
<td>37.0</td>
<td>31.78E-03</td>
<td>17.37E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 31.31E-03 [1/sec]
AVERAGE FLOWRATE= 17.11E-01 [mm/sec]
Tab. IF.241
PERMITTIVITY TEST

PLE: GEOTEXTILE A
T#: APT144 DATE: 06-10-1987

PERATURE= 28.3 [C]
VOLUME= 407001.8 [mm$^3$]

<table>
<thead>
<tr>
<th>ME READ. PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
<td>[1/sec]</td>
</tr>
<tr>
<td>23.7</td>
<td>88.83E-03</td>
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<tr>
<td>27.1</td>
<td>77.68E-03</td>
</tr>
<tr>
<td>22.3</td>
<td>94.41E-03</td>
</tr>
<tr>
<td>24.3</td>
<td>86.64E-03</td>
</tr>
<tr>
<td>24.6</td>
<td>85.61E-03</td>
</tr>
</tbody>
</table>

AGE PERMITTIVITY= 86.63E-03 [1/sec]
AGE FLOWRATE= 52.89E-01 [mm/sec]

LE: GEOTEXTILE A
H#: APT244 DATE: 06-10-1987

PERATURE= 28.3 [C]
VOLUME= 407001.8 [mm$^3$]

<table>
<thead>
<tr>
<th>ME READ. PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[sec]</td>
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</tr>
<tr>
<td>21.6</td>
<td>97.47E-03</td>
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<tr>
<td>22.7</td>
<td>92.74E-03</td>
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<td>94.41E-03</td>
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<tr>
<td>22.8</td>
<td>92.34E-03</td>
</tr>
<tr>
<td>23.5</td>
<td>89.59E-03</td>
</tr>
</tbody>
</table>

AGE PERMITTIVITY= 93.31E-03 [1/sec]
AGE FLOWRATE= 56.96E-01 [mm/sec]
### Tab. F.25

#### PERMITTIVITY TEST

**SAMPLE:** GEOTEXTILE B

**TEST #:** BPT244

**DATE:** 06-10-1987

**TEMPERATURE:** 28.9°C

**FLOW VOLUME:** 814003.6 [mm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOW RATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.3</td>
<td>40.11E-02</td>
<td>24.88E+00</td>
</tr>
<tr>
<td>9.7</td>
<td>42.89E-02</td>
<td>26.61E+00</td>
</tr>
<tr>
<td>9.9</td>
<td>41.68E-02</td>
<td>25.86E+00</td>
</tr>
<tr>
<td>9.6</td>
<td>43.07E-02</td>
<td>26.72E+00</td>
</tr>
<tr>
<td>10.8</td>
<td>38.29E-02</td>
<td>23.76E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY:** 41.21E-02 [1/sec]

**AVERAGE FLOW RATE:** 25.56E+00 [mm/sec]

---

**SAMPLE:** GEOTEXTILE B

**TEST #:** BPT144

**DATE:** 06-10-1987

**TEMPERATURE:** 28.3°C

**FLOW VOLUME:** 814003.6 [mm³]

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY [1/sec]</th>
<th>FLOW RATE [mm/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6</td>
<td>39.72E-02</td>
<td>24.25E+00</td>
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<tr>
<td>9.8</td>
<td>42.96E-02</td>
<td>26.23E+00</td>
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<tr>
<td>9.9</td>
<td>42.53E-02</td>
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<tr>
<td>9.6</td>
<td>43.86E-02</td>
<td>26.77E+00</td>
</tr>
</tbody>
</table>

**AVERAGE PERMITTIVITY:** 42.24E-02 [1/sec]

**AVERAGE FLOW RATE:** 25.78E+00 [mm/sec]
Tab. [F.26]

PERMITTIVITY TEST

PLE: GEOTEXTILE C  

T#: CPT144  

PERASURE= 28.9  

VOLUME= 407001.8

<table>
<thead>
<tr>
<th>TIME READ.</th>
<th>PERMITTIVITY</th>
<th>FLOWRATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[sec]</td>
<td>[1/sec]</td>
</tr>
<tr>
<td>6.6</td>
<td>31.39E-02</td>
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<td>5.0</td>
<td>41.43E-02</td>
<td>25.70E+00</td>
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<tr>
<td>7.0</td>
<td>23.59E-02</td>
<td>18.36E+00</td>
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<tr>
<td>7.2</td>
<td>28.77E-02</td>
<td>17.85E+00</td>
</tr>
</tbody>
</table>

AGE PERMITTIVITY= 31.23E-02  [1/sec]  

AGE FLOWRATE= 19.37E+00  [mm/sec] 

PLE: GEOTEXTILE C  

T#: CPT244  

PERASURE= 28.9  

VOLUME= 407001.8

<table>
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<th>FLOWRATE</th>
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<tr>
<td></td>
<td>[sec]</td>
<td>[1/sec]</td>
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<td>40.15E-02</td>
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<tr>
<td>5.2</td>
<td>39.54E-02</td>
<td>24.53E+00</td>
</tr>
<tr>
<td>7.2</td>
<td>28.77E-02</td>
<td>17.85E+00</td>
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<td>4.0</td>
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<tr>
<td>5.3</td>
<td>39.09E-02</td>
<td>24.25E+00</td>
</tr>
</tbody>
</table>

AGE PERMITTIVITY= 39.87E-02  [1/sec]  

AGE FLOWRATE= 24.73E+00  [mm/sec]
Tab. [F.27]  
PERMITTIVITY TEST

SAMPLE: GEOTEXTILE D  

TEST#: DPT144  
DATE: 06-10-1987

<table>
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<tr>
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<tr>
<td>[sec]</td>
<td>[1/sec]</td>
<td>[mm/sec]</td>
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<tr>
<td>68.8</td>
<td>30.60E-03</td>
<td>18.68E-01</td>
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<tr>
<td>90.0</td>
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</tr>
<tr>
<td>78.1</td>
<td>26.96E-03</td>
<td>16.46E-01</td>
</tr>
<tr>
<td>78.6</td>
<td>26.78E-03</td>
<td>16.35E-01</td>
</tr>
<tr>
<td>95.2</td>
<td>22.11E-03</td>
<td>13.50E-01</td>
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</tbody>
</table>

AVERAGE PERMITTIVITY= 25.97E-03 [1/sec]  
AVERAGE FLOWRATE= 15.85E-01 [mm/sec]

---

SAMPLE: GEOTEXTILE D  

TEST#: DPT244  
DATE: 06-10-1987

<table>
<thead>
<tr>
<th>TIME READ</th>
<th>PERMITTIVITY</th>
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</thead>
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<td>[sec]</td>
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<td>[mm/sec]</td>
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<td>28.06E-03</td>
<td>17.13E-01</td>
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<td>74.7</td>
<td>28.19E-03</td>
<td>17.21E-01</td>
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<tr>
<td>76.4</td>
<td>27.56E-03</td>
<td>16.82E-01</td>
</tr>
<tr>
<td>62.2</td>
<td>33.85E-03</td>
<td>20.66E-01</td>
</tr>
<tr>
<td>69.3</td>
<td>30.38E-03</td>
<td>18.54E-01</td>
</tr>
</tbody>
</table>

AVERAGE PERMITTIVITY= 29.61E-03 [1/sec]  
AVERAGE FLOWRATE= 18.07E-01 [mm/sec]
Appendix G Hydraulic Conductivity Test Results
Soil: Basalt Material Passing #4
Fabric: Geotextile A

$K_{(Soil)}$
$3.3 \times 10^{-6}$

Wet Density 112 pcf
CP: 60 - BP: 50 psi
$K_{(6/8)}$
$3.3 \times 10^{-7}$

$K 	imes 10^{-6}$ cm/sec

$H_C = 0.3 \times 10^{-7} / 3.3 \times 10^{-6} = 0.25$

Without Fabric
$i = 10$

With Fabric
$i = 20$
Soil: Fould Balast Material
Passing 1/2 Sieve

Fabric: Geotextile B
Wet Density = 119 pcf & W/C = 18.8%
CP: 70 & BP: 60 psi
K x 10^-6 cm/sec HCR = 1.7/3.4 = 0.5

K (Soil) 3.4 x 10^-6
K (G/S) 1.7 x 10^-6

Fig. 18.71 HCR Test Results, Geotextile B
Soil: Balast Material Passing #4
Fabric: Geotextile C

\[ k(\text{Soil}) = 1.7 \times 10^{-6} \]

Wet Density 116 pc\(^6\)

CP: 60 - BP: 50 psi

\[ k = 8.0 \times 10^{-7} \text{ cm/sec} \]

HCR = 8.0 \times 10^{-7} / 1.7 \times 10^{-6} = 0.47

---

Graph showing the comparison of water content with and without fabric.

- Without Fabric: i = 20
- With Fabric: i = 40
Soil: Fouled Ballast Material Passing 1/2 in. Sieve
Fabric: Geotextile D
CP: 60 - EP: 50 psi
MDD = 110pcf & OMC = 20%
K x10^-5 cm/sec  HCR = 1.2/4.2 = 0.29
Chlorox was added

Fig. [6.4] HCR Test Results, Geotextile D
### Appendix H  In Situ Strain Measurements

#### Table [H.1] In-Situ Strain Measurements
**Geotextile A**  After Installation

**Track Direction:**

<table>
<thead>
<tr>
<th># points</th>
<th>Init. Dist.</th>
<th>Displacement</th>
<th>Strain</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 E10</td>
<td>27</td>
<td>8.5</td>
<td>0.0124</td>
<td>G</td>
</tr>
<tr>
<td>A1 C10</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>G</td>
</tr>
<tr>
<td>I1 I10</td>
<td>27</td>
<td>-3</td>
<td>-0.0044</td>
<td>G</td>
</tr>
<tr>
<td>I1 I6</td>
<td>15</td>
<td>-9</td>
<td>0.0236</td>
<td>I</td>
</tr>
<tr>
<td>I6 I10</td>
<td>12</td>
<td>6</td>
<td>0.0197</td>
<td>I</td>
</tr>
<tr>
<td>E1 E6</td>
<td>15</td>
<td>10.5</td>
<td>0.0276</td>
<td>I</td>
</tr>
<tr>
<td>E6 E10</td>
<td>12</td>
<td>-2</td>
<td>-0.0066</td>
<td>I</td>
</tr>
<tr>
<td>C10 C5</td>
<td>15</td>
<td>7</td>
<td>0.0184</td>
<td>I</td>
</tr>
<tr>
<td>D8 C10</td>
<td>6</td>
<td>35</td>
<td>0.2296</td>
<td>L</td>
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</tbody>
</table>

**Cross Direction:**

<table>
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<th># points</th>
<th>Init. Dist.</th>
<th>Displacement</th>
<th>Strain</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 I1</td>
<td>24</td>
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<td>G</td>
</tr>
<tr>
<td>B5 I6</td>
<td>24</td>
<td>-14.5</td>
<td>-0.0238</td>
<td>G</td>
</tr>
<tr>
<td>E6 I6</td>
<td>15</td>
<td>10</td>
<td>0.0262</td>
<td>I</td>
</tr>
<tr>
<td>C10 I10</td>
<td>21</td>
<td>-27</td>
<td>-0.0506</td>
<td>I</td>
</tr>
<tr>
<td>A1 E1</td>
<td>12</td>
<td>5.5</td>
<td>0.018</td>
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</tr>
<tr>
<td>B5 C5</td>
<td>3</td>
<td>3.5</td>
<td>-0.0459</td>
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</tbody>
</table>
Table [H.2] Strain measurements
Geotextile A 2 Months after Installation

Track Direction:

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<th>Init.Dist. [in]</th>
<th>Displacement [mm]</th>
<th>Strain [-]</th>
<th>Category</th>
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</thead>
<tbody>
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<td>A1 A10</td>
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<td>-.0092</td>
<td>G</td>
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<td>D1 C10</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>G</td>
</tr>
<tr>
<td>B6 C10</td>
<td>12</td>
<td>4</td>
<td>0.0394</td>
<td>I</td>
</tr>
<tr>
<td>D6 D8</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>L</td>
</tr>
<tr>
<td>K7 K10</td>
<td>9</td>
<td>3.5</td>
<td>0.01531</td>
<td>L</td>
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Cross Direction:

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<th>Strain [-]</th>
<th>Category</th>
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</thead>
<tbody>
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<td>8.5</td>
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<td>G</td>
</tr>
<tr>
<td>K7 A8</td>
<td>30</td>
<td>2</td>
<td>0.0026</td>
<td>G</td>
</tr>
<tr>
<td>H8 A8</td>
<td>21</td>
<td>0.5</td>
<td>0.0009</td>
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<tr>
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<td>6</td>
<td>1.5</td>
<td>0.0098</td>
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</table>
Table [H.3] Strain measurements
Geotextile B After Installation

Track Direction:

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<th>Category</th>
</tr>
</thead>
<tbody>
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<td>G</td>
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<td>B10</td>
<td>24</td>
<td>-10.5</td>
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<td>G</td>
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<td>A1 F1</td>
<td>15</td>
<td>-2.5</td>
<td>-0.0066</td>
<td>I</td>
</tr>
<tr>
<td>F1 I1</td>
<td>12</td>
<td>-3</td>
<td>-0.0098</td>
<td>I</td>
</tr>
<tr>
<td>B10 F10</td>
<td>12</td>
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<td>-0.0246</td>
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<td>I7 H7</td>
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Cross Direction:

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<th>Strain</th>
<th>Category</th>
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</thead>
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<tr>
<td>A1 B10</td>
<td>27</td>
<td>12.5</td>
<td>0.0182</td>
<td>G</td>
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<td>F6 F10</td>
<td>12</td>
<td>3.5</td>
<td>0.0115</td>
<td>I</td>
</tr>
<tr>
<td>I1 I7</td>
<td>6</td>
<td>2</td>
<td>0.0029</td>
<td>I</td>
</tr>
<tr>
<td>I7 I10</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>L</td>
</tr>
<tr>
<td>I8 B10</td>
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<td>H4 H7</td>
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Table [H.4] Strain measurements
Geotextile B 1 Month after Installation

Track Direction:

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<th>Category</th>
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<td>I7 I10</td>
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<td>11</td>
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Cross Direction:

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<th>Category</th>
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Table [H.5] Strain measurements
Geotextile B 2 Months after Installation

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Table [H.6] Strain measurements
Geotextile C After Installation

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Table [H.7] Strain measurements
Geotextile C 1 Month after Installation

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Table [H.8] Strain measurements
Geotextile C 2 Months after Installation

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Table [H.9] Strain measurements
Geotextile D After Installation

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Table [H.11] Strain measurements
Geotextile D  2 Months After Installation

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Table CH.12] Strain measurements
Geotextile A 6 Months After Installation

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Table [H.13] Strain measurements
Geotextile B  6 Months After Installation

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Table [H.14] Strain measurements
Geotextile C 6 Months After Installation

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<td>K2, A5</td>
<td>30</td>
<td>3</td>
<td>0.00394</td>
<td>G</td>
</tr>
<tr>
<td>F4, B4</td>
<td>12</td>
<td>10</td>
<td>0.03281</td>
<td>I</td>
</tr>
<tr>
<td>F4, H4</td>
<td>6</td>
<td>17</td>
<td>0.1115</td>
<td>L</td>
</tr>
<tr>
<td>G4, F4</td>
<td>3</td>
<td>22</td>
<td>0.2887</td>
<td>L</td>
</tr>
<tr>
<td>H4, G4</td>
<td>3</td>
<td>5</td>
<td>0.0656</td>
<td>L</td>
</tr>
</tbody>
</table>
Table [H.15] Strain measurements
Geotextile D 6 Months After Installation

Track Direction:

<table>
<thead>
<tr>
<th># points</th>
<th>Init. Dist. [in]</th>
<th>Displacement [mm]</th>
<th>Strain [-]</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>G7 H1</td>
<td>18</td>
<td>27</td>
<td>0.0591</td>
<td>I</td>
</tr>
<tr>
<td>D1 C3</td>
<td>12</td>
<td>7</td>
<td>0.02297</td>
<td>I</td>
</tr>
<tr>
<td>K7 K10</td>
<td>9</td>
<td>1</td>
<td>0.00437</td>
<td>L</td>
</tr>
<tr>
<td>D1 C4</td>
<td>9</td>
<td>5</td>
<td>0.02187</td>
<td>L</td>
</tr>
<tr>
<td>G5 G7</td>
<td>6</td>
<td>37</td>
<td>0.243</td>
<td>L</td>
</tr>
</tbody>
</table>

Cross Direction:

<table>
<thead>
<tr>
<th># points</th>
<th>Init. Dist. [in]</th>
<th>Displacement [mm]</th>
<th>Strain [-]</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>K7 D7</td>
<td>21</td>
<td>1</td>
<td>0.00187</td>
<td>I</td>
</tr>
<tr>
<td>C3 H1</td>
<td>15</td>
<td>7</td>
<td>0.0184</td>
<td>I</td>
</tr>
<tr>
<td>K7 G7</td>
<td>12</td>
<td>2</td>
<td>0.00656</td>
<td>I</td>
</tr>
<tr>
<td>G7 D7</td>
<td>9</td>
<td>-1</td>
<td>-0.00437</td>
<td>L</td>
</tr>
</tbody>
</table>
APPENDIX I

I. 1 Program TESTWS

I. 1. 1 Users Manual

I. 1. 1. 1 Description

The program TESTWS.BAS is the software used in connection with the electronic data acquisition system and an on-sample-strain-measuring-device (OSSMD) for the wide strip tensile test. TESTWS.BAS is written in advanced basic for use in a IBM-personal computer with a TECMAR LABPAC Mother and Daughterboard. The motherboard has to be set on the starting address 784. The daughterboard has to be set to the highest channel number in the auto-incrementing feature. The gain is set to 1 and the input voltage to 10 V. See Figure [I.5].

The program accesses the input channels 1 to 3 of the daughterboard. Channels 1,3 are for the LVDT input, channel 2 is for the loadcell input. Using calibration coefficients specific to each LVDT or LOADCELL (Figures [I.1] to [I.3]) these values are converted to values of displacement in inches or load in pounds, respectively. The strain rate, time, both displacements and the load are displayed continuously on the screen. The values of displacement and load can be stored in an outputfile. This outputfile has to be located on a virtual disk on the RAM of the computer. Only so a constant rate of sampling is achieved. The average sampling rate with this setup was 20 reading per second.
I.1.1.2 Methodology

1.) Install disk Operating System containing the Virtual Disk Drive option with 256k capacity. Microsoft DOS

2.) Replace the DOS disk with the LABPAC 2.1 disk and type: A>LABPAC

A>BASICA

3.) Replace the LABPAC 2.1 disk with the TESTWS.BAS program disk and type: LOAD "TESTWS RUN

4.) The program will now prompt for input of OUTPUTFILE

Input: C:[desired name of outputfile]

SAMPLE WIDTH [cm]

STRAIN BASE LENGTH [in]

Input those values followed by RETURN

5.) Now the program will start displaying values on the screen. These values are, seen from left to right:

1. Displacement at LVDT1 [in]

2. Displacement at LVDT2 [in]

3. Force at the Loadcell [lbs]

4. Strain rate [1/min]

5. Time after start of the program [sec]
6.) The following are the F-key definitions that can be used to start storing, to reset or to terminate readings.

F-7: Stop storing and terminate program execution

F-8: Change calibration factors
The existing factors will be displayed and a prompt for new ones will appear.

F-9: Reset clock and zero output values
The clock and time output as well as the output values are set to zero.

F-10: Reset clock and start storing output values on disk.
The clock and time output are set to zero and the output for LVDT1, LVDT2 and the Loadcell will be stored on the previously defined outputfile.

7.) Now the sample and OSSMD can be installed.

8.) To start the test press F-9 and observe for stability. This has to be repeated in some cases.

9.) Start testing machine and press F-10 instantaneously

10.) Upon failure press F-7.

11.) Copy the outputfile on a floppy disk and erase the original file.
Fig. [I.5] Setting of jumpers and switches on TECMAR Daughterboard for Wide Strip Tensile Test
Program Listing TESTWS.BAS

REM***********************************************************
REM
REM PROGRAM TESTWS 	 PETER GRUBERT 	 JAN., '87
REM
REM PROGRAM SUPPORTING THE LABPAC BOARD FOR USE AS DATA ACQUISITION SOFTWARE FOR THE WIDE STRIP TENSILE TEST
REM 1) THE VOLTAGE INPUT IS READ.
REM 2) USING THE RESPECTIVE CALIBRATION FACTORS STRESS AND STRAIN VALUES ARE CALCULATED
REM 3) THE VALUES ARE DISPLAYED ON THE SCREEN AND CAN BE STORED ON DISK FOR FURTHER TREATMENT
REM
VAR 
F = CAL.FACTOR FOR THE LOADCELL
FL1, FL2 = CAL.FACTORS FOR THE LVDT'S
F1, F2, F3 = CAL. FACTORS FOR THE LVDT'S
F4, F5, F6 = USED FOR ZEROING OF OUTPUT
ADDR = STARTING ADDRESS SPECIFIED ON THE MOTHER BOARD
VOLTS = INPUT VALUE OF EACH CHANNEL
VOLTS = INPUT VALUE OF THE CHANNEL I
LVDT1(I) = DISPLACEMENT AT THE LVDT1
LVDT2(I) = DISPLACEMENT AT THE LVDT2
LVDT = AVERAGE OF BOTH
LC = LOAD IN LBS
OUTP(I) = INPUT VALUE OF THE CHANNEL I
LVDT = AVERAGE OF BOTH
TIME = TIME ELAPSED AFTER THE START OF THE TEST
STRA = STRAINRATE
B = PRINTER CONTROL VARIABLE

CALIBRATION COEFFICIENTS
F = 307.2603; FL1 = 1203.693; FL2 = 11800.905#

OPEN "B:EMERG.TES" FOR OUTPUT AS #2

F-KEY DEFINITIONS
KEY 9, CHR$(127): KEY 10, CHR$(129): KEY 7, CHR$(130): KEY 8, CHR$(131)
KEY 9 = ZERO VALUES (OUTPUT)
KEY 10 = RESET CLOCK AND START STORING OUTPUT
KEY 7 = STOP STORING AND TERMINATE PROGRAM
KEY 8 = CHANGE CALIBRATION FACTORS

DEFINE STARTING ADDRESS
ADDRESS = 784
DISPLAY CAL. COEFFICIENTS
PRINT "LC-FACTOR= "; F
PRINT "LVDT-FACTOR1= "; FL1
PRINT "LVDT-FACTOR2= "; FL2
**INPUT SAMPLE AND TEST PARAMETERS**

```plaintext
B=0:Z$="":P1=0:P2=0:P3=0
```

Input output file:

```plaintext
OPEN FIL$ FOR OUTPUT AS #1
```

Input sample width (cm³):

```plaintext
OPEN "SAMPLE WIDTH [cm³];WIDT
```

Input strain base length (in³):

```plaintext
OPEN "STRAIN BASE LENGTH [in³];DIST
```

Write:

```plaintext
CLS
```

Enable auto-incrementing:

```plaintext
OUT ADDRESS + 4,128
```

```plaintext
OUT ADDRESS + 5,255
```

```plaintext
OUT ADDRESS + 6,0
```

If input (ADDRESS + 4) < 128 then:

```plaintext
X=INP(ADDRESS+6)
```

```plaintext
OUT ADDRESS 4,0
```

```plaintext
OUT ADDRESS + 5,0
```

For Y = 0 to 2:

```plaintext
OUT ADDRESS + 6,0
```

Wait until bit 7 of status byte is a 1 signaling done converting.

```plaintext
LOW = INP( ADDRESS + 5 )
```

```plaintext
HIGH = INP( ADDRESS + 6 )
```

Convert from twos complement to a number between -10 and 10:

```plaintext
T = 256*HIGH + LOW
```

If T > 32767 then:

```plaintext
T = T-65536!
```

Convert into voltage value:

```plaintext
VOLTAGE = T/204.8
```

```plaintext
OUTP(Y+1)=VOLTAGE
```

Check for F-KEY after each reading:

```plaintext
A$=INKEY$
```

If A$=CHR$(131) then:

```plaintext
GOSUB 1100
```

If A$=CHR$(127) then:

```plaintext
GOSUB 1150
```

If A$=CHR$(129) then:

```plaintext
B=1
```

If A$=CHR$(129) then:

```plaintext
Z$="*
```

If A$=CHR$(129) then:

```plaintext
TIMES=TIMER
```

If A$=CHR$(130) then:

```plaintext
CLOSE #1
```

If A$=CHR$(130) then:

```plaintext
GOTO 440
```

If A$="L" then:

```plaintext
B=2
```

Check for F-KEY after each reading:

```plaintext
A$=INKEY$
```

If A$=CHR$(131) then:

```plaintext
GOSUB 1100
```

If A$=CHR$(127) then:

```plaintext
GOSUB 1150
```

If A$=CHR$(129) then:

```plaintext
B=1
```

If A$=CHR$(129) then:

```plaintext
Z$="*
```

If A$=CHR$(129) then:

```plaintext
TIMES=TIMER
```

If A$=CHR$(130) then:

```plaintext
CLOSE #1
```

If A$=CHR$(130) then:

```plaintext
GOTO 440
```

If A$="L" then:

```plaintext
B=2
```

Calculate stress and strain values:

```plaintext
LVDT1=(OUTP(1)-P1)*FL1
```

```plaintext
LVDT2=(OUTP(3)-P3)*FL2
```

```plaintext
LVDT=(LVDT1+LVDT2)/2
```

```plaintext
LC=(OUTP(2)-P2)*F
```

```plaintext
TIME=TIMER-TIMES
```

If PLVDT<>LVDT then:

```plaintext
STRA=(PLC-LC)/(PLVDT-LVDT)
```

If PLVDT = LVDT then:

```plaintext
STRA=9999
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```

If PLVDT = LVDT then:

```plaintext
TIME=TIME:PLC=LC
```
1020 REM Display on the screen
1030 PRINT USING P1$;LVDT1,LVDT2,LC,STRA,TIME,Z$
1040 REM******************************************************************************
1050 REM Store data on data file
1060 IF B=1 THEN WRITE #1,LVDT1,LVDT2,LC
1070 IF B=2 THEN WRITE #2,LVDT1,LVDT2,LC
1080 REM******************************************************************************
1090 GOTO 670
1100 REM******************************************************************************
1110 REM Change the calibration coefficients
1120 PRINT "LC=";F1;" FL1=";FL1;" FL2=";FL2
1130 INPUT "LC,FL1,FL2";F,FL1,FL2
1140 RETURN
1150 REM******************************************************************************
1160 REM Zero output
1170 P1=OUTP(1)
1180 P2=OUTP(2)
1190 P3=OUTP(3)
1200 TIMES=TIMER
1210 RETURN
I.2 Program REDUCWS.EXE

I.2.1 Users Manual

I.2.1.1 Description

The program REDUCWS.EXE is written to be used for the reduction of data given by the TESTWS.BAS program. REDUCWS.EXE is written in compiled basic.

Data stored in the output file created by the TESTWS.BAS program are accessed. The data are read in and the maximum loadcell value is detected. The number of data is reduced to 100 by equal distribution. The average of the two LVDT readings and the strain value is calculated by dividing the average displacement by the strain base length. The stress is determined by dividing the load by the sample width. These stress-strain data are stored in an output file in the format: STRAIN,STRESS

This file can be read by the Microsoft CHART program for a plot of the data. A printout consisting of a title and containing these data is created and stored in a print file.

I.2.1.2 Methodology

1.) Install the Microsoft DOS

2.) Insert the program disk in drive A:

        and the disk containing the data in drive B:

3.) Start the program by typing

        A>REDUCWS
4.) The program will prompt for:

NAME OF DATAFILE

Input the name of the file containing
the test data;

NAME OF OUTPUTFILE

Input the name of the file the reduced
data will be stored in;

NAME OF PRINTOUT

Input the name of the file the
printout will be stored in;

TITLE1 FOR PRINTOUT

TITLE2 FOR PRINTOUT

Input information that will appear on
the printout.

5.) Print the printoutputfile by typing

TYPE [Name of file]>PRN
I.2.2 Program Listing REDUCWS.EXE

10 REM***************************************************************************
20 REM
30 REM PROGRAM REDUCWS	 PETER A. GRUBERT	 JAN., '87
40 REM
50 REM PROGRAM TO REDUCE THE DATA FOR THE WIDE STRIP
60 REM TENSILE TEST
70 REM
80 REM 1) INPUT OF DATA FROM A DATAFILE "FILD$",
90 REM FORMAT: WIDT, DIST
100 REM LVDT1(I), LVDT2(I), LC(I)
110 REM 2) CALCULATION OF STRESS, STRAIN VALUES
120 REM LVDT2(I)=STRAIN
130 REM LC(I)=STRESS
140 REM 3) DETECTION OF THE PEAK STRESS VALUE
150 REM LC(MAX), LVDT2(MAX)
160 REM 4) REDUCTION TO LESS THAN 100 DATAPOINTS
170 REM 5) OUTPUT TO OUTPUTFILE "FILO$" IN
180 REM FORMAT: STRAIN(I), STRESS(I)
190 REM OUTPUT TO PRINTFILE "FILP$" IN
200 REM FORMAT: TITLE AND TEST DATA
210 REM STRAIN(I), STRESS(I) IN TABLE FORMAT
220 REM
230 REM VARIABLES:
240 REM WIDT : WIDTH OF SAMPLE
250 REM DIST : INITIAL DISTANCE OF FIXPOINTS ON GEOTEXTILE
270 REM LVDT1(I): DISPLACEMENT AT LVDT 1
280 REM LVDT2(I): DISPLACEMENT AT LVDT 2
290 REM LC(I) : TENSION FORCE AT LOAD CELL
300 REM LVDT2(I): LATER ASSIGNED THE VALUE STRAIN
320 REM LC(I) : LATER ASSIGNED THE VALUE STRESS
330 REM CON, I : ITERATION VARIABLES
340 REM MAX : DESIGNATES THE PEAK DATAPoint
350 REM
390 REM***************************************************************************
400 REM
420 INPUT "NAME OF DATAFILE"; FILD$
430 INPUT "NAME OF OUTPUTFILE"; FILO$
440 INPUT "NAME OF PRINTOUT"; FILP$
450 INPUT "TITLE 1 FOR PRINTOUT"; TIT1$
460 INPUT "TITLE 2 FOR PRINTOUT"; TIT2$
470 REM
480 REM
490 OPEN FILD$ FOR INPUT AS #1
500 OPEN FILO$ FOR OUTPUT AS #2
510 OPEN FILP$ FOR OUTPUT AS #3
520 REM
530 F1$="                                 
540 DIM LVDT1(4000),LVDT2(4000),LC(4000)
550 REM*****************************************************************************
560 REM 5) OUTPUT OF TITLE AND TEST DATA IN PRINTFILE
570 REM*****************************************************************************
580 PRINT #3,": WIDE STRIP TENSILE TEST ",DATE$;PRINT #3,":"
590 PRINT #3,"":PRINT #3,"
600 PRINT #3," 
610 PRINT #3,"  
620 PRINT #3," 
630 PRINT #3," 
640 PRINT #3,"  
650 PRINT #3," Strain  Stress   
660 PRINT #3," [-]   [lbs/ft] 
670 REM*****************************************************************************
680 REM 1) AND 2) INPUT AND CALCULATION
690 REM*****************************************************************************
700 CON=0
710 LCMAX=0
720 REM
730 INPUT #1,WIDT,DIST
740 REM
750 CON=CON+1
760 INPUT #1,LVDT1(CON),LVDT2(CON),LC(CON)
770 IF CON=1 THEN LVDT1(CON)=LV1;LVDT2(CON)=LV2
780 LVDT1(CON)=((LVDT1(CON)-LV1)+(LVDT2(CON)-LV2))/2
790 LVDT2(CON)=LVDT1(CON)/DIST
800 LC(CON)=LC(CON)/((WIDT/2.54)/12)
810 IF EOF(1) THEN GOTO 900
820 REM*****************************************************************************
830 REM 3) DETECTION OF PEAK VALUE
840 REM*****************************************************************************
850 REM
860 IF CON < 2 THEN GOTO 890
870 IF LC(CON)>LCMAX THEN MAX=CON
880 IF LC(CON)>LCMAX THEN LCMAX=LC(CON)
890 GOTO 740
900 REM*****************************************************************************
910 REM CONTROL OUTPUT AND CONTROL INPUT
920 REM*****************************************************************************
930 PRINT "I=",CON
940 PRINT "MAX=";MAX,"LCMAX= ";LCMAX
950 INPUT "LIMIT STRAIN";LIM
960 REM*****************************************************************************
970 REM 4) REDUCTION TO 100 DATAPOINTS
980 REM*****************************************************************************
990 IF CON < 100 THEN GOTO 1260
1000 IF CON > (LIM*MAX) THEN CON=(MAX*LIM)
1010 FAC=CON/100
1020 FAC=1/FAC
1030 COMP=0
1040 FOR I=1 TO CON
1050 IF I=1 THEN 1090
1060 IF I=MAX THEN 1160
1070 IF(INT((I*FAC)+.5) > COMP) THEN 1090
1080 GOTO 1230
1090 REM*****************************************************************************
1100 REM 5) OUTPUT OF THE REDUCED DATA
1110 REM*****************************************************************************
1120 WRITE #2,LVDT2(I),LC(I)
1130 PRINT #3, USING F1$; LVDT2(I); LC(I)
1140 COMP=COMP+1
1150 GOTO 1230
1160 REM*****************************************************************************
1170 REM 5) OUTPUT OF THE PEAK VALUE
1180 REM*****************************************************************************
1190 WRITE #2, LVDT2(MAX), LC(MAX)
1200 PRINT #3, USING F1$; LVDT2(MAX); LC(MAX)
1210 COMP=COMP+1
1220 REM
1230 NEXT I
1240 REM
1250 GOTO 1340
1260 REM*****************************************************************************
1270 REM 5) OUTPUT IF LESS THAN 100 DATA EXISTENT
1280 REM*****************************************************************************
1290 FOR I=1 TO CON
1300 WRITE #2, LVDT2(I), LC(I)
1310 PRINT #3, USING F1$; LVDT2(I); LC(I)
1320 NEXT I
1330 REM*****************************************************************************
1340 PRINT "COMP="; COMP
1350 REM
1360 END
I.3 Programs TESTPT.BAS and TESTTRT.BAS

I.3.1 Users Manual

I.3.1.1 Description

The programs TESTPT.BAS and TESTTRT.BAS are the software used in connection with the electronic data acquisition system for the puncture test and the trapezoidal tear test respectively. Because of their similarity they are explained together. The programs are written in advanced basic for use in an IBM-personal computer with a TECMAR LABPAC Mother and daughterboard. Several adjustments have to be performed on the boards. The motherboard has to be set to the starting address 784. The daughterboard has to be set to a gain of 1 and a maximum input voltage of 5 V. See Figure [I.6]. Channel 1 is used for the input voltage.

The program reads the voltage from this channel and converts it to a load value using a specific calibration coefficient. In TESTTRT.BAS the elapsed time is converted into a displacement value in inches, using the predetermined machine speed. The load in pounds and the time in seconds or displacement in inches are displayed on the screen continuously. About 10 readings per second are taken.

The values for load and elapsed time or displacement can be stored on a previously specified outputfile. For constant sampling speed and less disturbance this outputfile should be located on a virtual disk drive in the RAM.
I.3.1.2 Methodology

1.) Install the Microsoft DOS containing the virtual disk drive option with 256k capacity.

2.) Replace the DOS disk with the LABPAC 2.1 disk and type: A>LABPAC

A>BASICA

3.) Replace the LABPAC 2.1 disk with the program disk and type: LOAD"TESTPT or TESTTRT

RUN

4.) The program will now prompt for the name of the output file. Type any desired name.

5.) The next prompt will be

FACTOR?

If the predetermined calibration factor will be used, then type 0, otherwise the new calibration coefficient.

6.) Now values of load and time or displacement will appear on the screen.

7.) Place the sample in the testing machine and press F-9 to zero the output.

8.) To start the test, press F-10 and start the testing machine simultaneously.

9.) At the end of the test stop the program with F-7.
Fig.[I.6] Setting of jumpers and switches on TECMAR Daughterboard for Puncture and Taperoidal Tear Tests
1.3.2.1 Program Listing TESTPT.BAS

10 REM******************************************************************************
20 REM
30 REM PROGRAM TESTPT       PETER GRUBERT       JAN., '87
40 REM
50 REM TESTPT.BAS IS A PROGRAM WRITTEN TO BE USED IN AN
60 REM IBM PERSONAL COMPUTER WITH TECHMAR LABPAC BOARDS.
70 REM
80 REM IT IS USED IN CONNECTION WITH AN ELECTRONIC DATA
90 REM ACQUISITION SYSTEM FOR THE PUNCTURE TEST
100 REM
110 REM THE PROGRAM
120 REM 1.) OUTPUTFILE AND CALIBRATION FACTORS ARE DEFINED
130 REM 2.) CHANNEL 1 OF THE LABPAC DAUGHTER BOARD IS READ
140 REM CONTINUOUSLY
150 REM 3.) USING THE CALIBRATION FACTOR THE VOLTAGE IS
160 REM CONVERTED TO A LOADVALUE [LBS]
170 REM 4.) THE LOAD AND ELAPSED TIME IN [SEC] ARE DISPLAYED
180 REM ON THE SCREEN
190 REM 5.) THE DATA CAN BE STORED ON A SPECIFIED OUTPUTFILE
200 REM
210 REM
220 REM VARIABLES:
230 REM F    CALIBRATION FACTOR FOR THE LOADCELL
240 REM FIL$  NAME OF OUTPUTFILE
250 REM ADDR  STARTING ADDRESS OF THE BOARD
260 REM VOLT  VOLTAGE VALUE READ FROM CHANNEL 1
270 REM LOW, HIGH INPUT VARIABLES
271 REM TIM   ELAPSED TIME
280 REM
290 REM F-KEY DEFINITIONS:
300 REM F-7   STOP TEST
310 REM F-9   ZERO VALUES AND RESET TIMER
320 REM F-10  RESET TIMER AND START STORING DATA
330 REM******************************************************************************
340 REM******************************************************************************
350 REM DEFINE CALIBRATION COEFFICIENT
360 REM******************************************************************************
370 REM******************************************************************************
370 F=151.6277
380 B=0
390 F$="   #######   #######   #######   "
400 KEY 9,CHR$(127):KEY 10,CHR$(129):KEY 7,CHR$(130)
410 REM******************************************************************************
420 REM INITIAL INPUT
430 REM******************************************************************************
440 REM******************************************************************************
440 OPEN FIL$ FOR OUTPUTAS #1
450 PRINT "FACTOR = ",F
460 IF FM<>0 THEN F=FM
470 CLS
480 REM******************************************************************************
490 REM******************************************************************************
500 REM******************************************************************************
510 REM START READINGS
ADDRESS = 784
REM disable auto-incrementing, external start conversions, and all
REM interrupts. gain=1.
OUT ADDRESS+4,128
REM output channel number
OUT ADDRESS+5,0
REM start a conversion.
OUT ADDRESS+6,0
REM wait until bit 7 of status byte is a 1 signaling done converting
IF INP(ADDRESS + 4)< 128 THEN 620
REM read in the data.
LOW = INP( ADDRESS + 5 )
HIGH = INP( ADDRESS + 6 )
REM convert from twos complement to a number between -10 and 10
X = 256*HIGH + LOW
IF X > 32767 THEN X = X-65536!
REM CHECK FOR F-KEY STATUS
A$=INKEY$
IF A$=CHR$(127) THEN VOLTAGE1 = X/204.8:TIME= TIMER
IF A$=CHR$(129) THEN B=1
IF A$=CHR$(130) THEN GOTO 860
REM CONVERT VALUE
VOLTAGE = X/204.8
TIM=TIMER-TIME
LOD=(VOLTAGE-VOLTAGE1)*F
IF B=1 THEN WRITE #1, LOD,TIM
IF B=0 THEN PRINT LOD,TIM
GOTO 600
END
I.3.3.2 Program Listing TESTTRT.BAS

10 REM*****************************************************************************
20 REM
30 REM PROGRAM TESTTRT             PETER GRUBERT       JAN., '87
40 REM
50 REM TESTTRT.BAS IS A PROGRAM WRITTEN TO BE USED IN AN
60 REM IBM PERSONAL COMPUTER WITH TECHMAR LABPAC BOARDS.
70 REM
80 REM IT IS USED IN CONNECTION WITH AN ELECTRONIC DATA
90 REM ACQUISITION SYSTEM FOR THE TRAPEZOIDAL TEAR TEST
100 REM
110 REM THE PROGRAM
120 REM 1.) OUTPUTFILE AND CALIBRATION FACTORS ARE DEFINED
130 REM 2.) THE VOLTAGE AT CHANNEL 1 OF THE LABPAC DAUGHTER
135 REM BOARD IS READ CONTINUOUSLY
140 REM
150 REM 3.) USING THE CALIBRATION FACTOR THE VOLTAGE IS
155 REM CONVERTED TO A LOADVALUE [LBS]
160 REM AND THE ELAPSED TIME TO AN EXTENSION VALUE [IN]
165 REM
170 REM 4.) THE LOAD AND EXTENSION IN [IN] ARE DISPLAYED
175 REM ON THE SCREEN
180 REM FILE
190 REM
200 REM 5.) THE DATA CAN BE STORED ON A SPECIFIED
205 REM OUTPUTFILE
210 REM
220 REM VARIABLES:
230 REM F  CALIBRATION FACTOR FOR THE LOADCELL
240 REM T  CALIBRATION FACTOR RELATING MACHINE
250 REM SPEED TO AN EXTENSION [IN]
260 REM FIL$  NAME OF OUTPUTFILE
270 REM ADDRESS STARTING ADDRESS OF THE BOARD
280 REM VOLTAGE VOLTAGE VALUE READ FROM CHANNEL 1
290 REM LOW, HIGH INPUT VARIABLES
300 REM TIM ELAPSED TIME
310 REM LOAD FORCE AT THE LOADCELL
320 REM EXTEN EXTENSION VALUE
330 REM
340 REM F-KEY DEFINITIONS:
350 REM F-7  STOP TEST
360 REM F-9  ZERO VALUES AND RESET TIMER
370 REM F-10 RESET TIMER AND START STORING DATA
380 REM
390 REM*****************************************************************************
400 REM*****************************************************************************
410 REM DEFINE CALIBRATION COEFFICIENT
420 REM*****************************************************************************
430 REM
440 REM F=151.6277;T=7.162107E-02
450 REM*****************************************************************************
460 REM*****************************************************************************
470 REM*****************************************************************************
480 REM*****************************************************************************
490 REM*****************************************************************************
500 REM INITIAL INPUT
510 REM*****************************************************************************
520 INPUT "OUTPUTFILE";FIL$
530 OPEN FIL$ FOR OUTPUT AS #1
540 PRINT "FACTOR = ",F
550 INPUT "NEW FACTOR ?";FM
560 IF FM<>0 THEN F=FM
570 CLS
580 REM*******************************************************************************
590 REM START READINGS
600 REM*******************************************************************************
610 ADDRESS = 784
620 REM disable auto-incrementing, external start conversions, and all
630 REM interrupts. gain=1.
640 OUT ADDRESS+4,128
650 REM output channel number
660 OUT ADDRESS+5,0
670 REM start a conversion.
680 OUT ADDRESS+6,0
690 REM wait until bit 7 of status byte is a 1 signaling done
700 IF INP(ADDRESS + 4)< 128 THEN 700
710 REM read in the data.
720 LOW = INP( ADDRESS + 5)
730 HIGH = INP( ADDRESS + 6)
740 REM convert from twos complement to a number between -10 and 10
750 X = 256*HIGH + LOW
760 IF X > 32767 THEN X = X-65536!
770 REM*******************************************************************************
780 REM CHECK FOR F-KEY STATUS
790 REM*******************************************************************************
800 A$=INKEY$
810 IF A$=CHR$(127) THEN VOLTAGE1 = X/204.8:TIME= TIMER
820 IF A$=CHR$(129) THEN B=1
830 IF A$=CHR$(129) THEN TIME=TIMER
840 IF A$=CHR$(130) THEN GOTO 950
850 REM*******************************************************************************
860 REM CONVERT VALUE
870 REM*******************************************************************************
880 VOLTAGE = X/204.8
890 TIM=TIMER-TIME
900 LOD= (VOLTAGE - VOLTAGE1)*F
910 EXTEN = TIM*T
920 IF B=1 THEN WRITE #1,EXTEN,LOD
930 IF B=0 THEN PRINT EXTEN,LOD
940 GOTO 680
950 END
1.4 Programs REDUCPT.EXE and REDUCTRT.EXE

1.4.1 Users Manual

1.4.1.1 Description

The programs REDUCPT and REDUCTRT are written to be used for the data reduction of data given by the TESTPT.BAS and TESTTRT.BAS programs respectively. They are written in compiled basic.

Data stored in an outputfile created by testpt or testtrt are accessed. The data are read in and the peak load value is detected. The number of data is reduced to 100 in equal intervals without deleting the peak value. A printfile is created containing a few line sof text information and the 100 data points in form of a table. Also an outputfile is created, containing the 100 datasets separated by a comma. This outputfile can easily be accessed by the Microsoft CHART program for chart production.

1.4.1.2 Meythodology

1.) Install Microsoft DOS

2.) Insert the program disk in drive A:

and the disk containing the data in drive B:

3.) Start the program with

A> REDUCPT or REDUCTRT

4.) The program will prompt for:

NAME OF DATAFILE

Input the name of the file containing the data;
NAME OF OUTPUTFILE

Input the name of the file where the reduced data will be stored in;

NAME OF PRINTFILE

Input the name of the file where the printout will be stored in;

TITLE 1 FOR PRINTOUT

TITLE 2 FOR PRINTOUT

Input information you want to appear on the printout;

5.) Print the printout by typing

TYPE [Name of printfile]>PRN
I.4.2.1 Program Listing REDUCPT.EXE

10 REM******************************************************************************
20 REM
30 REM PROGRAM REDUCPT PETER GRUBERT FEB. '87
40 REM
50 REM REDUCPT.EXE IS USED IN CONJUNCTION WITH THE
60 REM TESTPT.BAS PROGRAM FOR THE REDUCTION OF DATA FROM
70 REM THE PUNCTURE TEST
80 REM
90 REM THE PROGRAM:
100 REM 1.) INPUT OF DATA FROM SPECIFIED DATAFILE "FILD$"
110 REM INPUT FORMAT: PISTON FORCE, ELAPSED TIME
120 REM 2.) DETECTION OF THE PEAK FORCE VALUE
130 REM 3.) REDUCTION TO 100 DATA POINTS
140 REM 4.) OUTPUT OF DATA TO OUTPUTFILE "FILO$"
150 REM OUTPUT FORMAT: ELAPSED TIME, PISTON FORCE
160 REM 5.) OUTPUT OF DATA TO PRINTFILE "FILP$"
170 REM OUTPUT FORMAT: TITLE TEXT
180 REM
190 REM
200 REM VARIABLES:
210 REM TIT1$,TIT2$ TITLE TEXT
220 REM TIME(CON) ELAPSED TIME
230 REM LC(CON) PISTON FORCE
240 REM CON CONTROL VARIABLE
250 REM MAX CONTROL VARIABLE FOR PEAK
260 REM FAC,COMP CONTROL VARIABLES FOR
270 REM
280 REM******************************************************************************
290 REM INPUT OF NAMES OF FILES AND TITLE TEXT
300 REM******************************************************************************
310 REM
320 REM******************************************************************************
330 REM
340 INPUT "NAME OF DATAFILE";FILD$
350 INPUT "NAME OF OUTPUTFILE";FILO$
360 INPUT "NAME OF PRINTOUT";FILP$
370 INPUT "TITLE 1 FOR PRINTOUT";TIT1$
380 INPUT "TITLE 2 FOR PRINTOUT";TIT2$
390 REM
400 REM
410 OPEN FILD$ FOR INPUT AS #1
420 OPEN FILO$ FOR OUTPUT AS #2
430 OPEN FILP$ FOR OUTPUT AS #3
440 REM
450 F1$=" 	#####.##### 	#####.##### 
460 DIM TIME(4000),LC(4000)
470 REM******************************************************************************
480 REM PRINTOUT OF TITLE TEXT
490 REM******************************************************************************
500 PRINT #3,"":PRINT #3,""
510 PRINT #3,"PUNCTURE TESTING 	",DATE$
520 PRINT #3,""
530 PRINT #3,TIT1$
540 PRINT #3,""
550 PRINT #3,TIT2$
560 PRINT #3,""
570 PRINT #3,""
580 PRINT #3," Elapsed Time	Piston Force "
590 PRINT #3," [sec] [lbs] "
600 CON=0
610 LCMAX=0
620 REM****************************-*****-****************************
630 REM INPUT OF DATA
640 REM****************************************************
650 CON=CON+1
660 INPUT #1,LC(CON),TIME(CON)
670 IF EOF(1) THEN GOTO 760
680 TIME(CON)=TIME(CON)-TIME(1)
690 REM*************************************************
700 REM DETECTION OF PEAK VALUE
710 REM*************************************************
720 IF CON < 2 THEN GOTO 750
730 IF LC(CON)>LCMAX THEN MAX=CON
740 IF LC(CON)>LCMAX THEN LCMAX=LC(CON)
750 GOTO 630
760 REM
770 PRINT "I=",CON
780 PRINT "MAX=",MAX,"LCMAX= ";LCMAX
790 REM***********************************************************-*****
800 REM REDUCTION TO 100 DATAPOINTS
810 REM***********************************************************-*****
820 IF CON < 100 THEN GOTO 1070
830 FAC=CON/100
840 FAC=1/FAC
850 REM
860 REM
870 COMP=0
880 FOR I=1 TO CON
890 IF I=1 THEN 940
900 IF I=MAX THEN 990
910 IF INT((I*FAC)+.5) > COMP) THEN 940
920 GOTO 1040
930 GOTO 1040
940 REM***********************************************************-*****
950 REM OUTPUT OF DATA TO OUTPUT AND PRINT FILE
960 WRITE #2,TIME(I),LC(I)
970 PRINT #3,USING F1$;TIME(I);LC(I)
980 COMP=COMP+1
990 GOTO 1040
1000 REM***********************************************************-*****
1010 PRINT #3,USING F1$;TIME(MAX);LC(MAX)
1020 COMP=COMP+1
1030 REM
1040 NEXT I
1050 REM***********************************************************-*****
1060 GOTO 1110
1070 REM**********************************************************
1080 FOR I=1 TO CON
1090 WRITE #2,TIME(I),LC(I)
1100 PRINT #3,USING F1#;TIME(I);LC(I)
1110 NEXT I
1120 REM**********************************************************
1130 PRINT "COMP=";COMP
1140 END
1.4.2.2 Program listing REDUCTRT.EXE

10 REM******************************************************************************
20 REM
30 REM PROGRAM REDUCTRT  PETER GRUBERT  FEB., '87
40 REM
50 REM REDUCTRT.EXE IS USED IN CONJUNCTION WITH THE
60 REM TESTPT.BAS PROGRAM FOR THE REDUCTION OF DATA FROM
70 REM THE TRAPEZOIDAL TEAR TEST
80 REM
90 REM 1.) INPUT OF DATA FROM DATAFILE "FILD$",
100 REM INPUTFORMAT: FORCE, DEFLECTION, TIME
110 REM 2.) DETECTION OF THE PEAK FORCE VALUE
120 REM 3.) REDUCTION TO 100 DATAPOINTS
130 REM 4.) OUTPUT OF DATA TO OUTPUTFILE "FILO$"
140 REM FORMAT: DEFLECTION, FORCE
150 REM 5.) OUTPUT OF A TITLE AND DATA TO
160 REM PRINTFILE "FILP$"
170 REM FORMAT: TITLE TEXT
180 REM DEFLECTION , FORCE
190 REM
200 REM VARIABLES:
210 REM TIT1$, TIT2$  TITLE TEXT
220 REM TIME(CON)  INPUT VALUE FOR TIME
230 REM LC(CON)  INPUT VALUE FOR FORCE
240 REM DEFL(CON)  INPUT VALUE FOR DEFLECTION
250 REM CON  CONTROL VARIABLE
260 REM FAC  CONTROL VARIABLE
270 REM
280 REM******************************************************************************
290 REM INPUT OF NAMES OF FILES AND TITLE TEXT
300 REM******************************************************************************
310 REM
320 INPUT "NAME OF DATAFILE"; FILD$
330 INPUT "NAME OF OUTPUTFILE"; FILO$
340 INPUT "NAME OF PRINTOUT"; FILP$
350 INPUT "TITLE 1 FOR PRINTOUT"; TIT1$
360 INPUT "TITLE 2 FOR PRINTOUT"; TIT2$
370 REM
380 REM
390 OPEN FILD$ FOR INPUT AS #1
400 OPEN FILO$ FOR OUTPUT AS #2
410 OPEN FILP$ FOR OUTPUT AS #3
420 REM
430 F1$= "#####.####  #####.####  "
440 DIM TIME(4000), LC(4000), DEFL(4000)
450 REM******************************************************************************
460 REM OUTPUT OF TITLE TEXT IN PRINTFILE
470 REM******************************************************************************
480 PRINT #3, "": PRINT #3, ""
490 PRINT #3, "TRAPEZOIDAL TEAR TESTING  ", DATE$
500 PRINT #3, ""
510 PRINT #3, TIT1$
520 PRINT #3, ""
530 PRINT #3,TIT2$
540 PRINT #3,"
550 PRINT #3,""
560 PRINT #3," Clamp Displacement Force "
570 PRINT #3," [in] [lbs]  "
580 REM*******************************************************************************
590 REM INPUT OF DATA FROM DATA FILE
600 REM*******************************************************************************
610 CON=0
620 LCMAX=0
630 REM
640 REM
650 CON=CON+1
660 INPUT #1,LC(CON),DEFL(CON),TIME(CON)
670 IF EOF(1) THEN GOTO 760
680 TIME(CON)=TIME(CON)-TIME(1)
690 REM*******************************************************************************
700 REM DETECTION OF THE PEAK FORCE VALUE
710 REM*******************************************************************************
720 IF CON < 2 THEN GOTO 750
730 IF LC(CON)>LCMAX THEN MAX=CON
740 IF LC(CON)>LCMAX THEN LCMAX=LC(CON)
750 GOTO 640
760 REM
770 PRINT "I=",CON
780 PRINT "MAX=","LMAX= ";LCMAX
790 REM*******************************************************************************
800 REM REDUCTION TO 100 DATAPPOINTS
810 REM*******************************************************************************
820 IF CON < 100 THEN GOTO 1090
830 FAC=CON/100
840 FAC=1/FAC
850 REM
860 REM
870 COMP=0
880 REM*******************************************************************************
890 FOR I=1 TO CON
900 IF I=1 THEN 940
910 IF I=MAX THEN 1010
920 IF(INT((I*FAC)+.5) > COMP) THEN 940
930 GOTO 1060
940 REM*******************************************************************************
950 REM OUTPUT DATA IN PRINT AND DATA FILES
960 REM*******************************************************************************
970 WRITE #2,DEFL(I),LC(I)
980 PRINT #3,USING F1$;DEFL(I);LC(I)
990 COMP=COMP+1
1000 GOTO 1060
1010 REM*******************************************************************************
1020 WRITE #2,DEFL(MAX),LC(MAX)
1030 PRINT #3,USING F1$;DEFL(MAX);LC(MAX)
1040 COMP=COMP+1
1050 REM
1060 NEXT I
1070 REM*****************************************************************************
1080 GOTO 1130
1090 REM*****************************************************************************
1100 FOR I=1 TO CON
1110 WRITE #2,DEFL(I),LC(I)
1120 PRINT #3,USING F1$;DEFL(I);LC(I)
1130 NEXT I
1140 REM*****************************************************************************
1150 PRINT "COMP=";COMP
1160 END
I.5 Program PERM.BAS

I.5.1 Users Manual

I.5.1.1 Description

The program PERM.BAS is written to be used for the reduction of data of the permittivity test. The test parameters and readings are input. Average permittivity and flowrate are calculated based on these readings. The program is set for a constant head value of 50 mm and 5 readings per test. Also, the cross-sectional area of the reservoir cylinder and the sample are set previously.

I.5.1.2 Methodology

1) Install the Microsoft DOS

2) Insert the program disk in drive B:

3) Type: A:BASIC

4) Type: LOAD "B:PERM"

5) The program will prompt for

   SAMPLE NAME

   Input the name of the sample:

   TEST NAME

   Input the name of the test;

   WATER LEVEL DROP

   Input the drop of water level in the reservoir cylinder used for the test;

   TEMP.[C]
Input the water temperature in degrees centigrade.

6) The program will prompt for five time readings:

TIME READING

Input 5 readings obtained for one test in sec.

7) The next prompt is:

PRINTER SET?

Set the printer on top of form and press ENTER.

8) The program will then print our copies of the input data and the calculations.
1.5.2 Program Listing PERM11.BAS

10 REM*******************************************************************************
20 REM
30 REM PROGRAM PERM11                PETER GRUBERT    FEB. '87
40 REM
50 REM PROGRAM FOR THE DATA REDUCTION OF THE
60 REM CONSTANT HEAD PERMITTIVITY TEST
70 REM
80 REM VARIABLES:
90 REM TIM(I)        TIME READING
100 REM Q            VOLUMETRIC FLOW
110 REM RT           TEMP. CORRECTION COEFF.
120 REM XI           PERMITTIVITY
130 REM SUMXI        AV. PERMITTIVITY
140 REM QTA          FLOWRATE
150 REM SUMQTA       AV. FLOWRATE
160 REM*******************************************************************************
170 REM*******************************************************************************
180 REM DEFINITION OF TEST PARAMETERS
190 REM AREAB= CROSSSECTIONAL AREA OF RESERVOIR CYLINDER
200 REM AREAS= CROSSSECTIONAL AREA OF SAMPLE SUBJECTED TO NORMAL FLOW
210 REM SNUM= NUMBER OF READINGS PER SAMPLE
220 REM H = AMOUNT OF CONSTANT HEAD [MM]
230 REM
240 AREAB=32047.38665#:AREAS=3166.9217#:SNUM=5:H=50
250 F$="#####.#  ###.##  ###.#" 
260 REM*******************************************************************************
270 REM INITIAL INPUT
280 REM*******************************************************************************
290 INPUT "SAMPLE NAME";SNAM$
300 INPUT "TEST NAME ";TNAM$
310 INPUT "WATER LEVEL DROP [mm]";WLD
320 INPUT "TEMP.[C]   ";TEMP
330 REM*******************************************************************************
340 REM INPUT OF READINGS
350 REM*******************************************************************************
360 FOR I=1 TO SNUM
370 INPUT "TIME READING ";TIM(I)
380 NEXT I
390 REM*******************************************************************************
400 FOR I= SNUM TO 2 STEP-1
410 TIM(I)=TIM(I)-TIM(I-1)
420 NEXT I
430 REM*******************************************************************************
440 REM CALCULATION OF TEMP. CORRECTION FACTOR
450 REM*******************************************************************************
460 REM*******************************************************************************
470 Q=WLD*AREAB
480 UT=(-.0000218*TEMP)+.001476
490 RT=UT/.001
500 REM*******************************************************************************
510 REM CALCULATIONS
520 REM***********************************************************
530 SUMXI=0
540 SUMQTA=0
550 FOR I=1 TO SNUM
560 XI(I)=(Q*RT)/(H*AREAS*TIM(I))
570 QTA(I)=XI(I)*H/RT
580 SUMXI=SUMXI+XI(I)
590 SUMQTA=SUMQTA+QTA(I)
600 NEXT I
610 SUMXI=SUMXI/SNUM
620 SUMQTA=SUMQTA/SNUM
630 REM***********************************************************
640 REM OUTPUT OF RESULTS
650 LPRINT "PERMITTIVITY TEST"
660 LPRINT "SAMPLE: ",SNAM$:
670 LPRINT "TEST#:",TNAM$," DATE: ",DATE$:
680 LPRINT "TEMPERATURE= ",TEMP," [C]
690 LPRINT "FLOW VOLUME= ",Q," [mm^3]
700 LPRINT "TIME READ. PERMITTIVITY FLOWRATE  
710 FOR I=1 TO SNUM
720 LPRINT USING F$;TIM(I),XI(I),QTA(I)
730 NEXT I
740 LPRINT "AVERAGE PERMITTIVITY=",SUMXI," [1/sec]"
750 LPRINT "AVERAGE FLOWRATE=",SUMQTA," [mm/sec]"
760 REM***********************************************************
770 INPUT "ANOTHER COPY";R$
780 IF R$="Y" THEN 630
790 IF R$="N" THEN 820
800 END
1.6 Calibration of LVDT's and the Loadcell

Prior to the start of the testing, the LVDT's and the load cell were calibrated. The loadcell was placed in a tensile testing machine and loads up to 3000 lbs were applied. Readings of the reference loadcell and output voltage at the amplifier were taken. The LVDT's were placed together with a reference dial gauge in a tensile testing machine and the crosshead moved. Readings of the reference dial gauge and the LVDT's were taken. The data were plot as reference value versus voltage. The linear portion of the curve gave the range of linearity, its slope the calibration coefficient. The plots are presented in Figures [I.1]-[I.4].
CALIBRATION
LVDT 3253

CALIBRATION
COEFFICIENT PC=0.113889 [in/V]

Fig.[1.1] Calibration Curve
Schaevitz LVDT 3253
Fig.II.31 Calibration Curve
Interface Load Cell for Wide Strip Test
CALIBRATION INTERFACE LOAD CELL

Fig. (1.4) Calibration Curve
Interface Load Cell for Puncture and