PERFORMANCE OF GEOTEXTILE SEPARATORS IN WESTERN WASHINGTON

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Fourteen geotextile separators, with different in-services ages, were exhumed in western Washington and their short (survivability) and long-term (filtration/drainage) performances were evaluated. The geotextile samples, which included six woven slit-films, six needle-punched nonwovens, and two heat-bonded nonwovens, were taken back to the laboratory in order to evaluate their overall condition and to perform permittivity and strength tests on specimens of each fabric. Samples of the subgrade and base materials were also evaluated in the laboratory.

The results indicated that all of the geotextile separators adequately performed their intended separation function, although they experienced very different levels of damage during construction. There was evidence of in-service mechanical damage at one of the sites. The damage to the geotextiles was influenced more by the base aggregate type, rather than the initial lift thickness, although both must be considered in design. All of the recovered geotextiles which were installed under an angular base aggregate sustained damage to some degree. Even two heavier weight fabrics, a 231 g/m^2 woven slit-film and a 204 g/m^2 needle-punched nonwoven, sustained damage under angular base material. All of the fabrics which were installed under subrounded to rounded base aggregate experienced minor to no damage. The woven slit-films and the needle-punched nonwovens experienced similar reductions in strength and both survived the installation conditions reasonably well (except for one lightweight needle-punched nonwoven fabric which was overstressed during installation and also may have been installed under too thin of a pavement section). The heat-bonded nonwovens were heavily damaged during installation; however, they were installed under some of the higher site survivability conditions.

The results of the permittivity tests indicated that the woven slit-films and the needled-punched nonwovens both had similar percent increases after being washed. The heat-bonded nonwovens had the highest percent increases in permittivity after being washed, which suggests that they clog more than the other fabrics. There is evidence that the woven slit-films experienced much more blinding than the other fabrics, and that iron staining and caking could also have a detrimental effect on their drainage performance. In all but one case, the woven slit-film fabrics did not meet the Task Force 25 (1989) and Christopher and Holtz (1989) filtration requirements needed for the subgrade soils with which they were in contact. The unwashed (i.e., "undisturbed") permittivity results also indicate that most of the permeabilities of the woven slit-film fabrics fell well below WSDOT's required value. The presence of caked fines on the upper surface of three woven slit-films could have indicated that their pore openings were too large for the intended filtration function and they might be subject to fines migration, although this was inconclusive. There was no other evidence of fines migration at any of the sites.

All of the pavements were in good condition, and the damage of the geotextile separators appeared to have no negative impact on the pavements' long-term performance. There was one pavement surface which showed signs of premature failure; however, this was not attributed to the performance of the geotextile separator.

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SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Fourteen geotextile separators, with different in-service ages, were exhumed in western Washington and their short (survivability) and long-term (filtration/drainage) performances were evaluated. The geotextile samples, which included six woven slit-films, six needle-punched nonwovens, and two heat-bonded nonwovens, were taken back to the laboratory in order to evaluate their overall condition and to perform permittivity and strength tests on specimens of each fabric. Samples of the subgrade and base materials were also evaluated in the laboratory.

The results indicated that all of the geotextile separators adequately performed their intended separation function, although they experienced very different levels of damage during construction. There was evidence of in-service mechanical damage at one of the sites. The damage to the geotextiles was influenced more by the base aggregate type, rather than the initial lift thickness, although both must be considered in design. All of the recovered geotextiles which were installed under an angular base aggregate sustained damage to some degree. Even two heavier weight fabrics, a 231 g/m^2 woven slit-film and a 204 g/m^2 needle-punched nonwoven, sustained damage under angular base material. All of the fabrics which were installed under subrounded to rounded base aggregate experienced minor to no damage. The woven slit-films and the needle-punched nonwovens experienced similar reductions in strength and both survived the installation conditions reasonably well (except for one lightweight needle-punched nonwoven fabric which was overstressed during installation and also may have been installed under too thin of a pavement section). The heat-bonded nonwovens were heavily damaged during installation; however they were installed under some of the higher site survivability conditions.

The results of the permittivity tests indicated that the woven slit-films and the needle-punched nonwovens both had similar percent increases after being washed. The heat-bonded nonwovens had the highest percent increases in permittivity after being washed, which suggests that they clog more than the other fabrics. There is evidence that the woven slit-films experienced much more blinding than the other fabrics, and that iron staining and caking could also have a detrimental effect on their drainage performance. In all but one case, the woven slit-film fabrics did not meet the Task Force 25 (1989) and Christopher and Holtz (1989) filtration requirements needed for the subgrade soils with which they were in contact. The unwashed (i.e. "undisturbed") permittivity results also indicate that most the permeabilities of the woven slit-film fabrics fell well below WSDOT's required value. The presence of caked fines on the upper surface of three woven slit-films could have indicated that their pore openings were too large for the intended filtration function and they might be subject to fines migration, although this was inconclusive. There was no other evidence of fines migration at any of the sites.

All of the pavements were in good condition, and the damage of the geotextile separators appeared to have no negative impact on the pavements' long-term performance. There was one pavement surface which showed signs of premature failure; however, this was not attributed to the performance of the geotextile separator.

CONCLUSIONS

Geotextiles installed between a soft subgrade and overlying base aggregate can prevent contamination of the aggregate and enhance the long-term performance of the pavement. There was no evidence that even heavy damage sustained by the geotextiles during the installation process had any effect on the performance of the pavement system.

The type of base aggregate is very important when assessing the level of survivability required for a fabric. If rounded to subrounded aggregate is placed according to WSDOT specifications, then even the lighter weight (136 g/m^2) fabrics can survive the construction operations reasonably well. The lighter weight fabrics should not be used under high survivability construction conditions when angular base aggregate is used. Based on the results from this study, in order to limit potential damage to the separators it is recommended that fabrics with minimum weights of 270 g/m^2 be used on sites having high survivability conditions.

The pore size openings for all of the woven slit-film fabrics do not meet the filtration requirements for the common soft fine-grained soils found in western Washington. Based on the subgrade soils from the sites investigated for this study, the maximum allowable apparent opening size (AOS) value should be less than 0.3 mm for all fabrics used over fine-grained soils in western Washington.

Blinding, caking and possibly even iron staining affect woven slit-film fabrics much more than nonwoven fabrics, and the permeability (or permittivity) of woven slit-films commonly dropped below 0.005 cm/sec, even with minimal blinding. Therefore, woven slit-films should not be used over soft silty soils when the separator application may be subject to high groundwater conditions (unless the permeability reductions of at least one order of magnitude, and most likely more, will not affect the performance of the roadway). The author suggests that the permeability of all fabrics used in separation applications involving high ground water conditions should be greater than 0.05 cm/sec to accommodate potential decreases in the hydraulic properties of geotextiles with time. Although there was limited information regarding the drainage performance of woven slit-film fabrics, the observations during this study as well as those made by Page (1990) do support the above conclusions. However, the performance of woven slit-films and needle-punched nonwovens are similar when the fabric is used as a construction aide over soft soils which are not affected by the groundwater conditions.

Many of the sites had soft subgrade soils which benefited from the use of a geotextile, and several inspectors mentioned that the subgrade conditions were poor and the geotextile expedited the construction operations. In conclusion, the geotextile separators were needed over the soft subgrade soils to expedite roadway construction and they have enhanced the long-term pavement performance for the roadways which were evaluated in this study.

RECOMMENDATIONS TO WSDOT

Based on the information for the seven WSDOT sites (Table 4.1), very good construction practices are being used by WSDOT in western Washington for the installation of geotextile separators. All of the recovered geotextiles from WSDOT sites had minor to no damage.

However, only the site on SR-14 had high construction survivability conditions. At this site a 231 g/m^2 woven slit-film was used, which was the heaviest weight woven slit-film fabric recovered, and it sustained minor damage. The SR-14 site was also the only WSDOT site which used an angular backfill material immediately over the geotextile. This would suggest that the installation of geotextiles under angular backfill materials will require the use of heavier weight (or stronger) fabrics in order to minimize the amount of damage to the geotextile. Based on the results from this study, Table 1 presents recommended survivability conditions as a function of aggregate type and initial lift thickness. This table is a modified form of Task Force 25's guidelines shown in Table 2.1. The required strength properties needed for the construction survivability conditions determined from Table 1 are the same as those recommended by Task Force 25 (1989), and shown in Table 2.2.

Since the strength properties required by WSDOT were similar to the Task Force 25 interim guidelines for high survivability conditions, then they are also similar to the 1989 Task Force 25 guidelines for medium survivability conditions.

With respect to filtration and drainage, it is recommended that WSDOT require a maximum AOS value of 0.3 mm for all fabrics used in separation applications. It is also advisable for WSDOT to review their current permeability requirements with respect to woven slit-film fabrics, due to the fact that these fabrics, when exposed to silty soils, are susceptible to even small amounts of blinding and/or caking, which can dramatically reduce their permeabilities (or permittivities). A minimum permeability of 0.05 cm/s is suggested for all fabrics used in separation applications subject to high groundwater conditions.

Table 1 - Recommended construction survivability ratings based on aggregate type[1].

Aggregate Type	Angular to Subangular			Rounded to Subrounded		
	Site Subgrade Soil[4] (CBR)					
Initial Lift Thickness[2,3] (cm)	< 1	1 - 2	> 2	< 1	1 - 2	> 2
15	NR	NR	NR	NR	NR	H
23	NR	NR	H	NR	H	M
30	NR	H	H	H	M	M
>45	H	M	M	M	M	M

H=High, M=Medium, NR=Not Recommended

[1] Based on equipment ground contact pressures greater than 350 kN/m^2 (50 psi).

[2] Maximum aggregate size not to exceed one half the compacted cover thickness.

[3] Vibratory compaction not permitted on the initial lift.

[4] Site subgrade to be relatively smooth and free of sharp objects or angular rocks.

As discussed in Section 4.1.2, there have been several instances in the past where geotextiles have been incorrectly used in the separation application. It appears that in these cases the fabrics are merely being installed to comply with the construction documents. It is highly recommended that inspectors and project engineers be well informed on the proper applications for geotextile separators. For example they could attend a seminar on the basic properties of geotextiles and proper installation techniques. It is also advisable to instruct inspectors to keep better records of the geotextile installation process, and that they treat the geotextile as they would any other engineering material (e.g. ACP, concrete, steel, etc.). There are numerous instances where the type of fabric is not even identified in the daily reports. The inspectors and project engineers should also be informed as to whether subgrade conditions require or do not require a separator, and project engineers should have the authority to require their use if needed or to reject them if the subgrade conditions do not require their use (even when shown on the construction documents).

RECOMMENDATIONS FOR FUTURE RESEARCH

The observations made during the site investigations yielded some expected and some unexpected results. It is highly recommended that most of these same sites be investigated in the future, say in five or ten years, in order to continue monitoring the long-term performance of the separators with respect to filtration/drainage, strength, as well as the pavement performance.

It would be extremely beneficial to the geotextile community if site investigations would be conducted with archive samples available from the same lots as the installed fabrics. This would require that WSDOT, or another agency, monitor some or all of their future separator installations and fully document the installation process (i.e. photographs, measurement of lift thickness, initial subgrade strength, etc.). The study could commence immediately after the initial lift is placed on the fabric, and then at predetermined times in the future site excavations could be performed.

Trends are developing with respect to the drainage and filtration properties of woven slit-film fabrics. The effects of blinding, caking, and even iron deposits may be detrimental to their long-term performances. Since there is limited information with respect to these issues, it is recommended that additional research be performed to investigate woven sit-film fabrics. Long-term laboratory flow tests should be conducted with representative soils from western Washington.

For reinforcement applications, the effects of iron staining, hydrolysis of polyester fabrics, and potential brittle behavior of polypropylene fabrics on the long-term strength of the geotextiles should be investigated. Although these effects were encountered or likely encountered during this study, there was not enough data to draw any conclusions with respect to the strength properties of the fabrics. Several of the sites investigated during this study had iron bearing subgrade soils which stained the bottom surface of the fabrics with a significant amount of iron deposits. If iron bearing soils are prevalent throughout western Washington then it would be prudent to understand their effects on geotextiles. The potential long-term brittle behavior of polypropylene fabrics which would reduce their elongations at break should be investigated. The effects of hydrolysis on polyester fabrics has been investigated by a few researchers but it may also require additional studies.

CHAPTER 1

INTRODUCTION

Roadway construction over soft, low strength soils commonly utilizes geotextiles as separators at the base/subgrade interface. Although this is one of the oldest applications for geotextiles, well-documented short and long-term performance data is lacking. The required properties which enable geotextiles to survive normal construction operations (short-term performance) are not well established, and there is little documentation with regard to the performance of geotextiles separators during the design life (long-term) of highway projects.

One of the major causes of premature failure of highway pavements constructed over soft soils occurs when the base/subbase aggregate intermixes with the finer grained subgrade soils, thus reducing the effective thickness of the aggregate. The soft subgrade soils usually consist of saturated fine-grained (silt and/or clay) soils with water contents at or above the plastic limit, or highly compressible peat deposits. Intermixing of the base/subbase materials and subgrade soils occurs due to (1) intrusion of the fine-grained subgrade soils into the aggregate because of pumping or subgrade weakening due to excess pore water pressures, or (2) penetration of the aggregate into the subgrade because of localized bearing capacity failures caused by high wheel load stresses.

The primary purpose of the geotextile separator is to prevent the mixing of the aggregate and subgrade materials. In order for the geotextile to be an effective separator during the life of the pavement system, it is generally recognized that the geotextile must also provide secondary functions at the soil/fabric interface such as filtration, drainage, and to some extent reinforcement. Resl and Werner (1986) concluded that "the reinforcing function of a geotextile is of secondary importance, whereas separation, filtration and drainage are the main functions in road construction". The physical properties required to make the geotextile an effective separator include both strength and hydraulic properties. The separator requires strength to resist the stresses induced by aggregate penetration into the subgrade, and hydraulic properties to prevent the subgrade fines from migrating up into the aggregate while still dissipating the excess pore water pressures. Geotextiles can be economically used in separation applications to maintain the designed aggregate thickness, reduce the needs for overexcavating and using stabilizing aggregate, and to expedite construction procedures.

Although geotextiles have been utilized in separation applications for many years, only recently have state and federal agencies attempted to specify guidelines for their use. Standardized tests have also been established to define the properties required to satisfy the primary and secondary functions of geotextile separators. The guidelines and test requirements allow designers to provide specifications for fabric strength, drainage, filtration and durability. Currently the specifications of many states, including the Washington State Department of Transportation (WSDOT), for construction survivability of geotextile separators have been based on the AASHTO-AGC-ARTBA Task Force 25 recommendations (Christopher and Holtz, 1985). The recommendations made by Task Force 25 have led to extensive use of woven slit-film geotextiles as separators because they meet the requirements for construction survivability and they are less expensive than similar weight nonwoven geotextiles. However, Task Force 25 did not include filtration and drainage properties in their 1985 specifications for geotextile separators and in many cases woven slit-film fabrics will not meet other drainage and filtration requirements. Although woven slit-film geotextiles may have the required properties for short-term performance (strength) they may not meet the requirements needed for the long-term performance (filtration and drainage) and may be subject to blinding or clogging.

The information contained in this report will address the short and long-term performance of 14 geotextile separators which were exhumed from roadways in western Washington. The long-term performance of the roadways were also evaluated. Comparisons will be made between the performance of the nonwoven and woven geotextile separators with respect to survivability and their filtration and drainage properties.

The results of Phase I, the geotextile separator study performed by Page (1990), will be summarized and a literature review will be presented in Chapter 2. The objectives and scope of work will be outlined in Chapter 3. Chapters 4 and 5 will present the site investigation procedures and results. Chapters 6, 7, and 8 will present the results of the observations and tests which were performed. An analysis of all the results will be presented in Chapter 9. The report will conclude with a brief summary of the results, conclusions, recommendations for WSDOT, and recommendation for future work, in Chapter 10. The appendices contain the results of all the laboratory observations and tests, as well as WSDOT's current specifications for construction geotextiles.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This chapter presents the results of the literature survey. Section 2.2 is a review of the results from some of the available published literature. Section 2.3 summarizes the results and conclusions from Phase I (Page, 1990) and Section 2.4 provides an overview of WSDOT's requirements for geotextile separators. Section 2.5 provides a brief summary of Chapter 2.

2.2 RESULTS OF THE LITERATURE SEARCH

This section summarizes relevant information gathered from the available literature with regard to the various functions and properties of geotextile separators. The main issues addressed are; separation/survivability, filtration/drainage, durability, and pavement performance. A brief review of the guidelines used by other state agencies is also presented. There have been numerous papers published on these topics and the following subsections are intended to only present brief discussions on some of the findings of other researchers. The literature review will provide information on research performed since Page (1990), as well as the results of some of the research performed prior to Page (1990) which may not have been addressed by him.

2.2.1 Separation/Survivability

Fabric survivability is defined as "its resistance to destruction during road construction and initial operation" (Christopher and Holtz, 1985). It is important that a fabric survives installation and construction operations, because if damaged, other functions of the geotextile may be diminished in the affected areas. Geotextile survivability may be the most important design criteria.

The level of survivability is governed by the initial site conditions, subgrade strength, construction equipment, aggregate type, and initial lift thickness. It is during the initial construction of a roadway where the geotextile will experience the highest stresses imposed on it. Thus, if a geotextile can survive the construction induced stresses, then it can also usually survive the in-service stresses. In an attempt to quantify the survivability conditions present at any site, Task Force 25 of the AASHTO-AGC-ARBTA Joint Committee on Materials provided a survivability rating system for design purposes. Interim guidelines were first proposed by Task Force 25 in 1983, but have since been revised (Task Force 25, 1989). Table 2.1 shows Task Force 25's current construction survivability rating system as a function of subgrade strength, cover thickness, and construction equipment contact pressure. Based on the required level of survivability from Table 2.1, the necessary minimum strength properties can be selected from Table 2.2. There is some question as to the validity of the strength property values shown in Table 2.2. These values were not based on any systematic research, but rather on property values of separators for which the committee members of Task Force 25 believed have performed satisfactorily in temporary roads and other similar applications.

Table 2.1 - Construction Survivability Ratings, Task Force 25.

Site Soil CBR at Installation		<1		1 - 2		>2	
Equipment Ground Contact Pressure	kN/m^2 (psi)	>350 (50)	<350 (50)	>350 (50)	<350 (50)	>350 (50)	<350 (50)
Cover Thickness[1] (Compacted) mm	(in.)						
100[2,3]	(4)	NR	NR	H	H	M	M
150	(6)	NR	NR	H	H	M	M
300	(12)	NR	H	M	M	M	M
450	(18)	H	M	M	M	M	M

H=High, M=Medium, NR=Not Recommended

[1] Maximum aggregate size not to exceed one half the compacted cover thickness.

[2] For low volume unpaved roads (ADT < 200 vehicles).

[3] The 100 mm minimum cover is limited to existing road bases and is not intended for use in new construction.

Table 2.2 - Physical Property Requirements[1,2,3], Task Force 25 (1989).

Survivability Level	Grab Strength ASTM D 4632 N (lb)	Puncture Resistance ASTM D 4833 N (lb)	Tear Strength ASTM D 4533 N (lb)
Medium	800/510 (180/115)	310/180 (70/40)	310/180 (70/40)
High	1200/800 (270/180)	445/335 (100/75)	445/335 (100/75)

Additional Requirements	Test Methods
Apparent Opening Size	
1. < 50% soil passing a No. 200 US sieve, AOS < 0.6 mm.	ASTM D 4751
2. > 50% soil passing a No. 200 US sieve, AOS < 0.3 mm.	
Permeability	
k of the geotextile > k of the soil (permittivity times the nominal geotextile thickness)	ASTM D 4491
Ultraviolet Degradation	
At 150 hours exposure, 70% strength retained for all cases.	ASTM D 4355
Geotextile Acceptance	ASTM D 4759

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[1] Note, for the index properties, the first value of each set (N or lb) is for geotextiles which fail at less than 50% elongation, while the second value is for fabrics which fail at greater than 50% elongation. Elongation as determined by ASTM D 4632.

[2] Values shown are minimum roll average values. Strength values are in the weakest principal direction.

[3] The values of the geotextile elongation do not imply the allowable consolidation properties of the subgrade soil. These must be determined by a separate investigation.

Task Force 25's 1983 interim guidelines did not address the filtration and drainage functions required by geotextile separators. The 1989 guidelines do address the filtration and drainage functions of separators and they are also listed in Table 2.2. The interim (1983) guidelines provided low, medium, high, very high, and not recommended survivability ratings. However, the 1989 guidelines have eliminated the low and very high ratings, and retained only medium, high, and not recommended survivability conditions. The strength values from the interim guidelines for high and very high conditions are similar to revised medium and high property requirements. The new guidelines provide recommended strength properties based on the elongation of the different geotextiles (woven and nonwoven). The Mullen burst test has also been eliminated from the 1989 guidelines for required strength properties.

In the past few years there has been more research performed to evaluate the condition of the geotextile separators after being installed. These studies include Brorsson and Eriksson (1986), Boneparte et al. (1988), Sprague and Cicoff (1989), Koerner and Koerner (1990), Richardson and Behr (1990), Paulson (1990), Page (1990), and Tsai et al. (1993). Based on their observations and test results, some conclusions have been drawn regarding survivability and required strength of geotextile separators.

Brorsson and Eriksson (1986) evaluated nine different geotextile separators after being installed in 1973. The geotextiles were exhumed after 5 and 10 years for analysis. They concluded that all the geotextiles performed well even though there were up to 50 percent reductions in strength and elongation of the fabrics. They concluded that "the geotextiles were subjected to their highest stress during installation and initial covering operations with heavy equipment". They also noted that the woven geotextile had the highest percent reduction in strength, most of the nonwovens showed little change in strength over the years, and the thermally-bonded nonwoven had the highest percent reduction in elongation.

Boneparte et al. (1988) evaluated two different thermally-bonded nonwoven geotextiles (136 and 204 g/m^2) exhumed from seven unpaved roadways. Test results indicated that the average residual strength ratios of 85, 75, and 50 percent were obtained from sites with moderate to high, high, and very high site survivability conditions, respectively. They also found the elongations at break were lower than the original values.

Most of the damage to the geotextiles was mechanical damage which occurred during construction. They concluded that although the geotextiles were damaged while the roadways were in good condition, the fabrics "...still carried out the required separation function". Also based on their observations they stated that "the traditional view that geotextiles survive only if they sustain very minor damage may require modification".

Sprague and Cicoff (1989) and Cicoff and Sprague (1991) present the same results and conclusions for construction survivability of three different geotextile separators (135 g/m^2 woven slit-film, and 135 and 204 g/m^2 needle-punched nonwovens). They were installed under a low volume road with very thin (38 and 76 mm) initial lift thicknesses, and the trucks were allowed to run and dump aggregate directly on the fabrics. They found that the 135 g/m^2 fabrics performed the same, in terms of survivability, under similar conditions and they were more susceptible to puncture than abrasion under the thin lifts. They concluded that the level of survivability must take into account initial lift thickness, roadway grade, subgrade strength, and equipment loads. For low survivability conditions they suggest that an initial lift thickness of 150 mm or more is required.

Koerner and Koerner (1990) performed a construction survivability study whereby 75 different geotextiles and geogrids from 48 different construction sites were evaluated immediately after installation. The results showed that the woven slit-film geotextiles (110 to 215 g/m^2) suffered the greatest reduction in percent retained strength and had the highest number of holes per m^2. The needle-punched nonwovens and the woven monofilaments of similar weight survived better. Their results also showed data trends that would be expected; (1) the higher the level of construction survivability the greater the installation damage sustained by the geotextiles, and (2) the lighter weight fabrics did not fare well at the higher survivability levels. They suggested the use of heavier weight fabrics for all geotextile types regardless of their application. They recommended a minimum mass per unit area of 270 g/m^2 which should eliminate the occurrence of holes and allow for an installation damage factor of safety of about 1.3 (Koerner and Koerner, 1988). This study differed from that of Boneparte et al. (1988) in that installation damage was the only type of degradation evaluated and in-service damage was not a factor.

Richardson and Behr (1990) evaluated four different geotextiles subject to similar traffic loadings in a paved parking lot. The fabrics were exhumed after eight years of in-service performance. The structural section over the geotextiles consisted of 200 mm of crushed gravel and 50 mm of bituminous pavement. During construction the gravel was dumped onto previously placed gravel (200 mm thick) and spread with rubber-tired equipment. All the exhumed samples were in excellent condition. Index tests on the samples did indicate that the woven slit-film and the spunbonded nonwoven had the highest percent reductions in strength in the highest trafficked areas as compared to the lower trafficked areas. They stated that "the reduction in properties appears to be more dependent on traffic conditions than on fabric type". They suggested that installation damage can clearly be limited with proper consideration of placement techniques and construction operation. They concluded that the fabrics have performed the intended separation function and that it was a successful application.

Paulson (1990) reviewed Boneparte et al. (1988) and Koerner and Koerner (1990) and evaluated their results. He also performed laboratory tests which simulated field installation conditions in order to evaluate installation damage to geotextiles. He concluded that laboratory tests can simulate field conditions. He stated "the strength loss associated with various lift thicknesses appeared to be relatively insignificant compared to the loss affected by aggregate type".

Page (1990) exhumed eight geotextile separators from highway sites in central and eastern Washington. He stated that all the geotextiles performed the separation function adequately and survived reasonably well (with one exception) although there was a wide variation in fabric damage. He noted that most of the damage was in the form of punctures. He concluded that lightweight (118 g/m^2) nonwoven geotextiles should not be used in any separation application regardless of the installation conditions. He also states that a relatively heavy (270 g/m^2) geotextile with high grab elongation be used to reduce installation damage. An expanded review of his results is presented in Section 2.3.

Tsai et al. (1993) conducted a full scale field test on five different geotextiles at a highway site in Washington which had a history of bad performance. They compared the performance of fabrics under two different lift thicknesses (150 and 300 mm). The geotextiles were immediately exhumed after placement of the base course. They found that the only fabric which did not survive installation was the 135 g/m^2 needle-punched nonwoven. They also state that compared with the other geotextiles in the study, the 270 g/m^2 needle-punched nonwoven had the best overall performance.

A laboratory construction installation damage study was performed by Watts and Brady (1990) to evaluate the amount of damage which three, plain weave, woven geotextiles received from a crushed limestone fill. Two different compaction conditions were used, standard compaction (as defined by the Department of Transport, London) and compaction to refusal. They placed 1 m by 3 m geotextile samples over 175 mm of compacted fill and then compacted an additional 175 mm lift of fill over the samples. The fill was compacted using a vibrating roller, and four passes of the roller met the standard compaction requirements, while 10 passes established compaction to refusal. The percent tensile strength reductions for the test specimens ranged from 4 to 37 percent for the standard compaction method, and 36 to 65 percent for the compaction to refusal method. They found that although the fabrics tensile strength and elongations at failure were both reduced, the stiffness was generally unaffected.

2.2.2 Filtration/Drainage

As stated earlier, a geotextile separator must also have hydraulic properties to prevent the migration of subgrade soils into the aggregate while also having the capacity to dissipate excess pore water pressures that may be generated in the subgrade. According to Task Force 25 (1989), the permeability of the geotextile must be at least as permeable as the subgrade. This of course assumes that the geotextile will never become clogged. Several studies have shown that when clogging occurs, the permeability of the geotextile decreases by an order of magnitude or more. It is recommended, since clogging is likely to occur under dynamic hydraulic loading conditions at the soil/fabric interface, that the permeability of the geotextile be at least ten times greater than the permeability of the soil, especially for permanent structures (Christopher and Holtz, 1991).

2.2.2.1 Geotextile Filtration/Drainage Properties

Carroll (1983) suggested that there are three basic elements for geotextile filter criteria: retention ability, permeability, and clogging resistance. He also made some general conclusions based on his and previous studies by others:

1. Fabric equivalent opening size EOS (now apparent opening size, AOS) and permeability coefficients do not indicate clogging potential.
2. All filter media are likely to experience some degree of clogging due to soil infiltration.
3. Well-graded soils are not prone to piping; however, high hydraulic gradients may cause infiltration of well-graded soils into a filter media.
4. Gap-graded soils are prone to soil piping and subsequent filter clogging, whereas high hydraulic gradients maximize the potential for piping in gap-graded soils.
5. A reasonable limit for the maximum allowable gradient ratio, GR, is 3.

Van der Sluys and Dierickx (1987) discussed the applicability of using Darcy's Law in determining the water permeability of geotextiles. They found that in most cases there is no laminar flow for wovens and nonwovens and the calculated permeability values are not exact; therefore, using Darcy's Law gives only approximate values. Although nonwovens have a three-dimensional structure, rather than the two-dimensional structure of wovens, they are still only partially similar to other porous media. There is also some difficulty in measuring the thickness of nonwovens. To avoid the thickness problems, the results can be expressed as permittivity but the more realistic character of a permeability coefficient is lost. They conclude that "...the water conductivity characteristics of geotextiles should be expressed as a discharge rate at a certain hydraulic loss". McGown et al. (1982) also studied hydraulic conductivity of three geotextiles, two nonwovens and one composite, and concluded that Darcy's Law does not hold. In a short discussion, Deberadino (1992) states that permittivity, rather than permeability, is the correct way for geotextile (nonwoven and woven) comparisons.

Several authors have studied geotextile compressibility, which is especially important for needle-punched nonwoven fabrics. Sato and Futaki (1986) conducted long-term drainage tests on initially dry geotextiles. They found the permeability of the tests decreased and self-induced filters were formed. The results from tests performed on a 400 g/m^2, 4 mm thick, needle-punched nonwoven geotextile are shown in Figure 2.1. Giroud (1981), McGown et al. (1982) and Kothari and Das (1992) also showed the same trends for the permeability and thickness as a function of compressive stress.

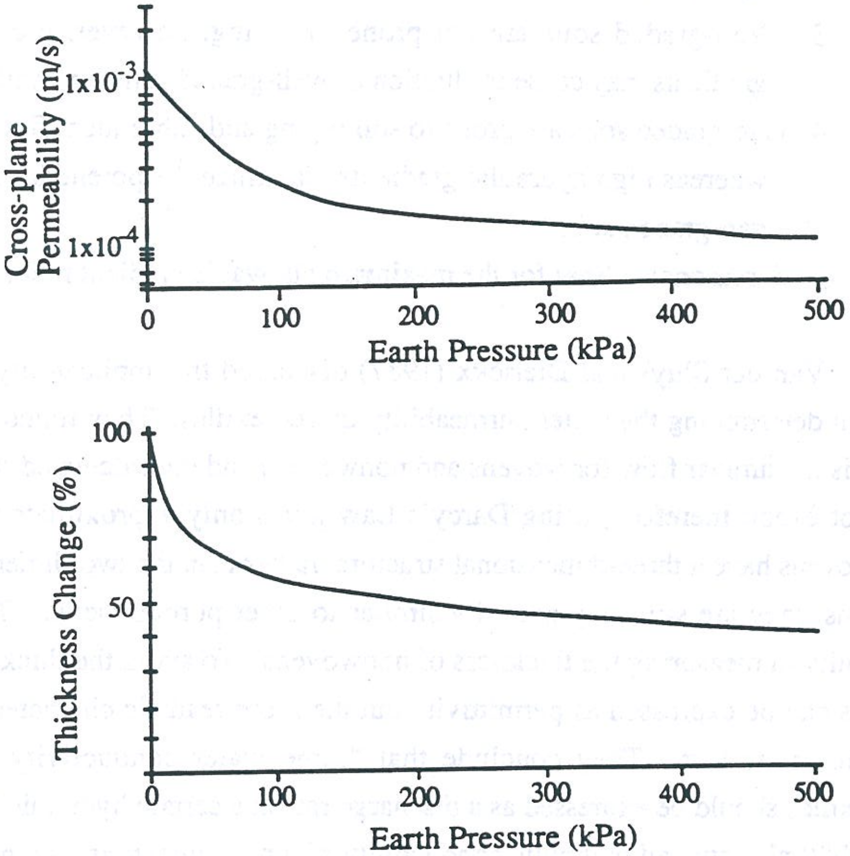

Figure 2.1 - Thickness and cross-plane permeability as a function of compressive stress (from Sato and Futaki, 1986).

Prapaharan et al. (1989) found that the pore size distribution of geotextiles changes with the compressive strain of the fabric; however, they found that the pore size distribution was not significantly altered for strains less than 20 percent. They found that a 4.7 mm thick fabric experiences about 8 percent strain at a pressure of 55 kPa (approximately 3 m of soil). They stated that in most cases the fabrics for drainage and filtration applications are installed at shallow depths and the field stresses will not compress the fabric beyond 20 percent strain. Therefore, the pore size distribution for the uncompressed thickness of the fabric can be used in most cases.

2.2.2.2 Migration of Fines and Clogging

According to Christopher and Holtz (1985) and Jorenby and Hicks (1986) it only takes approximately 20 percent by weight of subgrade fines (soil particles passing the No. 200 sieve) to intermix with base aggregate and reduce the bearing capacity to essentially that of the subgrade soils. Jorenby and Hicks (1986) performed a laboratory study to evaluate the effects that percent fines have on the resilient modulus of an aggregate base. They stated "..at 19.5 percent added fines the aggregate base is acting much like a subgrade material". They found that an aggregate base initially with 5.5 percent fines can tolerate up to 2.5 percent added fines to maintain drainage and up to 6 percent added fines before adversely affecting the stiffness of the base. Figure 2.2 shows their resilient modulus results as a function of percent added fines. While contamination will lead to reduced aggregate bearing capacity and lower permeability, Brandl (1982) also suggests that soil contamination will make the aggregate more susceptible to damage due to freezing and thawing.

Migration of fines up through the fabric, either by pumping or piping, is only one way a fabric may fail as a separator. The separator may also fail by being clogged and/or blinded. Clogging occurs when soil particles move into the pore spaces of the fabric and become embedded there, thus reducing the hydraulic properties of the separator. Clogging is controlled by the smaller pores in the geotextile (Prapaharan et al., 1989). Blinding (also called blocking) occurs when soil particles accumulate at the pore openings of a geotextile and block them, thus also reducing the geotextile's hydraulic properties. Blinding can occur immediately when the geotextile is placed on a fine-grained subgrade. Dierickx and

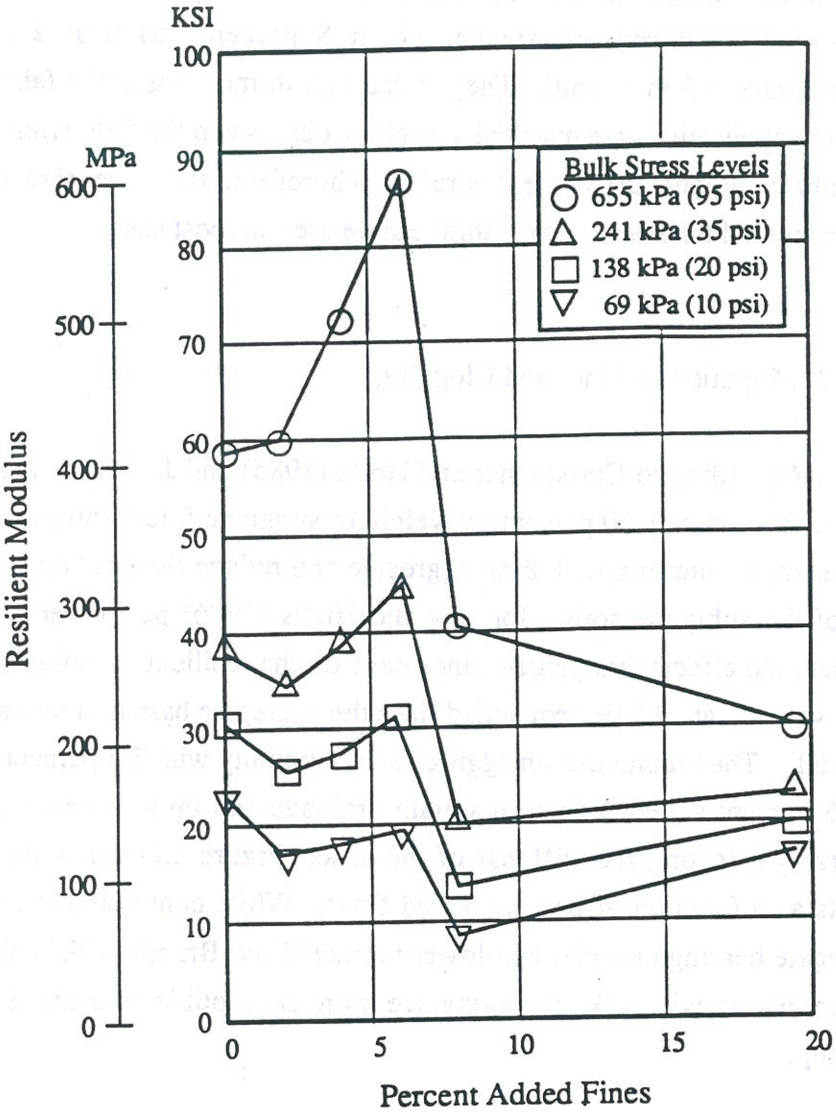

Figure 2.2 - Resilient modulus versus percent added fines (from Jorenby and Hicks, 1986).

van der Sluys (1990) also suggest that other types of blinding/clogging can include chemical (iron, manganese and calcareous deposits) and microbiological clogging (slime formation).

Several studies involving field observations of exhumed geotextile separators have indicated no evidence of fines migration up through the fabric (Brorsson and Eriksson, 1986; Boneparte et al., 1988; Barksdale et al., 1989; and Richardson and Behr, 1990). Rathmayer (1980) noted "a cake of fines could often be found immediately above the geotextile, generally as a thin layer of sediment fines". The sites he investigated included both wovens and nonwovens. All the sites investigated by Page (1990) showed slightly higher fines contents at the bottom of the base materials, but he was unable to conclude that it was due to subgrade fines migration. He also found evidence that woven slit-film fabrics became blinded, thus reducing the drainage capacity of the separators. Tsai et al. (1993) found evidence of fines migration up through a woven slit-film geotextile. Barksdale et al. (1989) concluded that thick nonwoven geotextiles, rather than thin nonwovens or wovens, perform the filtration function better because of their three-dimensional structure.

Rosen and Marks (1975) found that “less piping occurred with the more well-graded soils, which possessed greater plasticity and cohesion”. Dierickx and van der Sluys (1990) concluded that clogging is more obvious in fine-grained cohesionless soils. However, Lafleur et al. (1990) found clay particles, rather than silt, were more susceptible to piping and clogging of geotextiles and attributed it to the higher specific surface areas of the clay particles which cause more resistance to flow.

Rao et al. (1992) performed permeameter tests in which long-term flow rates as well as gradient ratio tests were conducted simultaneously with different soils at different soil densities. They found that unstable flow behavior occurred during the initial period of filtration. The flow rate increased due to fines passing through the fabric, or it decreased if fines were trapped within the fabric or retained upstream. The unstable period occurred for a longer period of time with increasing fines content. The long-term flow rate attained a stabilized condition after the initial unstable flow behavior. The unstable flow behavior continued for over 100 hours in most cases and up to 250-280 hours for the needle-punched nonwoven geotextiles. They stated that “the time required to attain this stabilized condition, after which no soil piping occurs and no geotextile openings clog, depends upon the soil fine content, soil density, and type of geotextile". They also suggested that the gradient ratio measured during the initial unstable condition does not indicate the true clogging behavior of the soil/fabric system. They recommend long-term stabilized gradient ratio tests be performed instead of the 24-hour test.

Earlier tests by Koerner and Ko (1982) and Lawson (1982) had similar results as Rao et al. (1992). Both studies found that the long-term flow tests through the soil/fabric systems showed the initial flow rates were governed by the soil while the final rates were governed by the soil/fabric interaction. Koerner and Ko (1982) found that stabilized flow conditions occurred after a few hours for sand soils, about 100 hours for silt soils, and approximately 200 hours for soils with a high clay content. They also concluded that long-term stabilized filtration tests, rather than the gradient ratio test, be used for the determination of clogging potential of a soil/fabric system.

Mlynarek et al. (1991) also had similar results as Rao et al. (1992), except that they tested primarily nonwoven fabrics and found the soil stabilization period to generally occur within 20 hours of testing. They also suggested that the permeability of the fabric must be higher than the soil, but small pore openings were required to (1) ensure a fast natural filter formation and (2) to decrease the hydraulic forces on the fines next to the geotextile to minimize the loss of fines.

2.2.2.3 Dynamic Loading Conditions

There have been several investigations with respect to the separation function of geotextiles under dynamic loading conditions.

Snaith and Bell (1978) found aggregate contamination above thinner nonwoven fabrics, while the woven fabrics behaved consistently a little better. The soil used in their tests consisted of 58 percent sand, and Ayers and McMorrow (1980) pointed out that the filtering results of fabrics used by Snaith and Bell (1978) should not be compared to finer-grained cohesive soils. Ayers and McMorrow (1980) also found no commercially available fabrics which could prevent the migration of clay fines in subgrade containing only silt and clay particles. Bell et al. (1982) suggested that "thick, relatively incompressible geotextiles with low pore sizes will be effective in limiting subbase contamination to an acceptable level". They also found nonwovens to be relatively ineffective in preventing clay migration but they were more successful in preventing aggregate penetration into the subgrade.

Hoare (1982) conducted dynamic tests similar to Snaith and Bell (1978) to evaluate soil migration and the effects that loading conditions have on different base/fabric systems. He found thicker fabrics passed less fines into the aggregate but even the thick needle-punched nonwoven geotextiles were not capable of totally preventing soil migration. Even after 216,000 load cycles soil migration continued. The migration of fines through the fabric occurred at subbase/subgrade contact points.

Andersson and Jonsson (1984) found up to 1 cm of fines deposited on the top of a heat-bonded nonwoven geotextile during laboratory dynamic load tests. Laier and Brau (1986) found that where an overlap occurred, with an nonwoven over a woven, the fine particles obviously migrated up through the woven slit-film and were deposited on the underside of the nonwoven.

Saxena and Hsu (1986) conducted experiments to evaluate the change in permeability of a simulated railroad system using two different needle-punched geotextiles (270 and 550 g/m^2) and compared their results to Hoare (1982). They found the permeability of the system to decrease, by about an order of magnitude, with time and with increased load repetitions. The initial permeability of the system was governed by the soil, but after a few load cycles the clogged geotextile dominated the permeability of the system. The tests also indicated that the permeability of the system was significantly affected by soil fines after about 500 cycles of loading, but the permeability became almost constant after 20,000 cycles of repeated load. A layer of fines was deposited on the top of the geotextiles after a number of loading cycles were completed. They suggested the fines migrated through the geotextile during the loading sequence and after the repeated load cycles terminated the fines would settle down on top of the fabric.

Dawson (1986) conducted an in-situ full-scale test to investigate the effect that two different nonwoven geotextiles have on controlling subbase contamination under dynamic loading. He found the heat-bonded and the needle-punched nonwoven to have had their permeabilities reduced by a factor of four. He also found the heat-bonded fabric more capable of preventing slurry initiation without clogging, while the needle-punched fabric was less successful.

Schneider and Puhringer (1986) performed laboratory tests to study the effects of dynamic loading on base/subgrade systems with geotextiles. They found that fabrics damaged during installation will permit more subgrade fine migration and the separation function was reduced under dynamic loads. All sections tested performed much better with the fabrics than without them. The results showed the 200 g/m^2 needle-punched nonwoven had the best drainage performance compared to the other fabrics (230 g/m^2 heat-bonded nonwoven, and 95 and 335 g/m^2 woven slit-films).

McMorrow (1990) performed laboratory tests to assess the separating abilities of a wide range of nonwoven geotextiles under dynamic loading conditions. He found no geotextile capable of preventing the migration of clay particles. The needle-punched nonwovens, rather than the heat-bonded nonwovens, were clearly more efficient in preventing fine migration. For applications in railways, he concluded, when choosing between two geotextiles equal in other regards (e.g. abrasion resistance, static filtering ability) preference should be given to the more flexible fabric.

Lafleur et al. (1990) conducted dynamic loading tests and found that clogging of a nonwoven fabric was nearly completed after 5,000 cycles. They also found that for a given subgrade soil, the rate of fabric clogging was directly related to the aggregate size.

2.2.3 Durability

The durability of a geotextile can be defined as its ability to resist short and long-term degradation when exposed to installation and in-service stresses, sunlight, moisture, extreme temperatures, and chemical and biological attack. Allen (1991) stated "designers of geosynthetic reinforced structures must be assured that long-term stresses in the reinforcement do not exceed the strength of the reinforcement at any time during the design life of the structure". Although the reinforcement provided by geotextiles in separator applications is usually of little concern, the statement by Allen (1991) shows the importance of long-term performance in any geotextile application. Barksdale et al. (1989) recommended that the design life of geotextiles in separation and filtration applications should be at least 20 years.

As described in Section 2.2.1, damage to a geotextile due to installation stresses (short-term degradation) can be quite severe. Installation damage alone has reduced the strength of some geotextiles by more than 50 percent. Recall that in-service stresses on the fabric are generally much smaller than the installation stresses, and therefore there should be little long-term mechanical degradation after the roadway construction has been completed.

The geotextile's strength can be rapidly reduced if exposed to ultraviolet (UV) radiation. UV degradation of geotextiles is a function of the fabric's thickness, density, polymer type, fiber thickness, presence of UV stabilizers, and length of exposure. However, in separation applications, the construction practices generally result in the fabric being buried soon after placement, and therefore geotextile degradation due to long-term UV exposure should be of little concern.

All separators are exposed to moisture to some degree, and all polymers absorb moisture. When geotextiles are exposed to moisture, two processes may occur, plasticization (moisture absorption) and hydrolysis (moisture reaction). Plasticization generally results in minimal (5-10 percent) modulus and strength reductions for fabrics composed of polyester and nylon, while polymers composed of polypropylene and polyethylene experience negligible reductions. Hydrolysis, rather than plasticization, is more significant and again only polyester and nylon are susceptible to this reaction (Elias, 1990). Hydrolysis occurs when the water molecules react with the polymers resulting in reduced molecular weight and decreased fiber tensile strength. Studies have shown that hydrolysis in alkaline environments can reduce polyester strength up to 50 percent in 17 years. In neutral pH environments the same strength loss is estimated to occur in excess of 50 years and possibly up to 150 years (Elias, 1990). Metal ions such as Ca and Na can accelerate hydrolysis of polyester materials (Billing et al., 1990). Barksdale et al. (1989) also suggest that polypropylenes and polyethylenes are susceptible to degradation in oxidizing environments in the presence of copper, iron, manganese, and zinc.

Generally, only extreme temperatures have an impact on the geotextile properties. Very cold temperatures can cause polymers to become brittle, while high temperatures can melt the fabrics. Polypropylene will melt at 165°C (325°F) and polyester will melt at 250°C (480°F). Geotextiles are exposed to high temperatures in paving operation where hot asphalt and joint sealers are used (Koerner, 1990).

When assessing the potential chemical effects that soil has on buried geotextiles the most important consideration is the soil pH. Generally, it is only the extreme pH environments which have an impact on the performance of geotextile polymers, while most polymers have good resistance to acid and alkaline attack in normal soil environments (Billing et al, 1990). Billing et al. (1990) performed chemical tests on different geotextile polymers and concluded that "all materials exhibited good chemical resistance in liquids whose range of pH far exceed those normally present in soil". Colin et al. (1986) tested the burst strength of five different geotextiles after being buried for up to seven years in an organic rich soil. They found negligible reductions in burst strength for all the samples, and no evidence of oxidation. Boneparte et al. (1988) and Richardson and Behr (1990) also found negligible or no chemical degradation of the geotextiles after being buried for several years. Boneparte et al. (1988) found only very minor evidence of long-term polymer degradation for geotextiles buried for up to 12 years, and it was apparently due to polymer oxidation. Richardson and Behr (1990) found no evidence of sizeable chemical degradation of the polymers after the geotextiles were buried for up to 8 years. Although geotextiles may perform well in normal soil environments, the effects of chemical spills and chemical attack by leachate in waste containment areas must also be considered.

Biological degradation of geotextiles from microorganisms such as fungi and bacteria is very unlikely. Allen (1991) recommended a partial factor of safety for biological degradation of one be used for temporary and noncritical permanent applications. Other forms of biological degradation may be caused by insects, rodents, and roots.

2.2.4 Pavement Performance

Boneparte et al. (1988) and Brorsson and Eriksson (1986) both found the pavement structures to be in good condition and with a history of good performance, although there was a wide range of damage to the separators. Richardson and Behr (1990) found the paved parking lot which used the geotextile separator to be performing very well, while adjacent parking lots without the separators had pumping failures. Scullion and Chou (1986) also reported on the benefits of using geotextile separators under thin pavements, on weak subgrades, while Ingold and Crowcroft (1984) discussed several case histories of good pavement performance using geotextile separators. Case histories of roadway failures which used geotextiles are also discussed by Ingold and Crowcroft (1984) and Christopher and Holtz (1985).

It should also be mentioned that Brorsson and Eriksson (1986) and Boneparte et al. (1988) both reported that upon excavation of all their sites the subgrades were firm and well consolidated.

The following references will not be discussed but are provided as additional information on the design of paved and unpaved roadways using geotextiles.

- Unpaved roadway design:
  Steward et al (1977), Giroud and Noiray (1981), Christopher and Holtz (1985), Holtz and Sivakugan (1987), and Hausmann (1987).
- Paved roadway design:
  Christopher and Holtz (1985), and Christopher and Holtz (1991).

2.2.5 Design Methods Used by Other States

Koerner and Wayne (1989) summarized the progress of 46 state agencies (includes the District of Columbia and Puerto Rico) in keeping up with current geosynthetic activity and specifications. The report primarily focused on the following geotextile applications: (1) Survivability/Separation, (2) Drainage/Filtration, (3) Silt Fences, (4) Reflective

Cracking, and (5) Erosion Control. Comparisons were also made on whether the agencies followed the guidelines established by AASHTO (1984) or the interim guidelines recommended by Task Force 25 in 1985.

Of the 46 agencies that responded to the survey 14 addressed the Survivability/Separation topic while 27 addressed the Drainage/Filtration topic. Nine of the 14 agencies addressing the Survivability/Separation topic followed AASHTO guidelines while four followed Task Force 25. With regard to the topic of Drainage/Filtration six of the 27 agencies followed AASHTO guidelines while no agencies followed Task Force 25. The principal difference between the two guidelines, AASHTO and Task Force 25, regarding Survivability/Separation is that AASHTO provides only minimum values which must be met for grab and puncture, while Task Force 25 provides a range of values for the four index strength tests which depend on the level of expected survivability. As mentioned in Section 2.2.1, Task Force 25 revised their interim guidelines in 1989.

2.2.6 Summary of the Literature Survey

Many studies, field and laboratory, have been performed to assess the short and long-term performance of geotextile separators. These studies have included short and long-term field and laboratory performance analyses to evaluate survivability, filtration/drainage, and durability of the geotextiles. Laboratory studies have also been performed to assess the above issues under dynamic loading conditions. Although the results of many of these studies are very different, inconclusive, and even conflicting, there appear to be a few trends emerging.

The studies with respect to separator survivability had many different but not necessarily always conflicting results. Some researchers found lightweight fabrics (135 g/m^2) to have survived well, while others have found them to have been subject to heavy damage, but the level of damage for each case had different backfill types, placement techniques, and degrees of compaction. Thus, the degree of damage is obviously more an issue of construction practices rather than geotextile type. It is generally advised not to end-dump directly onto the fabrics or operate equipment directly on the fabric or on very thin initial lifts, although an adequate initial lift thickness has not been agreed upon. If care is taken during construction and the proper equipment and thicker initial lifts are used, the lighter weight fabrics appear to survive adequately. But, there is a trend developing where under normal construction conditions lighter weight fabrics accrue more damage. Thus, a few authors have suggested that 270 g/m^2 fabrics have performed well and are recommended because they are expected to receive minimal or no damage during normal construction operations.

Most researchers recognize that filtration and drainage of geotextile separators is very important, although the requirements have not been adequately resolved. Several researchers have found no fabric capable of preventing fines migration under laboratory imposed dynamic loading conditions. Laboratory tests also indicate that the fabric will blind and clog under repeated dynamic loads, although the decrease in permeabilities varied and in some cases may not have been detrimental when compared to the subgrade soil permeability. Several field studies have showed no migration of fines up through the geotextiles while a few others had indications of subgrade fines migration; specific cited instances involved woven slit-film fabrics. It appears thicker geotextiles are more capable of preventing subgrade fines migration, although this statement is also inconclusive. There is also some evidence of clogging and blinding of geotextiles in the field, although there have been no reported negative effects on the pavement system.

In all the studies which evaluated the field performance of geotextile separators, the pavement performance has been satisfactory to very good. Good pavement performance occurred even when some of the geotextiles had sustained a significant amount of damage during construction. There are some indications that although the geotextiles may be damaged to some degree during construction, they can still perform the separation function satisfactorily.

The guidelines suggested by Task Force 25 (1989) are an improvement over their interim guidelines. The recent guidelines provide recommendation for filtration and drainage, as well as increased separator strength requirements for the level of expected survivability. Guidelines by Christopher and Holtz (1985 and 1989) and Koerner and Wayne (1989) are also recommended for design and construction using geotextile separators.

2.3 SUMMARY OF PHASE I RESULTS AND CONCLUSIONS

Eight sites were evaluated in eastern and central Washington as part of the Phase I study (Page, 1990). The data collected from these sites yielded information regarding retained strength, retained permittivity, and survivability as well as general performance observations of the geotextile separators. Page (1990) reported that at three of the sites, the geotextile separators were installed directly over imported gravel fills. He noted that these sites were only useful for evaluating the survivability conditions and comparing them to the damage which they may have received. A summary of the Phase I sites, installation conditions, and damage and clogging estimates are presented in Table 2.3.

All of the roadway pavement surfaces appeared to be in good condition with no signs of premature failure. All of the geotextiles apparently performed the separation function adequately even though three of them were not installed properly, as stated above. All of the geotextiles appeared to have survived construction reasonably well, except for the fabric from the SR-270 to Albion Rd. site, although several had minor to moderate damage. Page noted that most of the damage was in the form of punctures. Page stated that "there is no evidence that the presence of moderate construction damage to the geotextile separator significantly affected the performance of the roadway".

Based on the severe damage sustained by the 118 g/m^2 heat-bonded nonwoven geotextile from the SR-270 to Albion Rd. site, Page concluded that a lightweight (118 g/m^2) nonwoven geotextile should not be used in any separator application regardless of the subgrade material or the initial base course lift thickness. He also stated that the use of a relatively heavy geotextile, 270 g/m^2 or more, which meets the high survivability strength criteria with a high grab elongation will help minimize damage to the fabric which may occur during construction. The results of his laboratory strength tests are summarized in Table 2.4.

Most of the sites evaluated by Page showed small increases in the fines content of the base material immediately above the geotextile separator. Since they were such small increases he concluded that migration of fines up through the geotextiles was probably not a significant problem at the sites in his study.

Table 2.3 - Summary of Phase I site investigations.

SR & Site Name	Installation Date	Geotextile Type & Weight g/m^2 (oz/yd^2)	Subgrade Material	Base Material	Initial Lift Thickness (cm)	Survivability Rating	Degree of Damage	Degree of Blinding or Clogging
SR-395 Colville Vicinity	10/87	Supac 8NPUV NP-NW 270 (8)	Sandy gravel fill	Crushed rock ballast	30 - 46	Very high	None	None
SR-27 Fallon to Palouse	9/83	Mirafi 500X W-SF 136 (4)	Clayey silt w/ trace gravel	CSTC	15	?	None	Severe
SR-195 SR-270 to Albion Rd.	10/83	Heat-bonded nonwoven 118 (3.5)	Crushed rock fill	Crushed rock ballast	13 - 15	High	Severe	Minimal
SR-195 Albion Rd. to Parvin Rd.	9/85	Supac 5NP NP-NW 180 (5.3)	Clayey silt w/ occasional gravel	Crushed rock ballast	23	High	Moderate	Minimal
SR-90 Ritzville to Tokio	7/89	Mirafi 500X W-SF 136 (4)	Crushed rock fill	CSTC	15	Very high	Minimal	None
SR-20 Aeneas Valley to Wauconda Summit	6/89	Amoco 2002 W-SF 153 (4.5)	Silty sand	Crushed rock ballast	33	Moderate to high	Moderate	Minimal
SR-173 Rocky Butte to Bridgeport Bar	4/86	Mirafi 500X W-SF 136 (4)	Silty sand	Pit-run gravel	91	Moderate	None	Minimal
SR-172 SR2/Farmer to 5NW Road	7/88	Mirafi 500X W-SF 136 (4)	Sandy silt	CSTC	10	High	Minimal	Moderate

NP-NW - needle-punched nonwoven
W-SF - Woven slit-film

Table 2.4 - Summary of the Phase I index strength test results.

Site Name	Grab Tensile %	Trapezoidal Tear %	Puncture %	Burst %	Average % retained strength
Colville Vicinity	80	99	100	99	95
Fallon to Palouse	87	61	100	81	82
SR-270 to Albion		Severe	damage -	no tests	performed
Albion to Parvin	100	100	100	66	92
Ritzville to Tokio	76	41	100	67	72
Aeneas Valley	38	29	73	41	45
Rocky Butte	100	96	100	99	99
SR2/Farmer	62	61	100	63	72

Page also evaluated the geotextile separators with respect to blinding or clogging and he concluded that woven slit film fabrics "would be adequate for separation applications over most subgrade soils; however, they tend to become blinded more readily than nonwovens when used over clayey silt subgrades". Page based this conclusion on the results from one site, Fallon to Palouse, and it was the only woven slit-film installed over a clayey silt subgrade. Page also reported that no permittivity tests were conducted on three of the woven slit-films because the "geotextile was clean in-situ". The woven slit-film from the Fallon to Palouse site had a lot of iron-oxide deposits adhering to it. Page mentioned that these iron deposits acted as a binder which held the clay and silt particles together and to the geotextile. He interpreted this as clogging.

Page compared his washed permittivity values to the manufacturers' values and reported the percent permittivity retained. All the geotextiles retained more than 67 percent of their published permittivity values. But when he compared the unwashed to the washed test results, the Fallon to Palouse site showed a 1950 percent increase in permittivity. All of the other sites had washed permittivity increases less than 70 percent. He did note that the succeeding runs in the unwashed tests from the Aeneas Valley to Wauconda Summit woven slit-film geotextile did show permittivity increases of 71 and 153 percent. He then concluded that "for the woven slit-film geotextiles, only a small amount of contamination of the material by fine-grained soil particles is required to cause a significant drop in permittivity". Page eventually concluded that even if the geotextiles become blinded or clogged during the separation process, it has not been proven to be detrimental to the performance of the roadway.

Table 2.5 summarizes Page's permittivity tests results. The table was constructed using Pages unwashed and washed test results and these were used in determining the percent increases in permittivity (Manufacturers' and WSDOT values were not used). As Page noted, during each test the permittivities of each succeeding run for the unwashed tests tend to increase due to cleansing of the fabric. Therefore, each of Page's first unwashed test runs were compared to the corresponding averaged washed test results, as shown in Table 2.5.

Blinding of woven slit-film geotextiles installed over clayey silt subgrades was found by Page to be a potential problem. Although this conclusion was based on limited information, it does suggest the susceptibility of some fabrics to blinding and/or clogging by fine-grained soil particles. The potential decrease in permeability of the fabric should be considered. He also recommended that 270 g/m^2 fabrics be used to minimize damage to the separator during construction. He found that all the separators were adequately performing their intended separator function even though they experienced varying degrees of damage. At all of the sites which he investigated the pavements were performing well.

Table 2.5 - Summary of Phase I permittivity test results.

SR & Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Sample	Unwashed permittivity Ψ 1st run	Average washed permittivity Ψ	Permittivity increase %
SR-395 Colville Vicinity	Supac 8NPUV NP-NW 270 g/m^2 (8 oz/yd^2)	1	1.07	*0.96*	*0*
		2	0.93	-	-
		3	1.31	*1.13*	*0*
SR-27 Fallon to Palouse	Mirafi 500X W-SF (4 oz/yd^2)	1	0.030	0.67	2133
		2	0.021	0.10	376
		3	0.0089	0.45	4956
SR-195 SR-270 to Albion Rd.	Heat-bonded nonwoven (3.5 oz/yd^2)		Severe damage	no tests	performed
SR-195 Albion Rd. to Parvin Rd.	Supac 5NP NP-NW (5.3 oz/yd^2)	1	0.310	damaged	-
		2	0.4319	0.872	102
		3	0.4576	0.618	35
SR-90 Ritzville to Tokio	Mirafi 500X W-SF (4 oz/yd^2)	1	0.589	*0.743*	*26*
		2	0.665	*0.778*	*17*
		3	0.638	*0.585*	*0*
SR-20 Aeneas Valley to Wauconda Summit	Amoco 2002 W-SF (4.5 oz/yd^2)	1	0.313	*0.344*	*10*
		2	0.013	*0.033*	*154*
		3	0.021	*0.036*	*71*
SR-173 Rocky Butte to Bridgeport Bar	Mirafi 500X W-SF (4 oz/yd^2)	1	0.1004	*0.1088*	*8*
		2	0.0791	*0.0861*	*9*
		3	0.0507	*0.0504*	*0*
SR-172 SR2/Farmer to 5NW Rd.	Mirafi 500X W-SF (4 oz/yd^2)	1	0.0968	0.136	41
		2	0.0652	0.095	46
		3	0.0744	0.096	29

Italic - indicates no washed tests were performed because samples appeared to be clean. The indicated values are from the ***last recorded unwashed run*** for each test.

NP-NW - needle-punched nonwoven
W-SF - Woven slit-film

2.4 CURRENT WSDOT DESIGN METHODS

Current Washington State Department of Transportation (WSDOT) design specifications for survivability of construction geotextiles used in soil stabilization (separation) applications are based on the interim recommendations provided by Task Force 25 for construction survivability requirements of geotextiles (Christopher and Holtz, 1985). WSDOT provides additional requirements that address the filtration and drainage characteristics of geotextiles used in separation applications, which were not addressed by Task Force 25. As mentioned earlier, Task Force 25 did revise their guidelines for geotextiles in separation applications in 1989 to address filtration and drainage which were based on the recommendations provided by Christopher and Holtz (1985). WSDOT specifications for geotextile separators are not site specific. WSDOT assumes all the sites to have high survivability conditions and that all the sites will have fine-grained subgrade soils. Thus, whether the subgrade soils consist of fine sand, silt, clay, or a combination thereof, all the geotextiles will have to meet the same specifications for survivability and filtration/drainage. WSDOT's procedure for specifying geotextiles in separation applications is provided in the appropriate section of the General Special Provisions Division 8, a copy of which is provided in Appendix E.

2.4.1 Survivability and Installation Requirements

To meet the survivability conditions which occur during construction, WSDOT adapted the interim recommendations for high survivability conditions set forth by Task Force 25 (Christopher and Holtz, 1985). To satisfy the specifications required by WSDOT for geotextile separators, the fabric must meet the minimum values of four index strength tests (grab, tear, burst, and puncture) and one performance test (seam strength). The four index strength tests are required at all times, but the performance test is only required if joints are to be sewn, rather than overlapped during construction. Table 2.6 lists WSDOT test methods and the associated ASTM designations, as well as the minimum strength values required by WSDOT in order to satisfy their specifications before a geotextile can be used in separation applications.

Table 2.6 - WSDOT minimum strength requirements.

Test	WSDOT Test Method	ASTM	Required Minimum Value
Grab Tensile Strength (machine and cross-machine directions)	916	D 4632	180 lb
Burst Strength	920	D 3786	290 psi
Puncture Resistance	921	D 4833	75 lb
Tear Strength (machine and cross-machine directions)	919	D 4533	50 lb
Seam Breaking Strength	918 and 916 (Grab)	D 4884 D 4632	160 lb

WSDOT requires the subgrade beneath the area to be covered by the geotextile to be graded to a smooth, uniform condition free from ruts, potholes, and protruding objects such as rocks or sticks. The geotextile must not be left exposed to sunlight during installation for more than a total of five calendar days. WSDOT currently requires a minimum initial lift thickness of 30 cm (12 in.) and the cover material is not permitted to be end-dumped directly on the geotextile. Compaction of the initial lift is limited to the routing of placement and spreading equipment only, and vibratory compaction is not allowed. Rutting in the initial lift above the geotextile must be kept to less than 75 mm in order to prevent overstressing the geotextile. Vehicles are not permitted to make turns on the initial lift.

During installation the geotextile must be overlapped a minimum of 60 cm (2 ft) at all longitudinal and transverse joints, or the geotextile joints must be sewn. All damaged areas must be repaired by placing a patch new material (same type) and providing a 60 cm overlap beyond the edge of any part of the damaged area.

2.4.2 Filtration and Drainage Requirements

WSDOT also addresses the filtration and drainage characteristics for geotextiles in separation applications. WSDOT requires two tests with specific values which must be met in order for a geotextile to be used as a separator. The first test, WSDOT Test Method 922 (ASTM D 3776) tests the filtration characteristics of the geotextile and WSDOT requires the Apparent Opening Size (AOS) to be less than 0.42 mm (No. 40 US sieve). The second test, WSDOT Test Method 924 (ASTM D 4491) addresses the drainage properties of the geotextile. The permeability of the geotextile is determined by obtaining the average permittivity of a sample and multiplying it by the nominal thickness of the sample. The falling head and the constant head test are both permitted for determining the permittivity of geotextiles. At this time, the WSDOT Materials Laboratory uses the falling head method. WSDOT requires that all geotextiles to be used in separation applications have a permeability greater than 0.005 cm/sec.

2.5 SUMMARY

Researchers in the past few years have attempted to assess the short and long-term performance of geotextile separators, but the results are inconclusive. Survivability of geotextile separators was the focus of several papers, but many conclusions were different due to different conditions for which the geotextile were installed. Some researchers found lightweight (~135 g/m^2) fabrics to survive installation stresses satisfactorily, while others found that lightweight fabrics experienced considerable damage during construction and recommended the use of heavier weight (270 g/m^2) fabrics to minimize construction related damage.

The issue of filtration and drainage of geotextile separators has also had inconclusive results. Several laboratory studies have found that fabrics cannot prevent fines migration during dynamic loading tests. However, field studies have had very different results, in that most have reported no indications of fines migration through the geotextile, while a few others have reported some fines migration through woven slit-film fabrics. Evidence of blinding of woven slit-film fabrics was not described in detail by any of the research other than Page (1990).

All the studies which evaluated the performance of geotextile separators in the field, had reported good pavement performance. A few studies have indicated that construction damage sustained by the separators during the installation operations have not had any detrimental effects on the performance of the roadways.

As mentioned above, Page (1990) did find evidence that woven slit-film fabrics can blind which in turn diminishes their hydraulic properties. He also suggested that lightweight (118 g/m^2) nonwoven geotextiles should not be used for any separation application. Although several of the recovered geotextiles which he evaluated sustained construction damage, he concluded that all of the fabrics were still adequately performing their intended separation function and that all of the pavements were performing well.

The purpose of this study will be to evaluate the short and long-term performance of both woven slit-film and nonwoven geotextile separators at 13 sites in western Washington. Damage sustained by the geotextiles (if any) will be evaluated by quantitative and qualitative observations, as well as laboratory strength tests. The filtration and drainage characteristics of both woven slit-films and nonwovens will also be evaluated. The susceptibility of blinding by the woven slit-films fabrics will also be discussed. The results of all the site investigations will then be used to assess the overall performance of the geotextile separators with respect to their intended separation function and the performance of the roadways.

CHAPTER 3

OBJECTIVES AND SCOPE OF WORK

3.1 OBJECTIVES OF THE RESEARCH

The objectives of the research was to evaluate the performance of geotextiles used as separators in western Washington. Current WSDOT installation procedures, field inspections, and specifications were also reviewed. The principal issues addressed in this study include:

- Survivability - Assess the impact that construction operations have on the geotextile separator. This will include visual observations and laboratory strength test analyses. The variables are the initial subgrade conditions, climate, construction equipment, base material, initial lift thickness, and type of geotextile.

  Strength reduction: Grab tensile and wide width strength tests were performed on the exhumed geotextile samples and compared to WSDOT compliance tests and/or manufacturers' data in order to estimate the percent strength retained for each site. Variables include: Physical damage to structure of geotextile, chemical and biological degradation, and aging.

- Long-term performance of the geotextile - Assess possible clogging/blinding of the geotextile by visual observations and laboratory permittivity analyses.

  Clogging/blinding: Tests were conducted on the exhumed geotextile samples to estimate the percent increase in permittivity for each site. Variables include: Subgrade material, groundwater conditions, chemical and biological conditions, traffic, and type of geotextile.

- Long-term performance of the pavement - Correlate long-term roadway and pavement performance using the information gathered from the as-built conditions, site investigations, and laboratory analyses.

3.2 SCOPE OF THE WORK PERFORMED

In order to accomplish the objectives of this research project, cooperation and coordination of WSDOT and county/city personnel was required, sites were investigated, and laboratory analyses performed. The project was divided into six separate phases which were necessary to complete the research. These phases are:

1. Preliminary research and site selection,
2. Final site selection,
3. Site investigations,
4. Laboratory analyses,
5. Analysis of field and laboratory data, and
6. Phase II final report.

Phase 1 included reviewing WSDOT records of projects which used geotextile separators and then ranking them according to the available information, that included how well the sites were documented, age of the sites, available WSDOT laboratory test results, and probable site conditions. The final report from Phase I (Page, 1990) was reviewed and a literature search of additional relevant publications was conducted.

Phase 2 involved making contact with inspectors who were present at the time the geotextile separators were installed. Preliminary site visits were also made in an attempt to verify the existence and/or installation conditions of the geotextile. These preliminary site visits were important because during Phase I (Page, 1990) there were instances where the geotextile was not installed properly or it was not located at all, although the construction documents indicated otherwise. The preliminary sites were then ranked again and the final sites were selected. The final sites were selected primarily on the age of the site, geotextile type, verified existence, traffic control considerations, and probable excavation costs. A good mixture of geotextile types (wovens and nonwovens) as well as varying ages were desired.

Phase 3 involved the FWD tests, testpit excavations, observations, and detailed documentation for each site. Testpit excavation procedures were established based on the results of the Phase I report. A sample of the geotextile separator as well as samples of the base and subgrade materials were retrieved from each site. Sketches and measurements of the testpits were performed and photographs taken documenting the excavation process and conditions.

Phase 4 established laboratory test procedures, set up the testing equipment, and the necessary laboratory tests were performed. Grab tensile and wide width strength tests, as well as permittivity tests, were performed on random specimens of the geotextile samples retrieved from each site. In addition, soil classification tests and moisture contents were performed on representative soil samples from each site. The University of Washington's Geotechnical and Geosynthetics laboratories were set up to perform the necessary tests. Laboratory tests were performed as the site investigations were completed.

The field and laboratory data were analyzed as part of Phase 5. The results, conclusions, and recommendations were presented as part of the final report, Phase 6.

The following chapters will present detailed discussions of the techniques used, observations, results, and analyses needed to complete each phase. As part of Phase 1, the literature review was presented in Chapter 2, while the preliminary site selection procedures are discussed in Chapter 4. The final site selection procedures, Phase 2, are also presented in Chapter 4, and the results of the site investigations, Phase 3, are presented in Chapters 5 and 6. Chapters 7 and 8 present the results of the laboratory observations and tests, Phase 4. An analysis of the results and conclusions are presented in Chapters 9 and 10, Phase 5.

CHAPTER 4

SITE SELECTION AND INVESTIGATION PROCEDURES

4.1 SITE SELECTION PROCESS

The site selection process consisted of the preliminary and final site selection processes.

4.1.1 Preliminary Site Selection Process

The preliminary site selection process was used first to identify projects where geotextiles had been used as separators on WSDOT projects in western Washington. Mr. Tony Allen of WSDOT supplied a preliminary list of 19 projects in which geotextile separators had been used and which could be considered as possible candidate sites. Additional candidate sites were gathered by searching WSDOT records. The sources with the best information were the database of WSDOT conformance tests, change orders, and requests for approval of the geotextiles. The conformance tests are tests performed by WSDOT to ensure that the supplied geotextile meets the manufacturer's certified minimum average roll values. This initial process involved working together with personnel at WSDOT headquarters and district engineering and maintenance departments. While searching WSDOT records and making contacts with district personnel more sites were located involving city and county roadways. During this preliminary site selection process, more than 60 candidate sites were evaluated and ranked on a good/fair/poor system, according to as many of the following issues as possible:

- Geotextile within approximately 1 m of the pavement surface,
- Asphalt concrete pavement surface,
- Signs of pavement failure (fatigue cracking, rutting, etc.) or needing early resurfacing,
- Type of base course material,
- Soft, fine-grained subgrade soils,
- Possible high ground water conditions,

- Quality of documentation, such as inspectors daily reports, pay notes, change orders, construction plans, etc.,
- Availability of WSDOT compliance test results on the installed geotextile, and
- Age of the site, with older sites better for long-term performance evaluations.

4.1.2 Final Site Selection Process

The final site selection process commenced after the preliminary process was completed. Approximately the top 20 preliminary candidate sites were considered for further evaluation. Site visits were also conducted in an attempt to verify the existence of the geotextile separators and to check the subgrade soil conditions. When possible conversations with inspectors who had observed the installation of the geotextiles were then carried out.

Final site selections were made on the basis of the type of geotextile installed, verified installation locations and conditions, subgrade soil type, safety and traffic control considerations, excavation costs, and cooperation/coordination of the agencies involved. The sites were again ranked but this time on a numerical priority basis with the anticipated best site being given priority 1. The original intent of the selection process was to obtain equal nonwoven and woven sites for comparison purposes, but with varying ages and fabric weights. Initially nine sites were proposed for excavation and investigation, but with the interest and cooperation of three non-state agencies (Cowlitz County and the cities of Kelso and Tacoma), a total of 14 sites were ultimately selected for detailed investigations. Six sites contained woven slit-films, six contained needle-punched nonwovens, and two contained heat-bonded nonwoven geotextiles.

Table 4.1 lists the final selected, and investigated, sites showing the priority ranking, roadway name, WSDOT project name or the city/county (for non-WSDOT projects), and the WSDOT contract number. The final ranking of each site also ultimately became known as the site number for field and laboratory identification purposes. Two sites were selected on Columbia Heights Road, Cowlitz County, because the roadway was showing signs of premature failure in the form of localized fatigue

Table 4.1 - List of investigated sites.

Priority Ranking	State Route or Roadway Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	WSDOT Project Name or City/County Location	WSDOT Contract No.
1a	Columbia Heights Rd. (distressed pavement)	Needle-punched NW (Trevira 1114) 143 (4.2)	Cowlitz County	-
1	Columbia Heights Rd. (good pavement)	Needle-punched NW (Trevira 1114) 143 (4.2)	Cowlitz County	-
2	Coal Creek Rd.	Heat-bonded NW (Typar 3401) 136 (4.0)	Cowlitz County	-
3	Pacific Way	Needle-punched NW (Trevira 1115) 153 (4.5)	Cowlitz County	-
4	SR-14	Woven Slit-film (Exxon GTF 300) 231 (6.8)	SR-500 to Top of Steigerwald Hill	C-3821
6	SR-9 (Marsh Rd.)	Woven Slit-film (Permeatex 2350) 163 (4.8)	Lowell/Larimer Road to Snohomish River Bridge	C-3523
7	SR-546	Woven Slit-film (Propex 2002) 149 (4.4)	SR-539 to SR-9	C-3661
8	Carroll Rd.	Heat-bonded NW (Typar 3401) 136 (4.0)	City of Kelso	-
9	SR-504	Needle-punched NW (Trevira 1125) 251 (7.4)	Paine Road to Morgan Park	C-3279
10	49th Ave. NE	Woven Slit-film (Permeatex 2300) 153 (4.5)	City of Tacoma	-
11	SR-16	Woven Slit-film (Propex 2002) 149 (4.4)	Gig Harbor Olympic interchange	C-3336
13	SR-502	Needle-punched NW (Trevira 1115) 153 (4.5)	N.E. 72nd Avenue Intersection	C-3062
14	Olson Rd.	Needle-punched NW (Trevira 1120) 204 (6.0)	Cowlitz County	-
16	SR-9 (Sumas)	Woven Slit-film (Permeatex 2200) 122 (3.6)	Bridge 9/360 to International Boundary	C-3254

cracking and minor rutting. One site (1a) was selected to be investigated in an area of the distressed pavement, while the other site (1) was located in an adjacent area appearing to have good pavement conditions. Three sites (5,12, and 15) were assigned priority rankings but were not investigated and therefore they have been omitted from Table 4.1. The subgrade soils under the separators at sites 12 and 15 consisted of imported rock backfill, and site 5 was not excavated due to an uncooperative public agency. The approximate location of each site is shown on the Site Location Maps, Figures 4.1 and 4.2. Figure 4.2 shows the locations of the six additional sites which were investigated in Cowlitz County and the City of Kelso.

As previously mentioned, site visits were necessary in most cases to verify the traffic conditions, the site geology, and if possible the installation conditions of the geotextile, depth, and subgrade soil type. Although it was not possible to locate most of the geotextiles during the site visits due to the site conditions (e.g. curbs, wide ACP shoulders, installation depth, etc.), it was possible to locate a few which were installed under fill embankments. If the edges of the geotextiles were installed beyond the limits of the ACP while still under the embankment fill, then it was possible to dig a shallow trench into the side of the embankment and locate the edge of the fabric. Only four geotextiles were located during the site visits. Three of the four geotextile separators were improperly installed. The SR-504 site was properly installed and was included in the final selected sites. However, the other three sites were immediately dropped from the list of possible sites. Figures 4.3, 4.4, and 4.5 show the installation conditions of the geotextiles. Figures 4.3 and 4.4 were taken during the site visits, while the photograph in Figure 4.5 (provided by Amy Revis, District 4, Assistant Project Engineer) was taken during the installation of the geotextile.

The geotextile shown in Figure 4.3 was installed as part of the SR-16 Tremont Interchange construction (Contract no. C-3025) in 1986. It can be seen that the fill above and below the geotextile consists of the same gravel and sand material. This fabric was installed in the middle of the embankment. The geotextile shown in Figure 4.4 was used under Parpalla Road which was constructed as part of the SR-101 Naselle River Bridge construction (contract no. C-2641) in 1985. The material under the geotextile is the same crushed gravel and cobble sized material (ledge rock) which was on top of the geotextile. The photograph in Figure 4.5 shows the geotextile separator being placed in the middle of

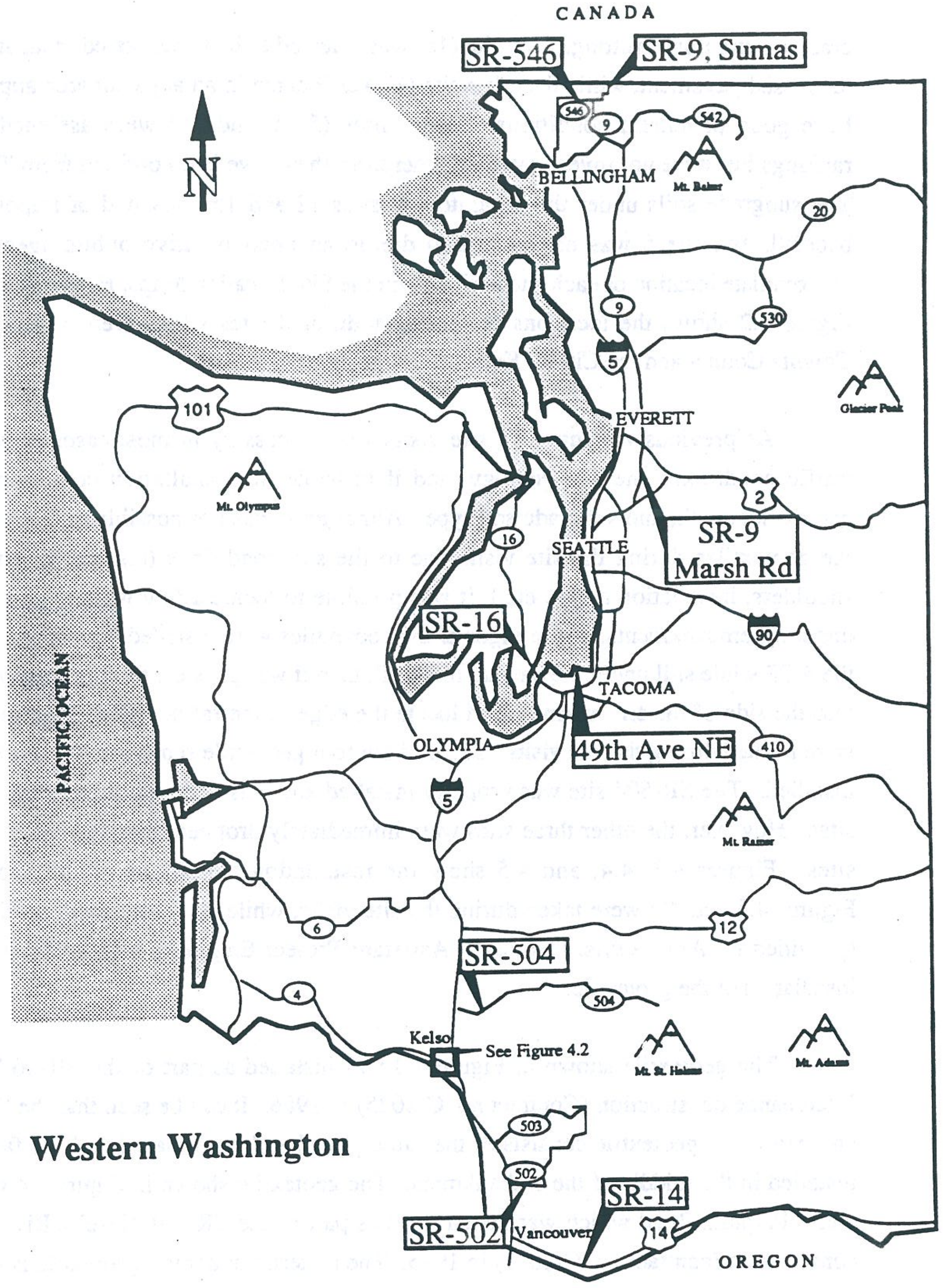

Figure 4.1 - Site location map.

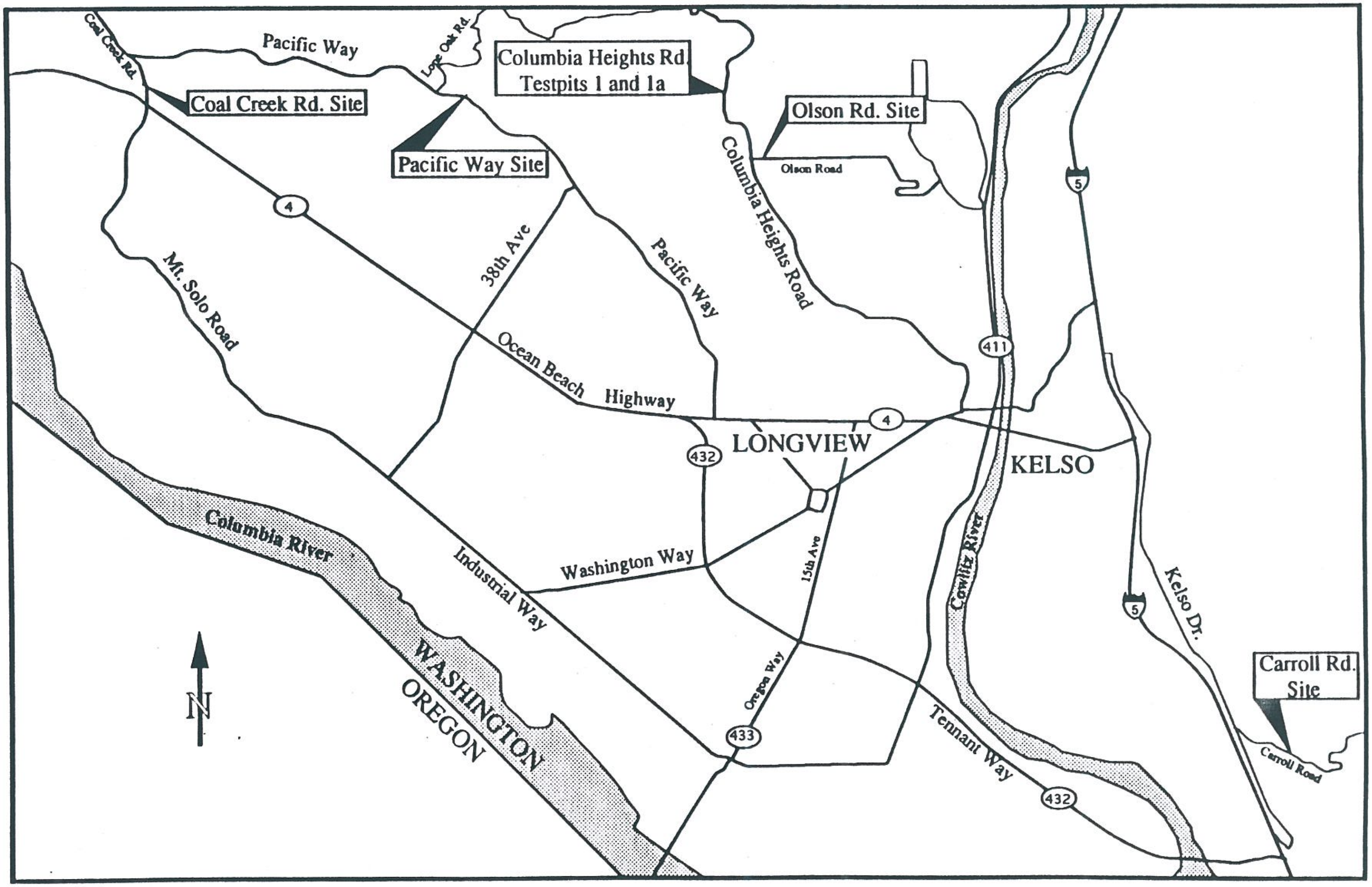

Figure 4.2 - Cowlitz County and City of Kelso Site Locations.

Figure 4.3 - Exposed geotextile separator at Tremont Interchange, SR-16.

Figure 4.4 - Exposed subgrade under fabric on Parpalla Road.

Figure 4.5 - Geotextile being installed in the middle of the embankment during the construction of the Deep River Bridges project.

a fill embankment which was constructed as part of the SR-4 Deep River Bridges project (contract no. C-3358) in 1988. Although this application would have been too deep for the purpose of this study, it still shows the apparent misapplication of the separator.

4.2 SITE INVESTIGATION PROCEDURES

Although the site investigation procedures were primarily directed towards the retrieval of the geotextile separator, detailed documentation of the conditions of the pavement, base course, subgrade, and especially the geotextile were also performed. Each testpit was documented by taking field notes, making sketches, and taking numerous photographs before and during the investigation.

The site investigation procedures were primarily based on the procedures developed by Page (1990) during Phase I of this research. A few modifications were made to these procedures to expedite the excavation process and to obtain improved information.

Each site was visited prior to the day of the planned investigation in order to meet with maintenance personnel and locate the best possible area for the testpit. In addition to evaluating the traffic control and safety issues, results of FWD analyses were also used at several sites to locate potential "soft" subgrade conditions which would be better for this study. The testpits were located on or as close as possible to areas with a low subgrade modulus as determined by the FWD analyses. FWD tests were not performed on some of the sites. These sites typically had the geotextile located in a specific area and FWD tests would not have been as useful since the location of the testpit was already predetermined. Generally the sites without FWD tests were based on traffic control restrictions, potential worst subgrade conditions cited by the inspectors, or localized uses of the separator. Once the sites were discussed with the maintenance personnel, then the best location for each testpit was marked. An approximate 1.2 m by 1.8 m rectangular area was marked on the pavement surface with white spray paint to identify the limits of the testpit area.

Generally a few days before the investigation date for a site, maintenance personnel would visit the site and saw-cut along the marked limits of the testpit. In all cases the maintenance supervisors desired that saw-cuts, rather than jack-hammer cuts, be used in

asphalt concrete pavements (ACP) in order to make better patches upon completion of the testpit. On the day of the excavation a pneumatic jack-hammer was used to break up the previously saw-cut pavement into manageable chunks for hand removal. Once the pavement was removed, then normal excavation procedures with shovels could be performed. The jack-hammer was also used to loosen densely compacted, angular, base courses which were overlying some of the geotextile separators. Shovels alone worked best where the backfill consisted primarily of sandy materials.

Cowlitz county personnel opted to use a different and, as it turned out, much more effective way to excavate the base course materials. After removing the ACP and the top course at the Coal Creek Road site, a very thick ballast material, up to 90 cm thick and consisting of 50 to 100 mm crushed angular basalt, was encountered over the geotextile. This base material would have been difficult and very time consuming to remove by normal excavation procedures because it would have to be removed almost entirely by hand since shovels were ineffective. The county maintenance supervisor opted to use an Elgin "Vac-all" to remove this material. The equipment, normally used to clean gutters and storm drains, consists of a large (about 250 mm diameter) semi-flexible suction tube connected to a truck-mounted container in which the material is deposited. The Vac-all very easily and rapidly removed the backfill material. After the necessary tests were performed and information gathered for the site, the excavation was backfilled by dumping the rock back into the testpit directly from the Vac-all. The Vac-all was also used later at the Pacific Way and Olson Road sites. Care had to be taken when operating the suction tube immediately above the geotextile so that the fabric would not be physically damaged and to avoid the possibility of having clogged subgrade material "sucked" out from between the yarns of the geotextile.

The SR-9 (Marsh Rd.) site was the only other site where different equipment was used to excavate the backfill material. In this case the geotextile was located approximately 1.1 m below the pavement surface and the maintenance crew opted to bring in a backhoe to remove the sandy base material.

4.2.1 Testpit Excavation Procedures

The field investigation and evaluation/documentation process consisted of the following procedures:

1. Identify each site, mark the limits of the testpit, and have the testpit saw-cut prior to the date of the excavation as previously described .

2. Set up the excavation dates and times with the maintenance personnel for each site. Discuss traffic control needs, and arrange for the necessary equipment to be at the site including the jack hammer, compressor, shovels, breaker bar, hot mix for patching, truck to haul away the old asphalt concrete pavement, etc.

3. Document each site with sketches and detailed photographs prior to commencement of the excavation process. Note the surrounding site and pavement conditions, and identify the location of the testpit.

4. Remove the previously saw-cut asphalt concrete pavement surface by using the jack hammer to break the pavement into manageable sized pieces.

5. At one corner of the test excavation, begin removing the top course (if it exists) and base material to find the depth to the geotextile. Only excavate out an area about 50 cm square to begin with and enlarge to the width of the testpit (1.2 m) as the excavation becomes deeper. Use the jack-hammer in this area to speed up the removal process of the base material when locating the geotextile. It is intended that if any damage is done to the geotextile it will be limited to this exploratory end of the excavation. This process of excavating one end of the testpit will help identify the exact depth of the geotextile so that rapid removal of the remaining base material can be done. Also by knowing the depth to the geotextile the jack-hammer can be used very effectively to loosen the remaining base material to a depth of about 150 mm above the geotextile and damage to the fabric can be avoided. This procedure will also save a lot of time, especially if the geotextile is not encountered.

6. Prior to excavating the remaining base material, take a disturbed sample near the top of the base material for laboratory testing. About 5 to 10 kg of material should be sampled, although more should be taken if the aggregate size is larger than about 25 mm. If there is a top course present then take a disturbed sample of the top course at any depth, and then take a sample near the top of the base material.

7. Excavate the remaining base material to within about 150 mm of the geotextile. The jack-hammer and shovels can be used.

8. Remove the remaining 150 mm of base material by carefully using a flat ended shovel. The final 25 to 50 mm should be removed using a trowel or "soft" (flat ended) rock hammer and hands. Care must be taken not to step on the geotextile and cause damage when it has little of no backfill cover. Take a disturbed sample of base material from 0 to 50 mm above the geotextile for later analysis.

9. Document the appearance of the surface of the geotextile by noting any holes, folds, large indentations, staining, etc. Make a sketch of the geotextile and document the depth from the top of the pavement. Take photographs of the surface of the geotextile, the overlying roadway section, etc.

10. Cut along the perimeter of the geotextile within about 50 mm of the vertically exposed base material. An X-acto knife or equivalent is best suited for cutting the in-situ geotextile (Plan on at least one blade per site as they dull quickly). Prior to taking the geotextile out of the excavation, carefully fold it back and photograph the bottom surface along with a portion of the subgrade.

11. Remove the geotextile from the excavation and photograph the top and bottom surfaces. Note the condition of the bottom surface, especially evidence of blinding or clogging. Detailed observation of the geotextile's condition will be performed later at the laboratory.

12. Place the geotextile sample in a black or dark brown plastic bag to protect it from sunlight. The geotextile sample should be folded as few times as possible prior to placing it in the bag to avoid causing creases with may interfere with later laboratory

observations and tests. Seal the plastic bag with plastic tape or duct tape to maintain the moisture in the geotextile. Label the bag.

13. Photograph and document the subgrade surface conditions. Note the subgrade conditions, such as soil type and color, staining, indentations, rutting, etc.

14. Perform pocket penetrometer and torvane tests at various locations on the subgrade surface.

15. Push or drive two 73 mm diameter and 102 mm long Shelby tubes into representative areas of the subgrade and then dig them out with a shovel. Cap both ends of the tube, seal the caps with plastic tape, and label the tubes.

16. Take a disturbed sample of the subgrade. Visually classify the subgrade in the field and photograph again.

17. Record the thicknesses of the pavement, top course (if any), base material, and depth to the geotextile on all four sides of the excavation.

18. Install a replacement geotextile, ordinarily provided by WSDOT (should be of equal or better properties than those of the removed material), in the excavation. The replacement geotextile should overlap the existing fabric by at least 25 mm. Place backfill material along the edges of the replacement geotextile to secure its position.

19. Backfill or assist in backfilling and patching the excavation under the direction of the maintenance personnel.

CHAPTER 5

RESULTS OF THE SITE INVESTIGATIONS

5.1 INTRODUCTION

All 14 sites, as shown in Table 4.1, were investigated between June 18 and September 18, 1992. A geotextile separator was retrieved from every site. Two of the sites required a second excavation to locate a geotextile sample. At the SR-16 site, no geotextile was found in the first testpit, so a second testpit was excavated to the south of the first one. At the Carroll Road site, the testpit had to be relocated because the backfill material at the first location became too deep and further excavating would have been difficult and time consuming.

Laboratory tests on the subgrade, base course, and geotextile samples were performed at the Geotechnical and Geosynthetics Laboratories at the University of Washington. The subgrade and base course samples were tested for grain size distribution, plasticity (subgrade only), and moisture content. The geotextile samples were tested for permittivity and retained tensile strength. The results of the laboratory tests are discussed in Chapter 7.

5.2 RESULTS OF THE SITE INVESTIGATIONS

The following sections provide a discussion of each site investigation. The conditions encountered at each site are described and photographs depicting the excavation processes and the conditions of the subgrade and geotextile are presented.

Generally the site discussions are broken into three separate parts in which the major points are described: (1) Describes the location of the site, the initial construction conditions, roadway dimensions, and the geotextile type and year installed. (2) Gives the initial site visit date and describes the location of the testpit. (3) Gives the excavation date, pavement condition, depth to the geotextile, pavement section, and detailed observations with respect to the geotextile and the excavation. As mentioned above, photographs were taken to document the site, excavation, and geotextile conditions. The photographs for each site investigation will be presented at the conclusion of the discussion for that particular site. A summary of the site investigations is presented at the end of this chapter.

5.2.1 Columbia Heights Road, Cowlitz County

These two testpits (1 and 1a) are located on Columbia Heights Road, between mile posts 2.77 and 2.78, in Cowlitz County, north of the town of Longview (see Fig. 4.2). The testpits are in the south bound (downhill) lane on the east facing flank of a hill side. The roadway consists of two lanes which were reconstructed in the summer of 1990. The roadway carries mixed traffic. Surface soils on the adjacent, east facing, cut slope consisted of very moist, tan to reddish-brown, iron stained, lean to fat clay. There are active slides in the immediate area, and very wet areas (seeps) on the cut slope and in the drainage ditch were visible. A 143 g/m^2 (4.2 oz/yd^2) needle-punched nonwoven geotextile separator (Trevira 1114) was specified for this reconstruction due to the presence of soft, wet, clayey subgrade soils. During construction, the geotextile was placed on the subgrade and an initial lift of approximately 230 mm of crushed surfacing base course (CSBC) was spread over it. The base course was apparently dumped at the edge of the fabric and spread out in the direction of the travel lanes. The base course was compacted with a vibratory roller prior to placing a 75 mm crushed surfacing top course (CSTC) layer. Construction equipment operated on the CSBC after it had been placed and compacted over the entire project, and while placing the CSTC layer.

The site was initially visited in January, 1992, to observe the conditions of the pavement and to select potential areas for future investigation. The pavement surface between mile posts 2.7 and 2.8 had two large areas, 3 to 4.5 m long and 1.2 to 1.5 m wide, which exhibited signs of extensive fatigue cracking and some rutting (see Fig. 5.1). These distressed areas were considered to be an ideal site for the testpits. As mentioned earlier, in Section 4.1, two sites were selected, one in the failing pavement surface (testpit 1a) and the other in an adjacent good pavement condition area (testpit 1). A return site visit in May, 1992, indicated that both the large failing pavement sections had been repaired and subdrains installed under the repaired pavement sections. Although the two ideal sections were repaired, there was one smaller area, approximately 1.2 by 1.5 m, with fatigue cracks and a small amount of rutting. This area was selected as the new location for the distressed pavement site investigation (1a). Figure 5.2 shows the locations of the two excavations with testpit 1a in the foreground, and testpit 1, 9 m to the north and adjacent to the west side of the south bound lane. Note one of the two earlier repaired sections in the background. The roadway was to receive an additional 50 mm of asphalt concrete pavement (ACP) in the summer of 1992. The two testpits were marked on June 2, 1992, for future sawcutting and excavation.

These two testpits, 1 and 1a, on Columbia Heights Road were excavated on June 25, 1992.

Figure 5.3 shows the surface conditions of the pavement for testpit 1a. The fatigue cracks were typically found in square patterns with 150 to 300 mm sides; some patterns were 100 to 130 mm square. The widths of the fatigue cracks were generally 1 to 3 mm wide. The principal path of rutting went directly through the middle of testpit 1a, in the direction of traffic flow, and was on the order of 5 to 15 mm deep. The geotextile was encountered below 31 to 38 mm of ACP and about 270 mm of CSTC and CSBC. There was a 130 mm rut in the subgrade, parallel to the roadway, on the west side of the testpit making the depth to the geotextile approximately 43 cm below the top of ACP in this area.

The exhumed geotextile, in testpit 1a, at first appeared to be in relatively good condition, Figure 5.4. There were several folds in the fabric and a construction overlap was also encountered on the east side of the excavation. The exposed geotextile overlapped a much thicker, probably a 200 g/m^2 (6 oz/yd^2) needle-punched nonwoven, geotextile which extended 53 cm into the testpit. Later conversations with Richard Black, the county engineer, revealed that the contractor sometimes placed a heavier weight geotextile in areas in which worse subgrade conditions were encountered. There were several small holes, up to about 10 mm in diameter, throughout the geotextiles surface.

When the geotextile was cut and folded back, Figure 5.5, the subgrade was exposed and consisted of a reddish-brown, heavily iron stained, lean to fat clay, with some gravels at the surface which probably came from the placement of the base course, Figure 5.6. Note in Figure 5.6 the change in the subgrade indentations just below the scale where the overlap existed. The gravel indentations in the subgrade above the scale are more numerous and much more pronounced, and should be expected since there is only one layer of geotextile in this area. Upon closer observation when the underlying thicker geotextile was removed, there was a large number of very small, approximately 2 to 3 mm in diameter, holes in the overlapping geotextile which was in contact with the base course. Surprisingly, fewer holes were found in the fabric where it was only one layer thick and where there were deeper indentations in the subgrade. Figure 5.7 shows a photograph of the bottom surface of the exhumed geotextile placed on a light table, with the section in contact with the subgrade on the right side and the overlap on the left side. Note the sharp color contrast due to the iron staining and the fewer holes on the right side. Figure 5.8 shows a magnified (~2X) photograph of some of the holes in the overlapping geotextile. Note the very rounded appearance of the holes. Figure 5.9 is a close-up (magnified ~2X) of the bottom surface of the geotextile showing the iron staining and gravel indentations. The geotextile appeared to be moderately clogged with the fine-grained subgrade soils.

Figure 5.1 - Distressed pavement on Columbia Heights Road.

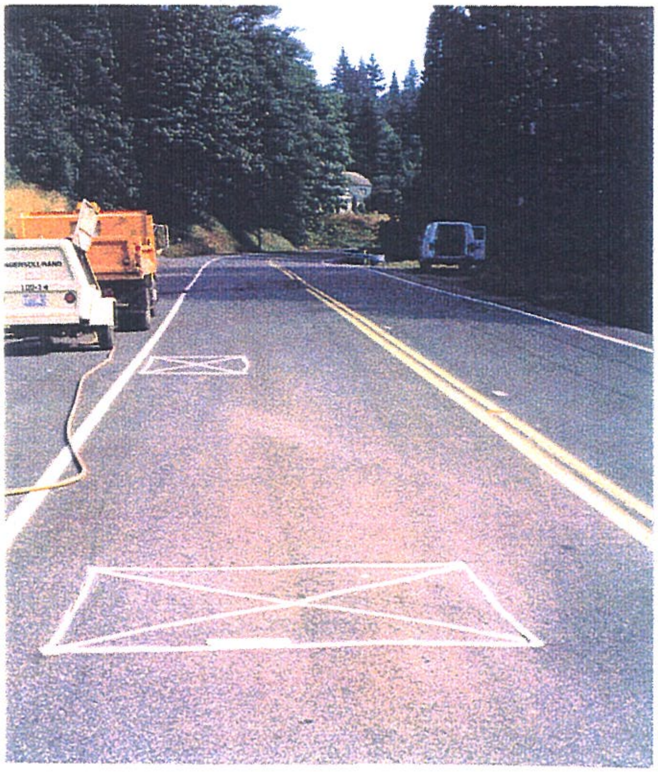

Figure 5.2 - Testpit layout; testpit 1a is in the foreground.

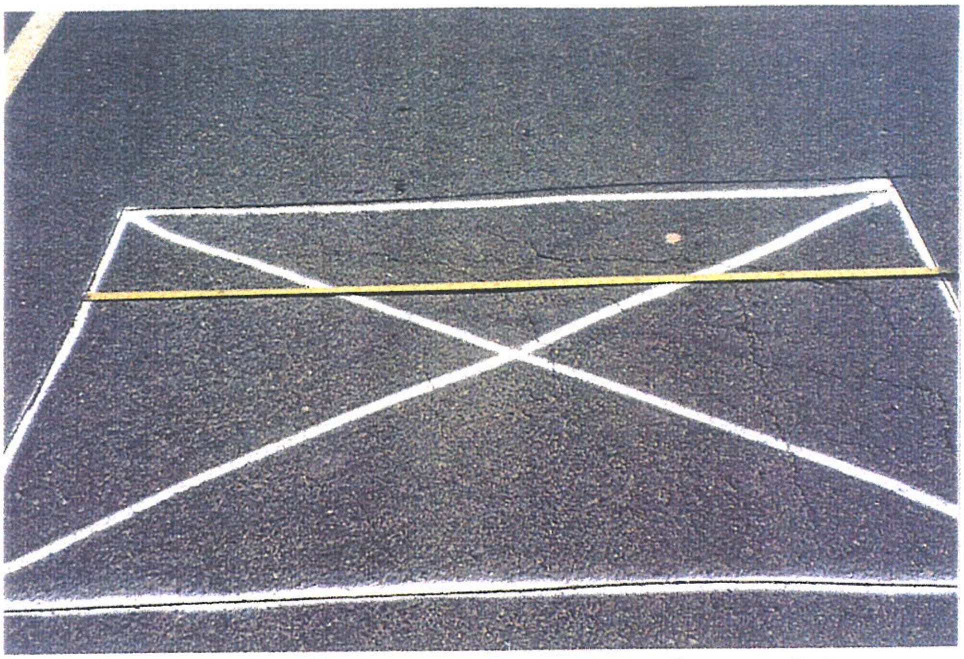

Figure 5.3 - Fatigue cracking in pavement surface, testpit 1a.

Figure 5.4 - Surface of the exposed geotextile showing folds and overlap (bottom).

Figure 5.5 - Geotextile folded back exposing the heavily iron stained geotextile underside and subgrade, testpit 1a.

Figure 5.6 - Subgrade surface after subgrade samples had been taken, testpit 1a.

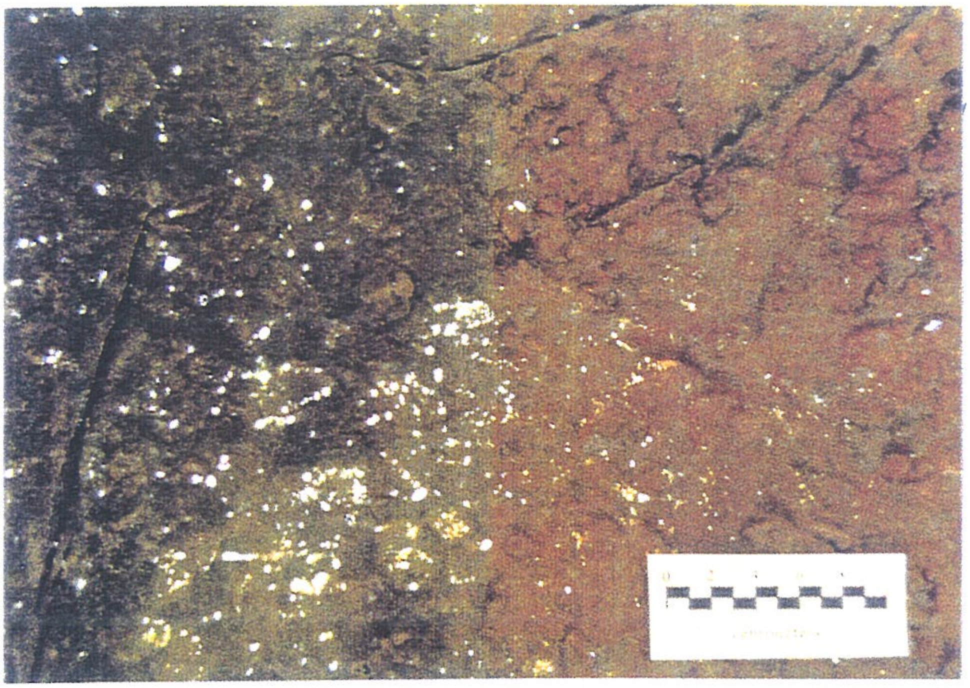

Figure 5.7 - Laboratory photograph on a light table showing the contrast in color, and numerous holes on the left side of the overlap contact, testpit 1a.

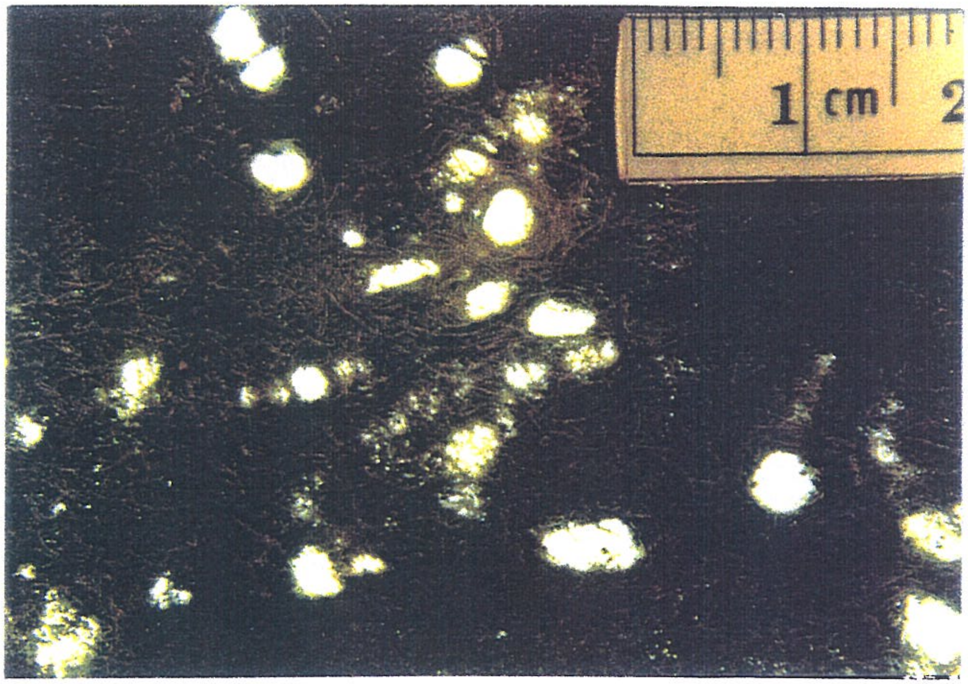

Figure 5.8 - Magnified (~2X) laboratory photograph of the small holes in the overlap.

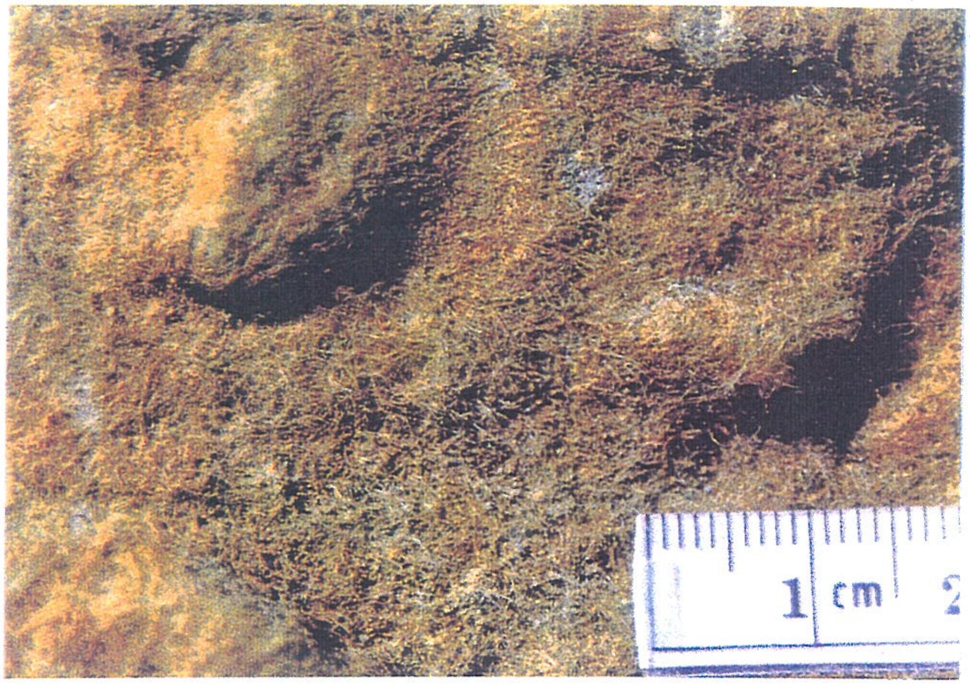

Figure 5.9 - Magnified (~2X) close-up of the bottom surface, showing the gravel indentations and iron staining, testpit 1a.

Figure 5.12 - Exposed geotextile and clay protrusions, testpit 1.

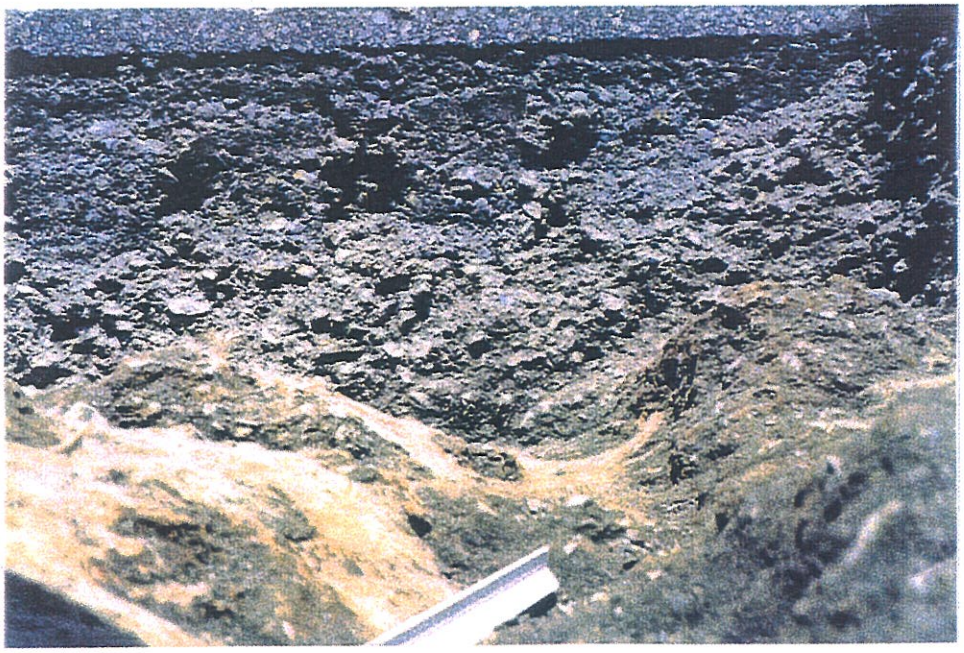

Figure 5.13 - Shows up to 130 mm of rutting which occurred during construction.

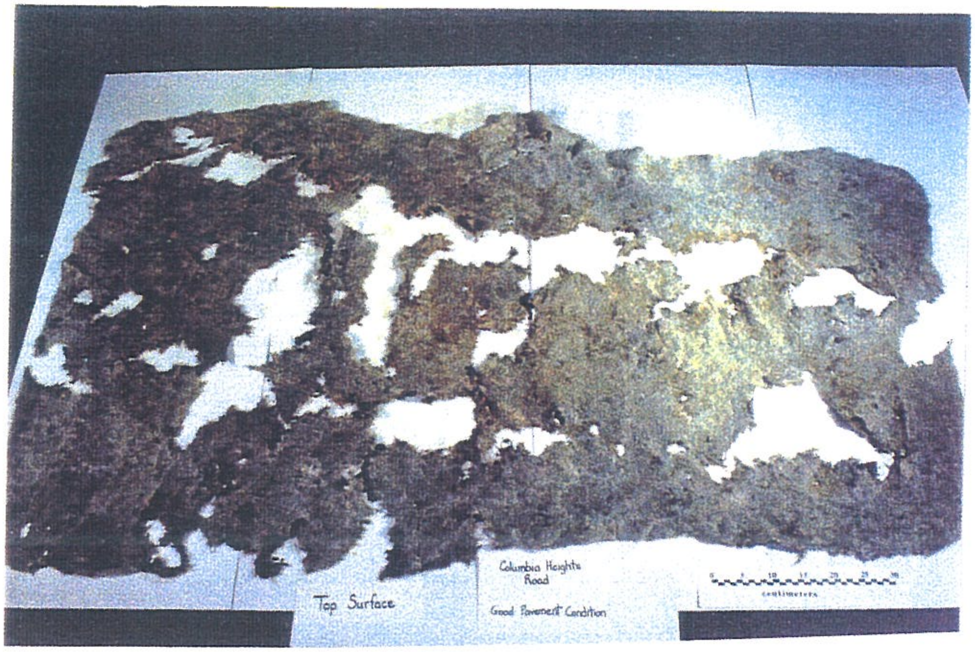

Figure 5.14 - Laboratory photograph of the exhumed geotextile separator, testpit 1.

Figure 5.15 - Photograph of iron staining and condition of a relatively undamaged area on the bottom surface of the geotextile, testpit 1.

area was the site of an old timber holding area for a local lumber mill. Figure 5.21 shows the exposed subgrade conditions with the two Shelby tubes driven in and ready to be retrieved.

The exhumed geotextile had tears in it up to 75 to 100 mm long. Figure 5.22 shows a laboratory photograph of the bottom surface of the geotextile with a small iron stained spot (bottom middle). Figure 5.23 shows a photograph of the geotextile over a light table in the laboratory. The heaviest damage was generally on the north side of the exhumed geotextile. The geotextile appeared to be minor to moderately clogged with silt and fine wood particles. The geotextile was typically moderately damaged, although it was severely damaged in local areas.

Figure 5.16 - Testpit location and pavement conditions.

Figure 5.17 - Using the jack hammer to remove the ACP.

Figure 5.18 - Vac-all extension removing the ballast material.

Figure 5.19 - Exposed geotextile separator and pavement section.

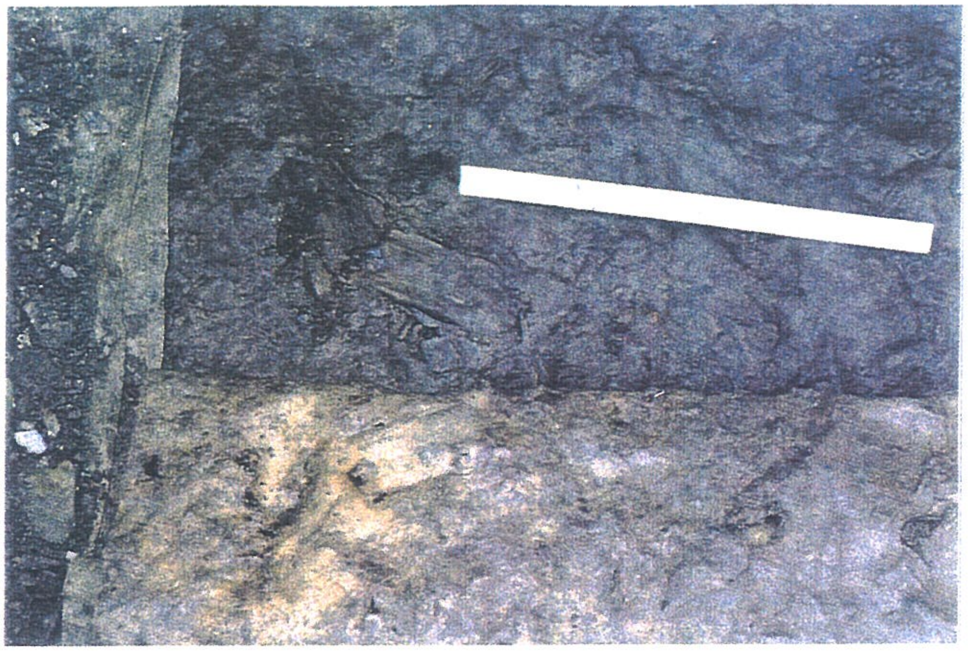

Figure 5.20 - Geotextile separator folded back to expose the subgrade.

Figure 5.21 - Exposed subgrade with driven Shelby tube samples.

Figure 5.22 - Laboratory photograph of the bottom surface of the geotextile with a small iron stained area.

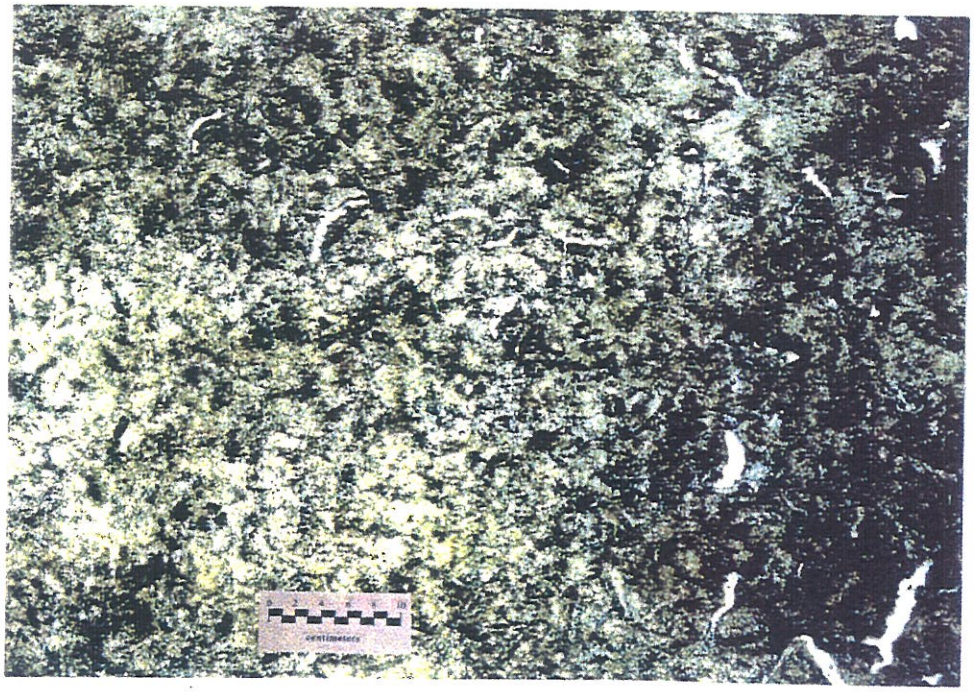

Figure 5.23 - Photograph of the geotextile over a light table.

5.2.3 Pacific Way, Cowlitz County

The site is located in the east bound lane near mile post 2.66 on Pacific Way, in Cowlitz County, Figure 4.2. The roadway consists of two 3.7 m lanes with 60 cm shoulders which are generally curb and gutter structures. Improvements to the roadway, in the area of the site, were performed during the summer of 1982. The grade was lowered and the roadway widened as part of the reconstruction project. The roadway generally carries automobiles and some truck traffic. The site is located on a south facing hill slope and the soils are typically colluvial deposits consisting of fine sands, silts, and clays. Due to the presence of soft, pumping silts and clays, a 153 g/m^2 (4.5 oz/yd^2) needle-punched nonwoven geotextile separator (Trevira 1115) was used on the project. The full base course depth, approximately 33 cm thick, was spread over the geotextile as the initial lift. The county engineer (Richard Black) mentioned that during construction there were several instances where the subgrade and geotextile pumped up through the base course in the form of clay bulges similar to that shown on Columbia Heights Road, Figure 5.10. Many of these bulges were removed by overexcavating and placing a new geotextile layer at a greater depth.

The site was initially visited in January, 1992, to discuss the project with the county engineer and to locate a section of roadway for future investigation. The testpit was marked on June 2, 1992, for future saw-cutting and investigation. The testpit was located about 1 m north of the curb (Fig. 5.24).

The testpit was excavated on June 26, 1992. The pavement surface was in good condition with no signs of distress. Figure 5.25 shows the pavement removed and the CSTC being removed by hand to locate the depth to the geotextile. The geotextile was located 56 to 64 cm below the pavement surface. The roadway section overlying the geotextile consisted of 130 mm of ACP, over 115 to 130 mm of CSTC (brown material), which in turn was over 33 to 36 cm of CSBC. The bottom portion of the base course was quite wet, as shown in Figure 5.26. Figure 5.27 shows the exposed geotextile and the roadway section over it. After the geotextile was located, the Vac-all was used to remove all but about the last 20 to 30 mm of the material from above it. Figure 5.27 also shows the relatively wet portion of the base course as indicated by approximately 100 mm of dark grey material just above the geotextile.

The geotextile had numerous indentations in it from the overlying gravels penetrating down into the subgrade. Although the geotextile was deformed there were no holes of significant size visible. Also shown in Figure 5.27 is an iron stained area which originated from the subgrade material and come up through to the upper surface of the geotextile. Figure 5.28 shows the geotextile pulled back exposing the subgrade surface. The subgrade consisted of brown, iron stained, clayey sand to sandy lean clay. Note the water sheen and the rust and black colored stains on the subgrade surface. Figure 5.29 shows the east side of the subgrade surface with the geotextile removed. Again there were several iron stained patterns exposed, especially in the middle and south side (right side of Fig. 5.29) of the testpit. Figure 5.30 is a photograph showing the iron stained patterns on the bottom surface of the geotextile. Figure 5.31 is a close-up (~2X magnification) of the iron staining taken from the iron stained pattern which is at the very top and middle of Figure 5.30. The geotextile appeared to be very good condition. There were a couple of folds in the fabric on the north side of the testpit. There were several areas in the geotextile which appeared to be partially clogged.

Figure 5.24 - Testpit location for the Pacific Way site, with the ACP being removed.

Figure 5.25 - Looking for the geotextile on the west side of the testpit. The CSTC is being removed.

Figure 5.26 - Wet base course immediately above the geotextile.

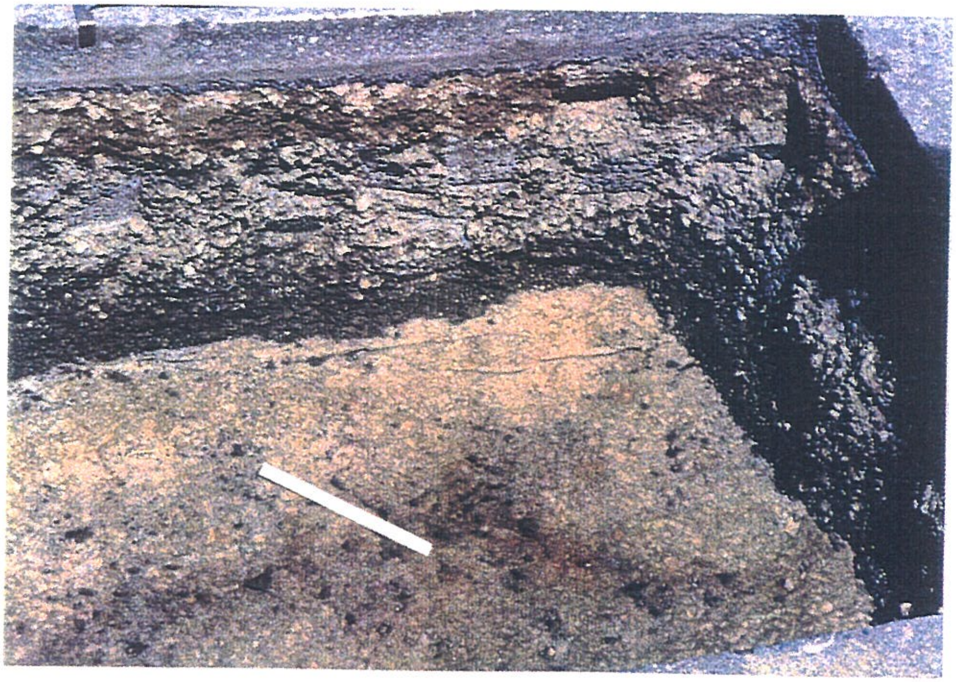

Figure 5.27 - Exposed geotextile surface. Note the iron staining on the fabric and the wet base rock immediately above the geotextile.

Figure 5.28 - Geotextile pulled back to expose the subgrade surface.

Figure 5.29 - Subgrade surface with iron stained patterns.

Figure 5.30 - Laboratory photograph of the bottom surface of the exhumed geotextile.

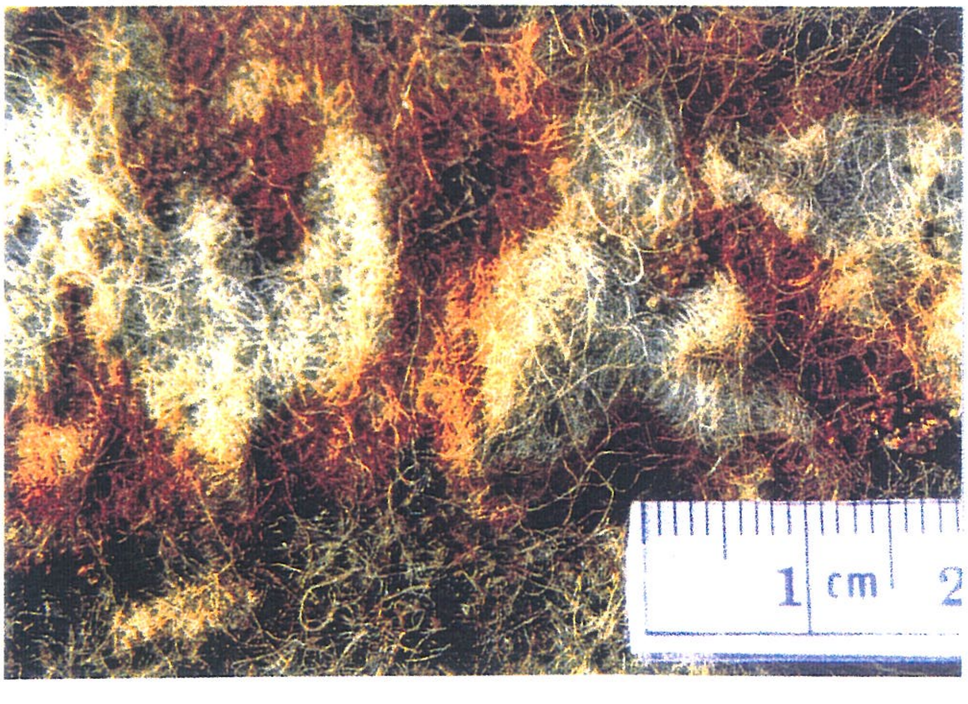

Figure 5.31 - Close-up (~2X magnification) of an iron stained area on the bottom surface of the geotextile.

5.2.4 SR-14, SR-500 to Top of Steigerwald Hill

The site is located near mile post 17.02, on SR-14, in the east bound deceleration lane for 32nd Street, Clark County, (see Fig. 4.1). The roadway in this area consists of two 3.7 m wide traffic lanes, two 3.7 m wide acceleration/deceleration lanes, a 4.6 m wide left turn lane, and 2.4 m shoulders. The deceleration lane where the site is located experiences mixed traffic with the majority of the vehicles being heavy trucks. The construction occurred in the summer/fall of 1990 and included the widening of the highway for the deceleration lane. The deceleration lane is located on an existing embankment where the subgrade soils were reported to consist of silts and clays in a very wet condition, thus requiring the use of a separator for construction of the pavement section. The geotextile, a 231 g/m^2 ($6.8\ oz/yd^2$) woven slit film (Exxon GTF 300) was placed in early October 1990, with no problems reported during installation.

The site was initially visited on March 24, 1992, to discuss any traffic control problems and to get more information on the initial construction conditions. The testpit was marked on June 2, 1992, for sawcutting and excavation. The testpit limits were marked adjacent to and north of the white safety line, placing it under the right wheel path of traffic.

The testpit was excavated on June 23, 1992. The pavement was in good condition with no signs of distress. The geotextile was located about 40 to 43 cm below the pavement surface. As shown in Figures 5.32 and 5.33 the ACP was approximately 250 mm thick, with 150 to 180 mm of CSBC immediately over the geotextile. The upper surface of the geotextile was heavily caked with silt particles which may have settled down during the construction operation or may be due to subgrade fine migration. Figure 5.34 shows a representative photograph (~2X magnification) of the caked upper surface of the geotextile. There were many small abrasions on individual tapes and several small punctures in the geotextile due to the base course penetrating down into the subgrade. Figure 5.35 shows a magnified (~2X) photograph of a typical puncture viewed from the bottom surface. There appeared to be minor to moderate damage to the geotextile. Upon removal of the geotextile the exposed subgrade was found to be imported pitrun rock consisting of subrounded sands, gravels, and some silt. The very upper surface of the subgrade had a thin, 0.5 to 1 mm, silt layer which had the geotextile weave imprinted on it. The bottom of the geotextile showed evidence of minor blinding.

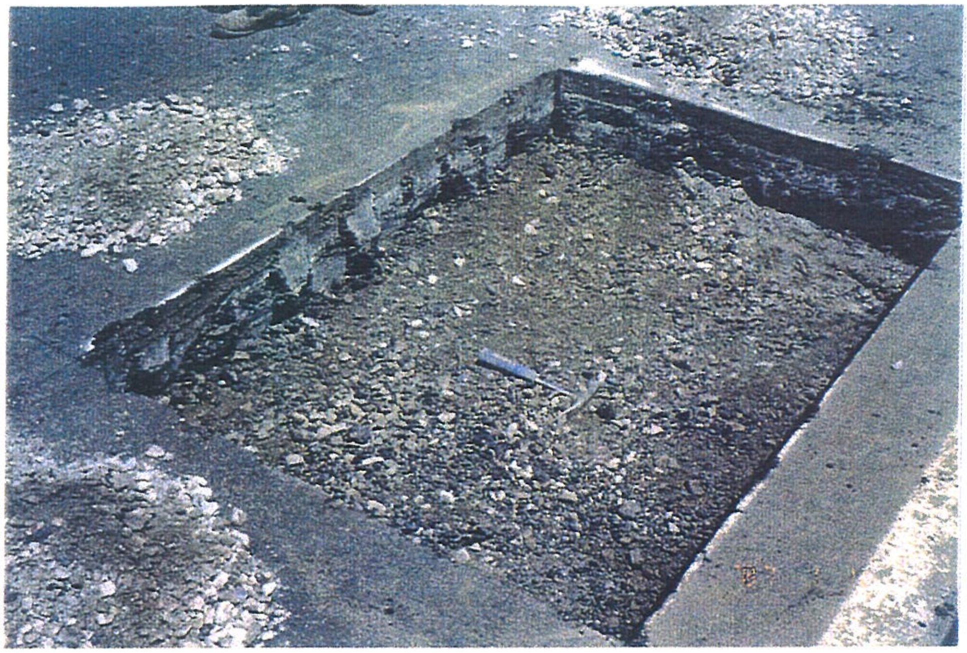

Figure 5.32 - Photograph of excavation with asphalt concrete removed.

Figure 5.33 - Photograph showing exposed geotextile and pavement/base course section.

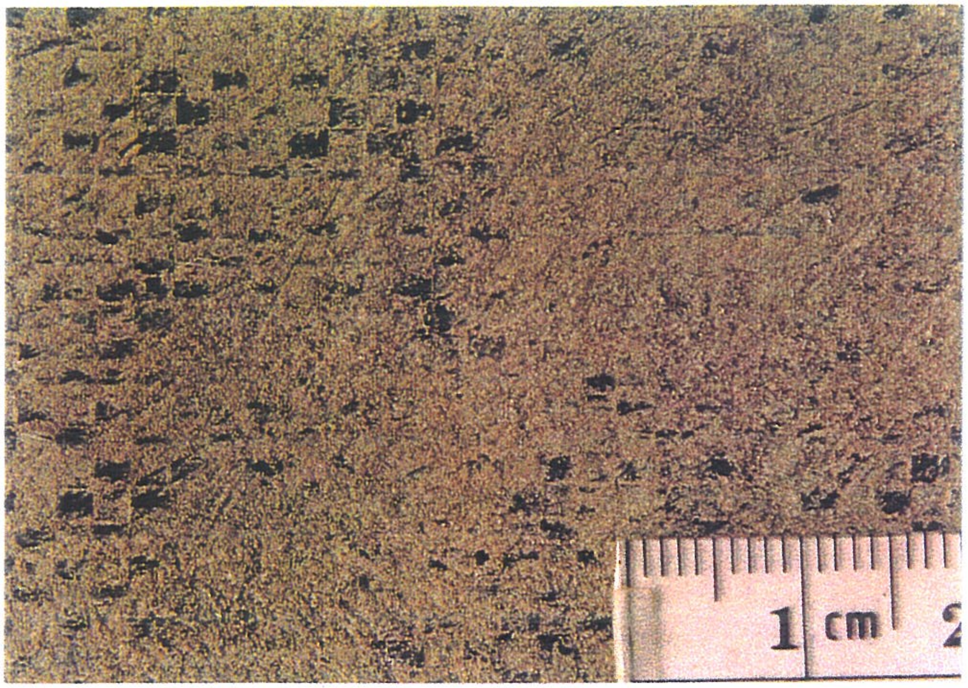

Figure 5.34 - Typical photograph of caked upper geotextile surface (magnified ~2X).

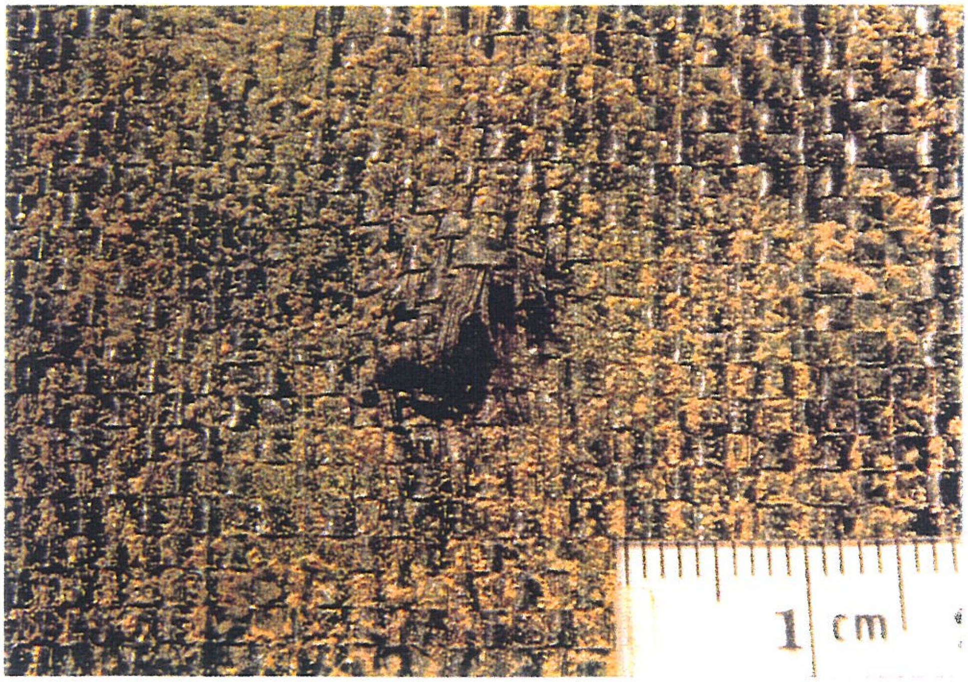

Figure 5.35 - Photograph of a typical puncture in the geotextile (magnified ~2X). The bottom surface is shown.

5.2.5 SR-9, Lowell/Larimer Road to Snohomish River Bridge (Marsh Road)

The site is located near mile post 8.35 on SR-9, in Snohomish County, south of the town of Snohomish, Figure 4.1. This section of highway was reconstructed and widened during the summer of 1989 and consists of two 3.7 m wide travel lanes, north bound right and left turn lanes, and 1.2 m shoulders. The highway carries mixed traffic. The site is situated on Snohomish River floodplain deposits and the native subgrade soils were reported to consist of silt and clay. A 163 g/m^2 (4.8 oz/yd^2) woven slit film, geotextile separator (Permeatex 2350) was approved for this project and was placed during May, 1989. The inspector at the time of installation recalled the initial lift over the geotextile as being approximately 60 cm thick and it was compacted with a smooth drum vibratory roller. According to WSDOT maintenance personnel, this section of the highway was partially washed out during flooding which took place in the winter of 1990. In the area where the testpit was located only parts of the highway shoulders were washed away.

The site was initially visited on March 26, 1992, to discuss traffic control with WSDOT personnel and to try to verify that the geotextile was not washed away in this section of the highway. Due to traffic control constraints and a limited section of roadway where the testpit could be located, no FWD tests were performed for this site. The testpit limits were marked for sawcutting on June 14, 1992. The testpit is located adjacent to the white safety line in the southbound travel lane, just south of the Marsh Road intersection.

The testpit was excavated on June 19, 1992. The pavement surface was in good condition. The excavation, by hand, at one end of the testpit became quite deep until the geotextile was located about 1.1 m below the pavement surface. WSDOT personnel opted to use a backhoe to excavate the remainder of the backfill material. The roadway section overlying the geotextile consisted of 200 to 230 mm of ACP, over 75 to 100 mm of CSTC, over 79 to 81 cm of base material. The base material consisted of clean sand with some subrounded gravels.

The exposed geotextile was in very good condition with no holes or signs of abrasions. As shown in Figure 5.36, the geotextile had a few small folds. Figure 5.37 shows that the geotextile was installed directly over the native vegetation which consisted of a mat of grasses and small plants in this excavation. Note that in some areas the grey silty subgrade was in direct contact with the geotextile. When the geotextile was removed some of the vegetation remained adhered to the bottom surface. Figure 5.38 shows a photograph of the bottom surface of the geotextile. Figure 5.39 shows a close-up (~2X magnification) over a light table of the organic blinding caused by the vegetation, while Figure 5.40 shows a close-up (~2X magnification) of a typical area blinded with organics and silt particles. Note the iron-oxide deposits forming between the weaves in Figure 5.40. The iron-oxide deposits may be clogging the pore openings of the fabric.

As might be expected there was very little blinding from silt particles due to the filtering action of the vegetation mat. The effects of the iron deposits and the "organic blinding" on the permittivity of the geotextile was not distinguished from blinding or clogging from the fine-grained soil particles. It should be expected that the iron-oxide deposits would decrease the size of the openings between weaves thus lowering the permittivity of the geotextile. The organics would prevent blinding by the silt particles although the organics themselves may cause blinding to some degree.

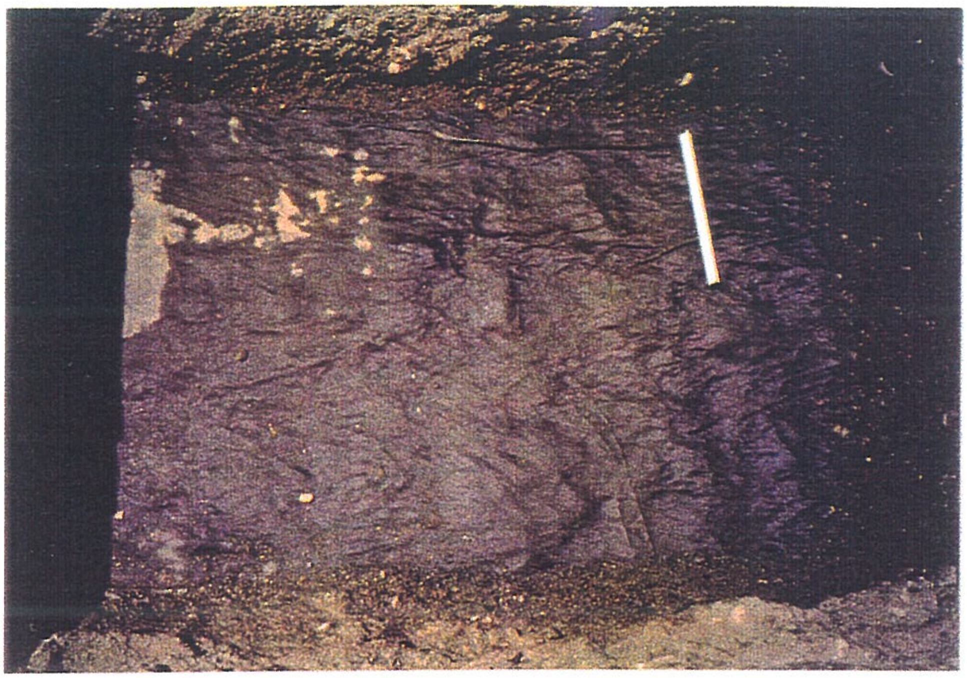

Figure 5.36 - Upper surface of the geotextile exposed in the testpit.

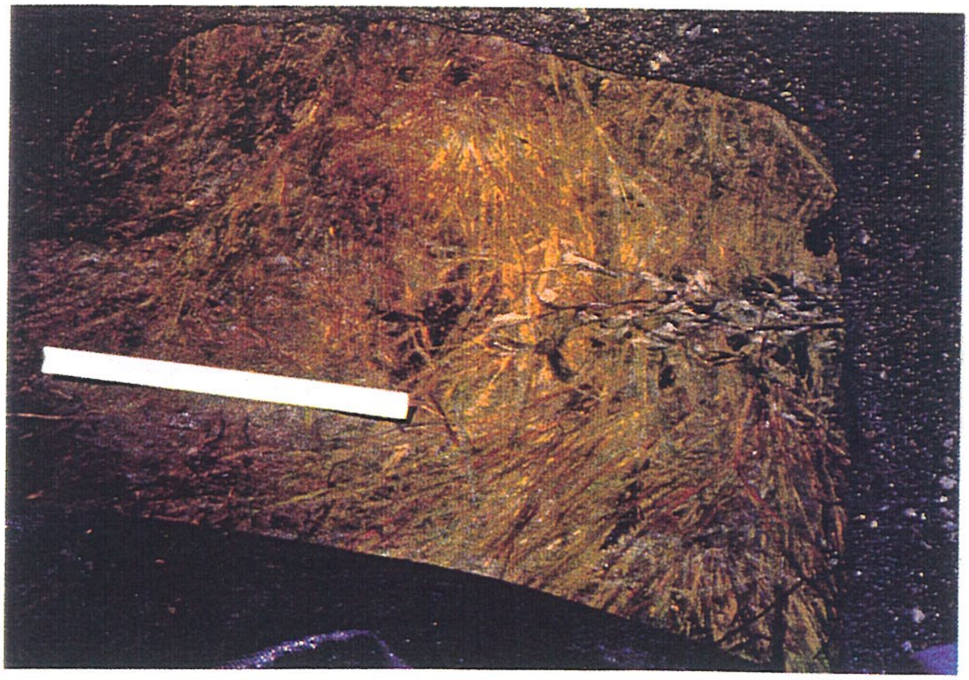

Figure 5.37 - Geotextile folded back and an organic mat exposed overlying the silty subgrade.

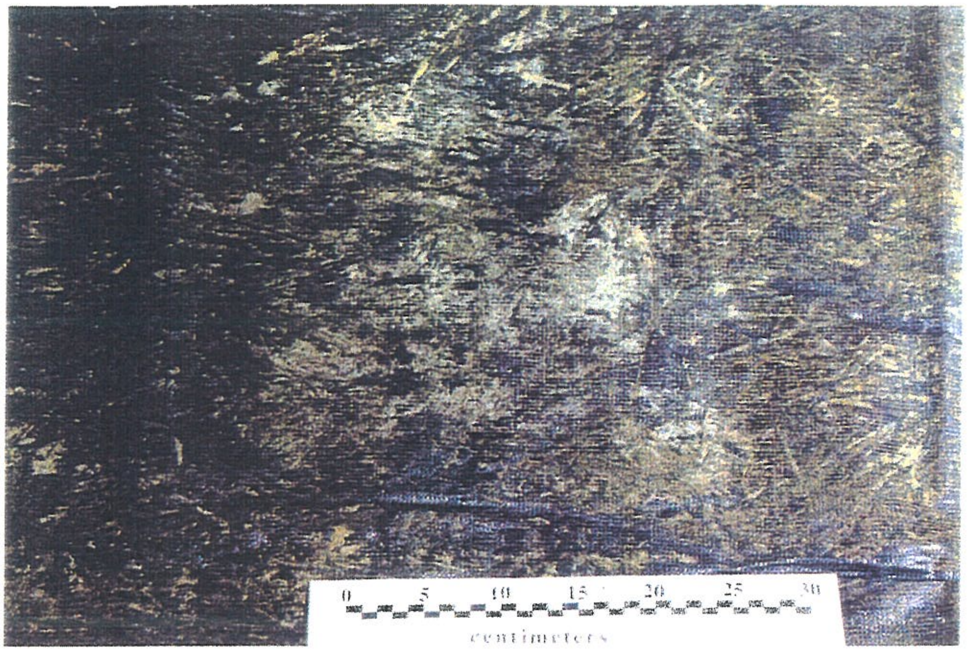

Figure 5.38 - Laboratory photograph of the organics on the bottom surface of the geotextile.

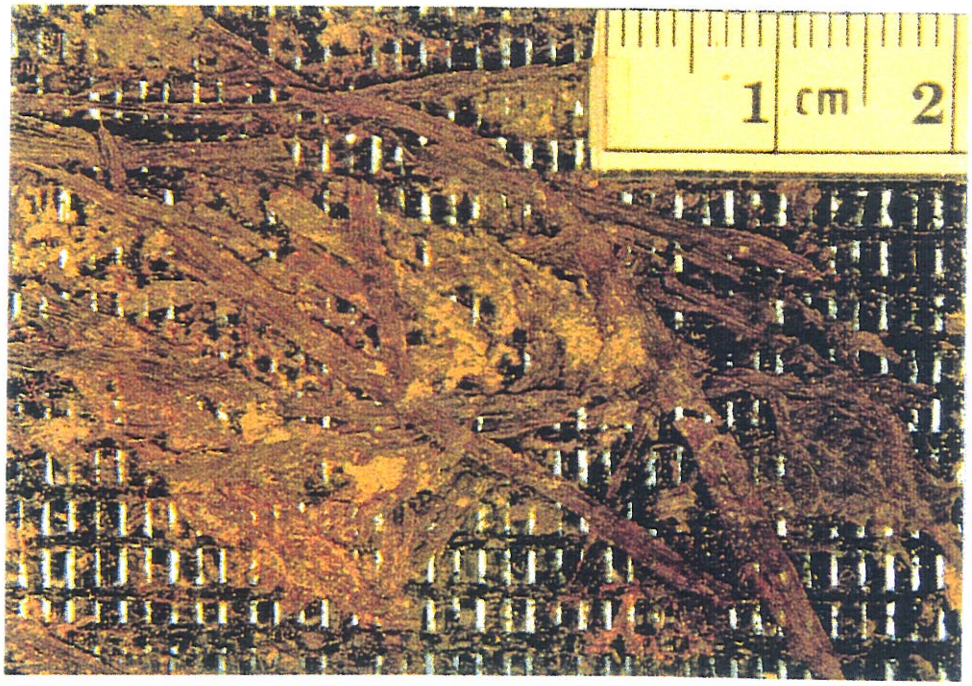

Figure 5.39 - Close-up (magnified ~2X) of the organics on the geotextile. Illuminated behind by a light table.

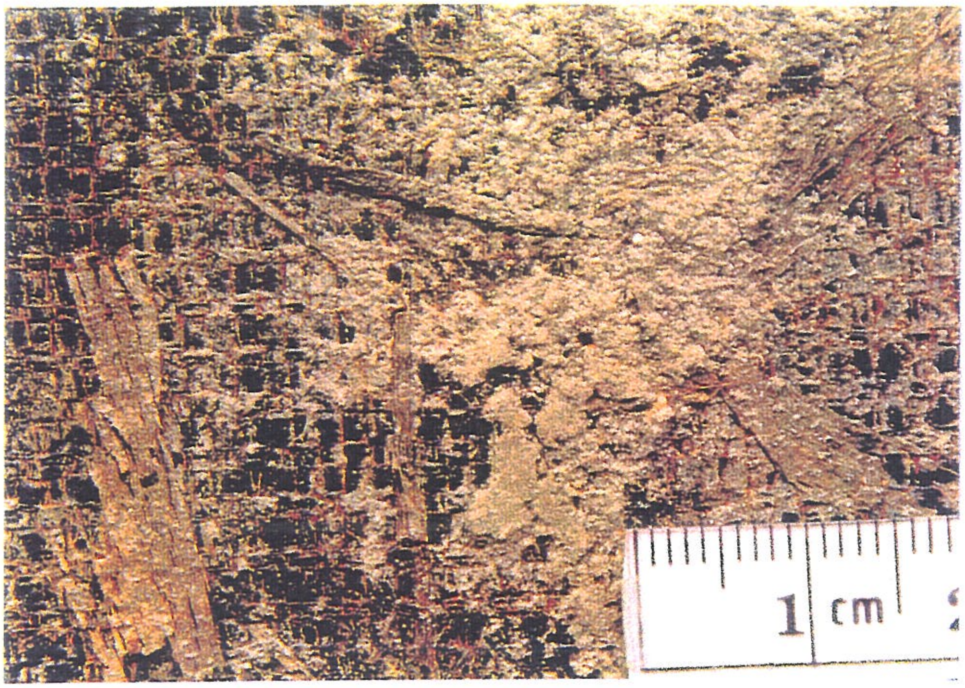

Figure 5.40 - Close-up (magnified ~2X) of organics and silt particles blinding the bottom geotextile surface.

The upper surface of the geotextile, Figure 5.45, was in relatively good condition with only a few small holes but it had numerous indentations. Figure 5.46 shows the geotextile folded back to expose the subgrade which consisted of a moist, dark brown, subrounded gravel with silt and sand. The gravel in the subgrade appeared to be very similar to the base material, may have been placed on the softer subgrade material during construction to provide better working conditions. Although there was a high content of coarse material in the subgrade, the geotextile weave was still imprinted on the surface of the subgrade soils. Figure 5.47 is a photograph of the bottom surface of the geotextile showing minimal blinding and revealing that most of the indentations penetrate upwards from the subgrade into the backfill material. Figure 5.48 shows typical water stain patterns on the bottom surface of the geotextile. Figure 5.49 is a magnified (~2X) photograph showing typical blinding on the bottom surface of the geotextile. Overall, the geotextile appeared to show minimal damage.

Figure 5.41 - Typical geotextile installation procedure for the turn pockets (Courtesy of WSDOT).

Figure 5.42 - Typical installation procedure for the radius widening areas. Note the backfill placement technique on the far right side (Courtesy of WSDOT).

Figure 5.43 - Testpit location in the right turn pocket of SR-546.

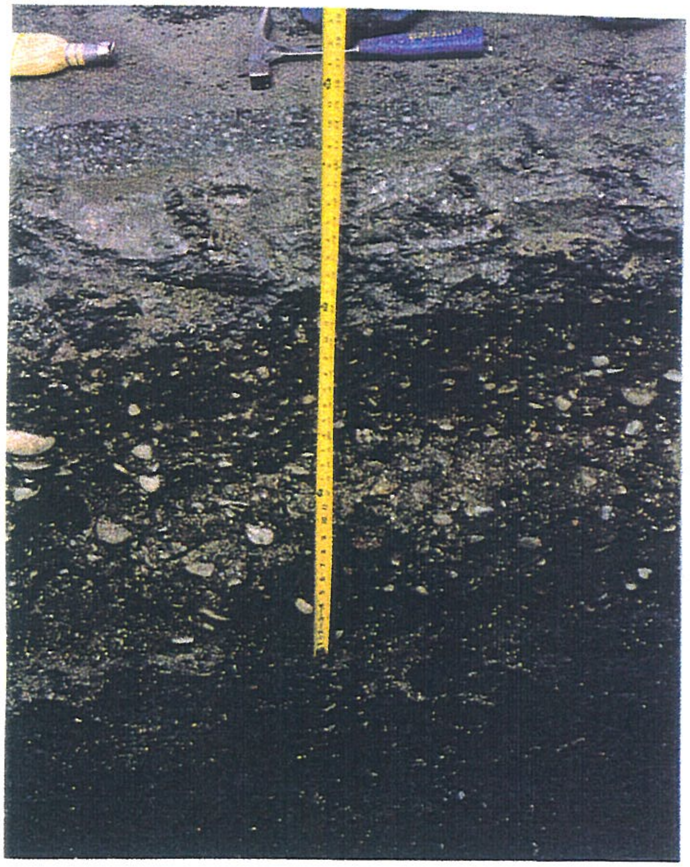

Figure 5.44 - Roadway section overlying the geotextile separator.

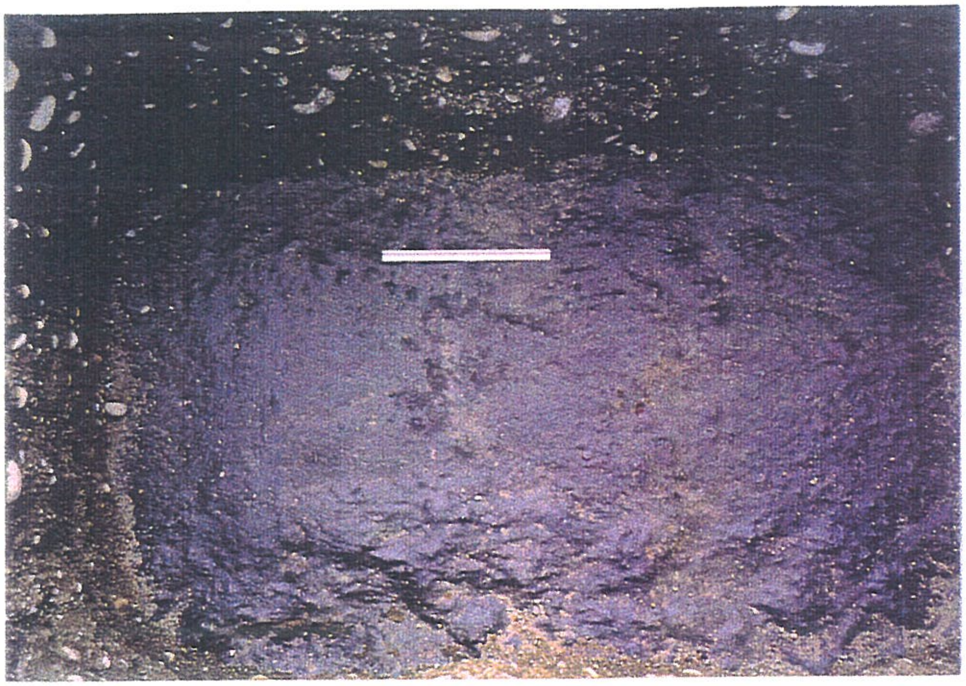

Figure 5.45 - Upper surface of the geotextile exposed in the testpit.

Figure 5.46 - Geotextile folded back to expose the subgrade material.

Figure 5.47 - Laboratory photograph of the bottom surface of the geotextile.

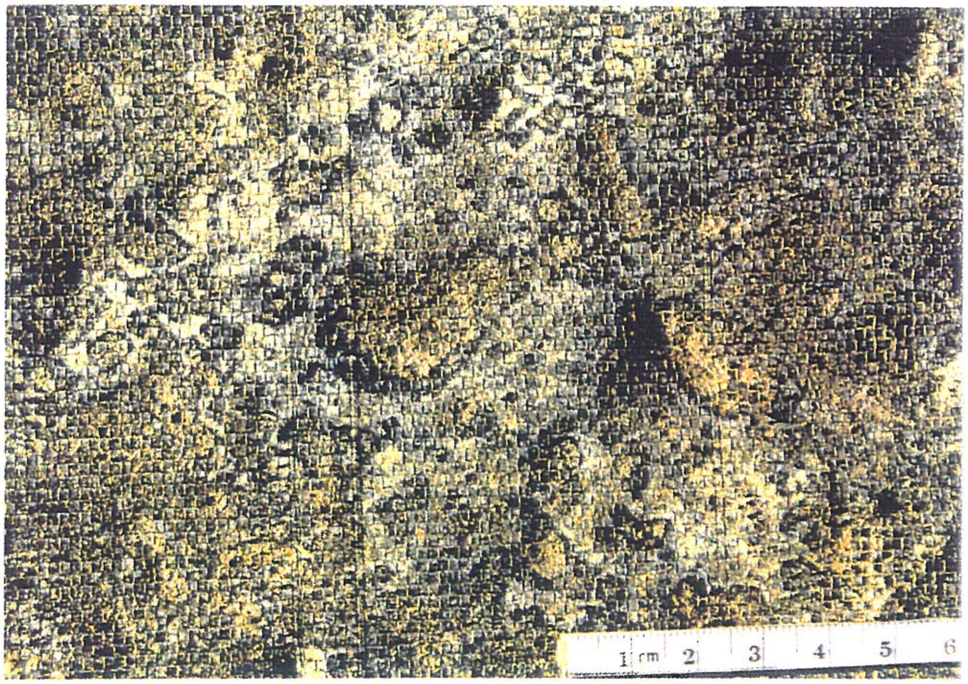

Figure 5.48 - Water stained patterns on the bottom surface of the geotextile.

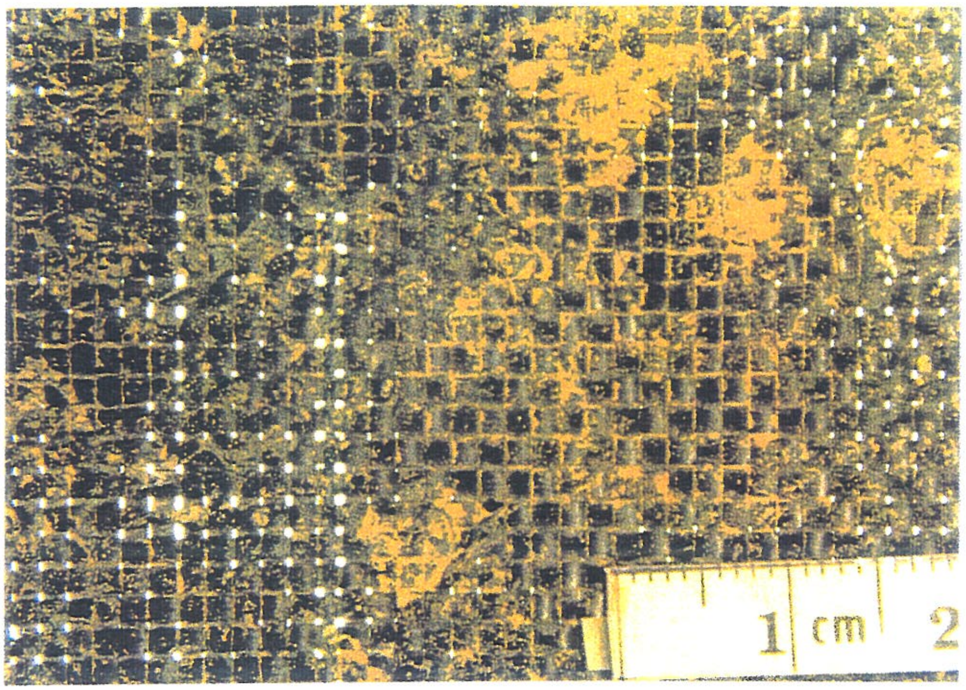

Figure 5.49 - Typical blinding of the bottom surface (magnified ~2X).
Illuminated behind by a light table.

5.2.7 Carroll Road, City of Kelso

The site is located in the west bound traffic lane near mile post 0.57 on Carroll Road, in the City of Kelso, Cowlitz County (Fig. 4.2). The roadway consists of two travel lanes, approximately 3 m wide, with shoulders about 60 cm wide and is situated on a south facing hill slope. The roadway was constructed in 1978 and/or 1979; the exact time is only an estimate from county and city engineers and inspectors because no construction documents are available (and probably did not exist) for this project. Apparently this was an unpaved roadway used mainly a route for rock quarry trucks at that time. The subgrade soils were very poor and trucks occasionally got stuck in it. For the construction of the paved roadway a 136 g/m^2 (4.0 oz/yd^2) heat-bonded nonwoven geotextile separator (Typar 3401) was approved for the project. The roadway is still used by the rock quarry trucks but there is more use from residential traffic. This site was selected because it was the oldest site with geotextiles in the area and it was also a second site with a heat-bonded nonwoven material. Richard Black (Cowlitz County engineer) mentioned that Carroll Road was an early successful application of a geotextile separator in the area.

The site was initially visited in January, 1992, to select the best location for the testpit. Based on conversations with an inspector who was present at the time of construction, a location was selected about 100 feet west of the pump house, located on the south side of the roadway, around mile post 0.3. The testpit was later marked for sawcutting and future excavation.

The testpit west of the pump house was excavated on June 24, 1992. After excavating down 1 m below the pavement surface no geotextile was found. Conversations with another inspector who was also present at the time of construction indicated that there was at least 30 to 60 cm of 50 to 100 mm diameter crushed rock immediately over the geotextile. We had encountered only subrounded gravels with sand. Therefore, the excavation was stopped due to the depth involved. The same inspector took us to another location on the roadway, between mile posts 0.5 to 0.6, where he recalled much shallower depths to the geotextile. The testpit limits were later marked for sawcutting and future investigation. The testpit was located approximately 88 m west of the eastern Kelso City limits and about 30 cm off the white safety line (Fig. 5.50).

The second testpit, near mile post 0.57, was excavated on July 15, 1992. The pavement surface was in good condition with no signs of distress. The ACP was removed and the base course was slowly taken out on the west side of the testpit. The geotextile was encountered about 43 cm below the pavement surface, but unfortunately this was shallower than expected and the fabric was damaged by several jackhammer blade punctures on the west side. Figure 5.51 shows the roadway section overlying the geotextile. The section over the geotextile consisted of 110 to 115 mm of ACP, overlying 23 to 33 cm of 50 to 100 mm crushed rock with a high percentage of fines (which the inspector called "reject" material). Since the geotextile was severely damaged on the west side by the jackhammer blade, the testpit was enlarged to approximately 1.2 m by 2.4 m in order to be able to recover the required fabric sample size.

As shown in Figure 5.51, the geotextile blended in with the subgrade very well and was difficult to see. Figure 5.52 shows numerous angular holes, typically 6 to 25 mm long, in the geotextile with rocks in the subgrade protruding up through them. The geotextile was then folded back to expose the subgrade (Fig. 5.53). The subgrade generally consisted of the same material as the base course, except that the subgrade appeared to have more fines (silts and clays). Figure 5.54 shows the entire subgrade surface with the geotextile removed. Figure 5.55 shows the condition of the bottom surface of the geotextile immediately after it was removed from the testpit. Note the dark brown areas which consisted of silt and clay, and the white areas which were almost like new. Figure 5.56 is a photograph of the severely damaged geotextile and the multitude of angular holes. There were many areas on the geotextile which appeared to be moderately to heavily clogged. The clean looking fabric appeared to be located in areas where the geotextile bridged across coarse gravel in the subgrade.

After discussing the subgrade conditions with the inspector and the county engineer, it was revealed that there were several instances prior to the paving of the roadway where crushed rock was placed over the subgrade and compacted in with passes of the quarry trucks. Apparently, as the subgrade fines migrated up through the crushed rock then more rock was placed, and with time, each subsequent layer of rock became contaminated with fines. To try to stop this process, the engineers at that time decided to install a geotextile separator. The initial lift thickness in the area of the testpit was obviously less than 33 cm thick. The inspector also mentioned that during placement of the cover material the rock trucks drove directly on the fabric. The geotextile was placed prior to paving the roadway and a vibratory roller similar to a Dynapac CC-10 was used to compact the base material. The roadway is reported to be performing very well and as Richard Black (Cowlitz County engineer) mentioned, this appears to be a successful application of a geotextile separator, even though it was severely damaged during construction.

Figure 5.50 - Carroll Road testpit location.

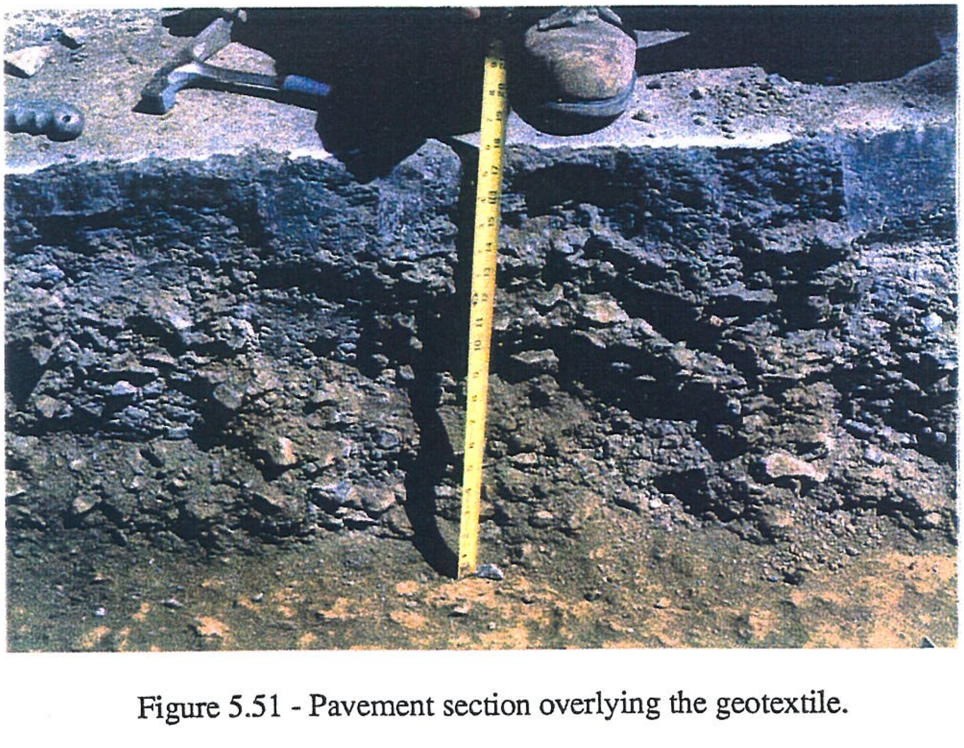

Figure 5.51 - Pavement section overlying the geotextile.

Figure 5.52 - Close-up of the geotextile showing gravels in the subgrade penetrating up through the fabric.

Figure 5.53 - Geotextile folded back revealing the gravelly subgrade.

5.2.8 SR-504, Paine Road to Morgan Park

The site is located on SR-504 in the west bound lane, near mile post 6.49, north of Silver Lake and west of Toutle, Cowlitz County (Fig. 4.1). The highway consists of two 3.7 m lanes with 1.2 m shoulders. The highway carries mixed traffic with a high percentage of logging trucks. The roadway was reconstructed during the summer of 1988. The old roadway was removed and the subgrade was overexcavated 60 to 90 cm and then backfilled with about 1 m of sandy gravel base material. Apparently during the night, the very soft and wet silty clay subgrade pumped up through the base material and conditions were so bad that logging trucks could not pass the next day without getting stuck. The base material was then removed back down to the native subgrade soils and a 251 g/m^2 (7.4 oz/yd^2) needle-punched nonwoven geotextile separator (Trevira 1125) was installed. The geotextile was installed under a change order during June, 1988. The on-site field inspector recalled that the gravel base material was placed in 60 to 90 cm thick initial lifts over the geotextile, spread with a dozer, and compacted with a Dynapac smooth drum vibratory roller.

The site was initially visited on March 24, 1992, to check traffic conditions and to try to verify the location of the geotextile since it was installed under a short section of roadway. The geotextile was located, near mile post 6.49, about 46 cm below the westbound shoulder of the highway. The testpit limits were marked on June 2, 1992, for future sawcutting and investigation. The testpit was located adjacent to the white safety line, about 20 m west of Owens Road (Fig. 5.57).

The testpit was excavated on June 24, 1992. The pavement surface was in good condition. The geotextile was located about 99 cm below the pavement surface. The roadway section consisted of 180 mm of ACP, over 150 mm of CSTC, which was over approximately 66 cm of base material consisting of sand with gravel and many subrounded cobbles and small boulders. Some of the boulders were 30 to 46 cm in diameter. Figure 5.58 shows the exposed geotextile and the roadway section. Note the size of the cobbles immediately over the geotextile, although these were not the largest. Figure 5.59 shows the exposed surface of the geotextile with a large fold on the north side. The geotextile was in very good condition with no obvious signs of damage. There were some small indentations in the subgrade due to the overlying cobbles.

Figure 5.60 shows the geotextile folded back and the subgrade surface exposed. The occasional gravel particles at the surface of the silty subgrade may have been left from the initial backfilling operation prior to installing the geotextile. The subgrade surface was very moist and a moisture sheen can be seen in Figure 5.60. Figure 5.61 is a photograph of the bottom surface of the exhumed geotextile. Note several white spots where the geotextile was in an almost new condition. Figure 5.62 is a close-up (magnified ~2X) of a clean spot and the surrounding soiled geotextile. From a distance the geotextile appeared to be moderately clogged with soil particles. Figure 5.63 is a photograph (magnified ~2X) of one of the clean spots taken over a light table. Note that most of the soil trapped within the fibers of the fabric are sand particles. The sand particles shown generally came from the overlying base material.

Figure 5.57 - SR-504 site location, looking west.

Figure 5.58 - Roadway section overlying the exposed geotextile.

typical degree of blinding experienced by the bottom surface of the geotextile. There also appeared to be a significant amount of fines caked to the upper surface of the geotextile. Figure 5.69 shows a photograph (magnified ~2X) over a light table of one of the larger holes caused by a gravel particle penetrating down into the subgrade soil. The geotextile appeared to be in fair condition although it had numerous small holes.

Figure 5.64 - Site location, 49th Avenue N.E., Tacoma.

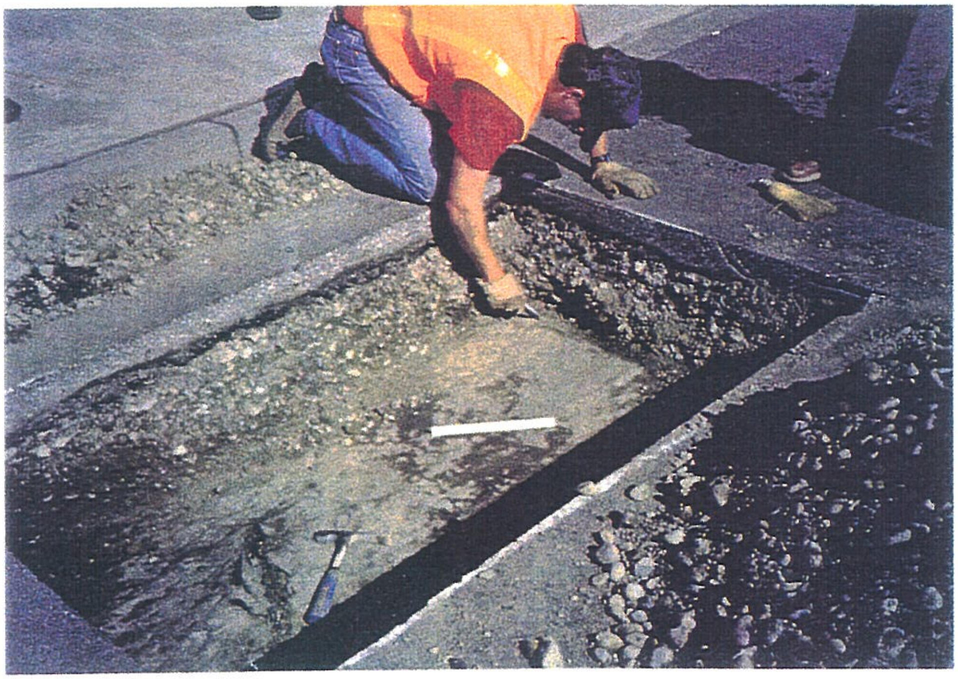

Figure 5.65 - Geotextile being cut prior to being removed.

Figure 5.66 - Geotextile folded back exposing the subgrade surface.

Figure 5.67 - Disturbed subgrade soil, after taking soil samples.

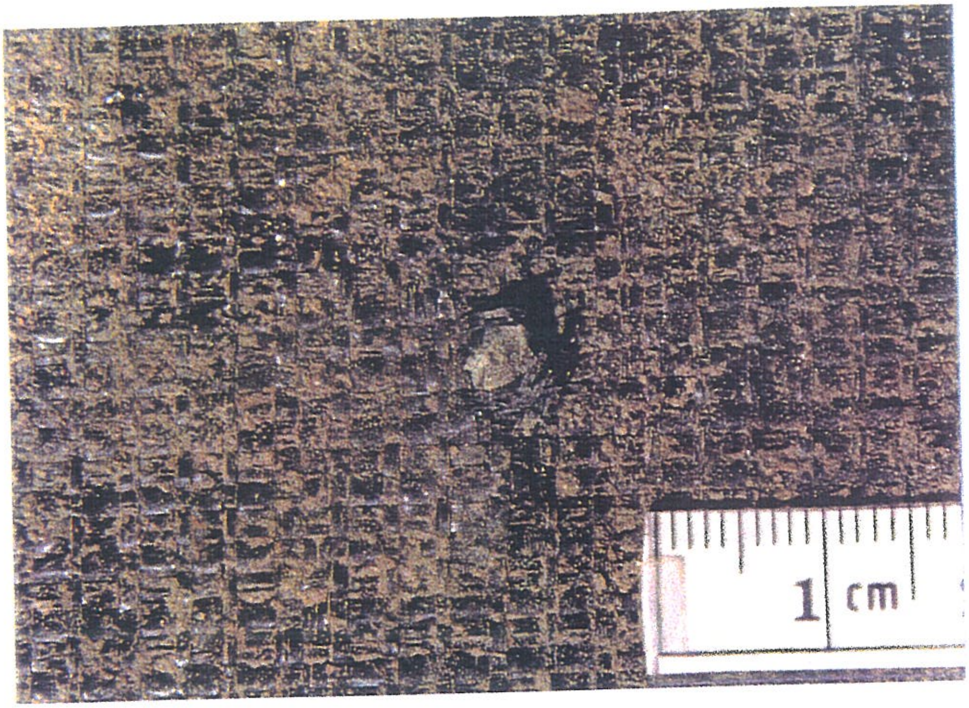

Figure 5.68 - Typical blinding on the bottom surface of the geotextile, and typical damage caused by the overlying base material (magnified ~2X).

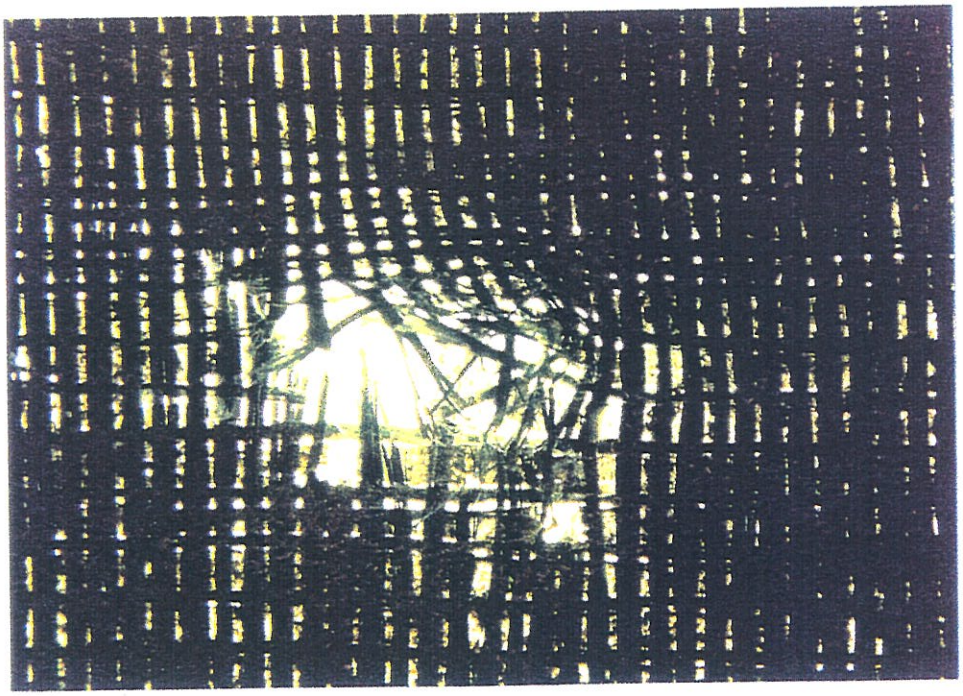

Figure 5.69 - Laboratory photograph over a light table showing typical damage (magnified ~2X).

5.2.10 SR-16, Olympic Interchange

The site is located on the south bound off ramp near mile post 10.85, on SR-16 in Pierce County just outside the southern Gig Harbor city limits (Fig. 4.1). The off ramp traffic lane is approximately 4.3 m wide with a 1.2 m shoulder on the east side and an 2.4 m shoulder on the west side, Figure 5.70. This is a very busy off ramp which carries mixed traffic. The subgrade conditions encountered during construction consisted primarily of very wet soft clays which were overexcavated in some areas prior to placing the geotextile. Figure 5.71 shows the condition of the overexcavated subgrade prior to placing the geotextile. A 149 g/m^2 (4.4 oz/yd^2) woven slit-film geotextile separator (Propex 2002) was approved for the project, and installed during April, 1988. The initial lift over the geotextile was approximately 30 cm thick and was dumped at the edge of the fabric, spread with a D7 dozer, and compacted with a Raygo SDV roller. Figure 5.72 shows the initial lift of the base material being spread by the dozer after it was dumped at the edge of the geotextile. The initial lift was compacted with the vibrator turned off. The right side of Figure 5.72 also shows the installation of a subgrade drainage system.

The site was initially visited on March 25, 1992, to discuss potential testpit locations and traffic control with WSDOT maintenance personnel. The testpit limits were marked on June 2, 1992, for future sawcutting and excavation. The testpit was located in the travel lane adjacent to the western white safety line.

The testpit was excavated on June 18, 1992. The pavement surface was in good condition with no signs of distress. The testpit at SR-16 was first excavated near mile post 10.90, but no geotextile was found above the subgrade, which was encountered at a depth of approximately 45 cm below the pavement surface. The testpit was moved to the south and a second excavation was performed at mile post 10.85. The geotextile was encountered approximately 99 cm below the pavement surface. The roadway section overlying the geotextile consisted of 190 to 200 mm of ACP, over 125 mm of CSTC, which was over about 66 cm of base material consisting of a very sandy subrounded gravel with some cobbles. Figure 5.73 shows the base material and depth of the testpit.

Figure 5.74 shows the condition of the top surface of the geotextile after the base material was removed. The geotextile was in very good condition with no holes or other damage. The upper surface did have fines caked on it which may have come from the overlying base material or they may be subgrade fines. Figure 5.75 shows the geotextile folded back and the subgrade surface exposed. The weave of the geotextile was imprinted over the entire surface of the subgrade which was composed of a moist, brown, lean clay. Figure 5.76 is a photograph of the bottom surface of the geotextile immediately after being removed and Figure 5.77 is a laboratory photograph (~2X magnification) over a light table showing minor blinding which was typical throughout the bottom surface of the geotextile.

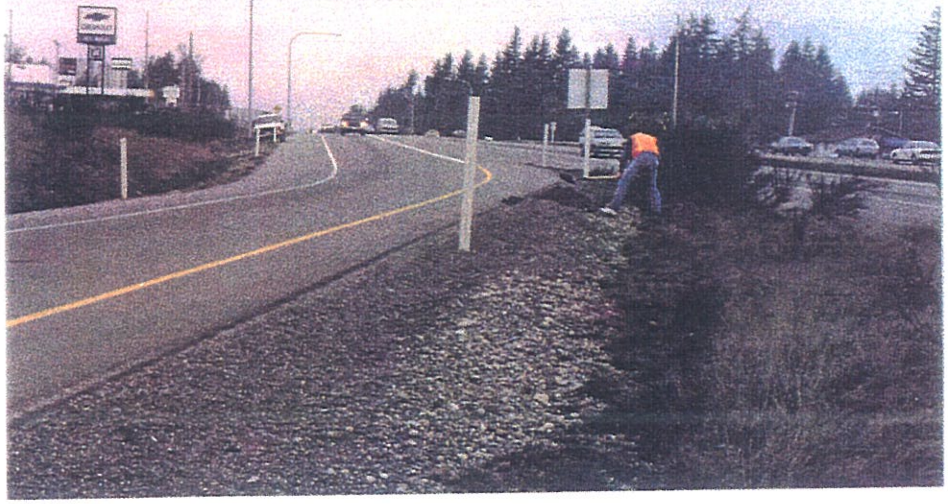

Figure 5.70 - Looking north at the south bound SR-16 off ramp.

Figure 5.71 - Photograph showing the overexcavated subgrade conditions (Courtesy of WSDOT).

Figure 5.72 - Dozer spreading the initial lift over the geotextile separator (Courtesy of WSDOT).

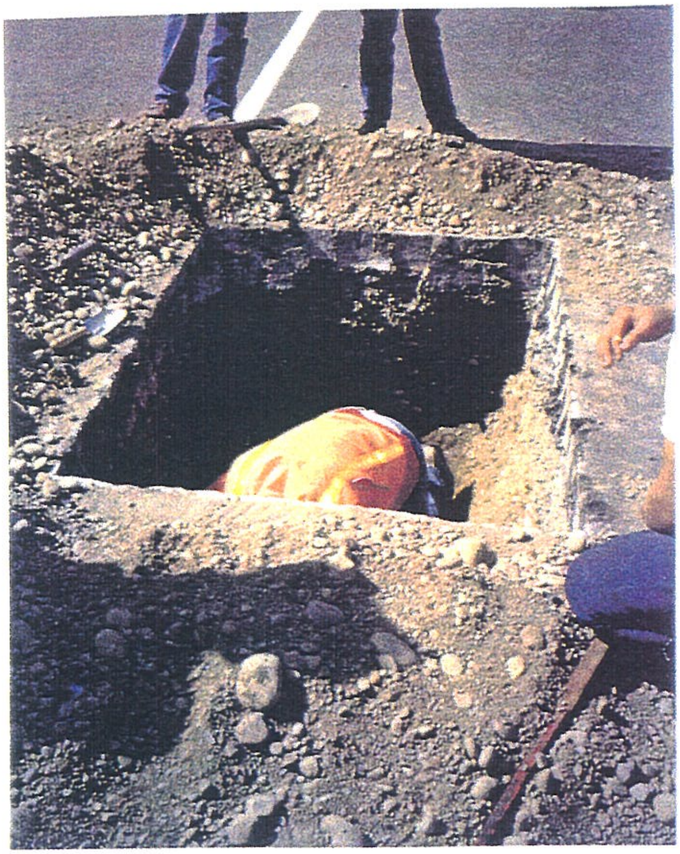

Figure 5.73 - Photograph of the testpit and base material.

Figure 5.74 - Upper surface of the exposed geotextile separator.

Figure 5.75 - Geotextile folded back exposing the subgrade surface.

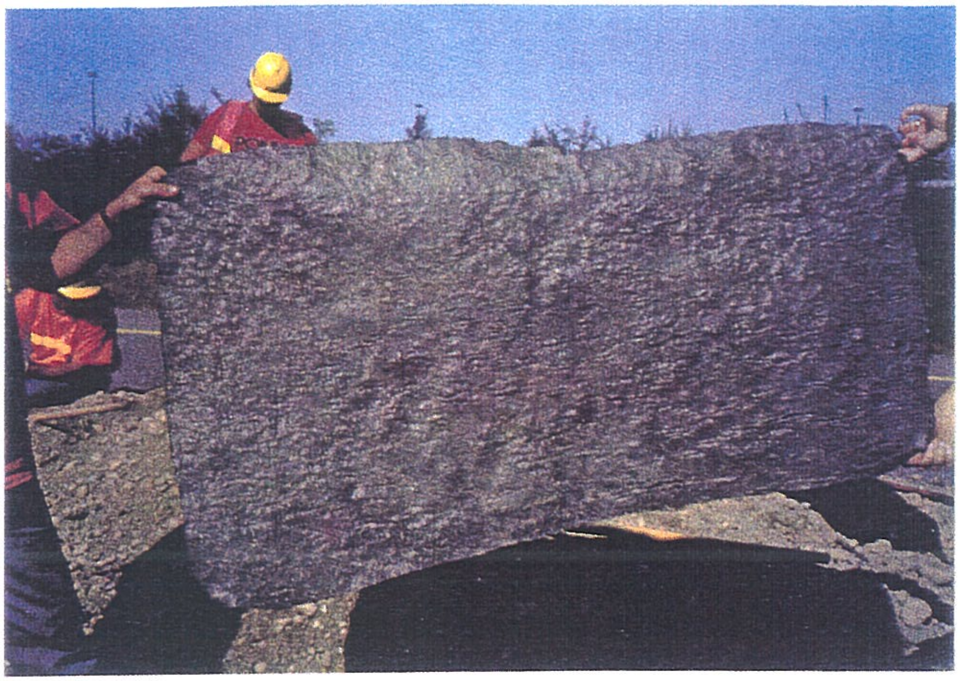

Figure 5.76 - Bottom surface of the exhumed geotextile.

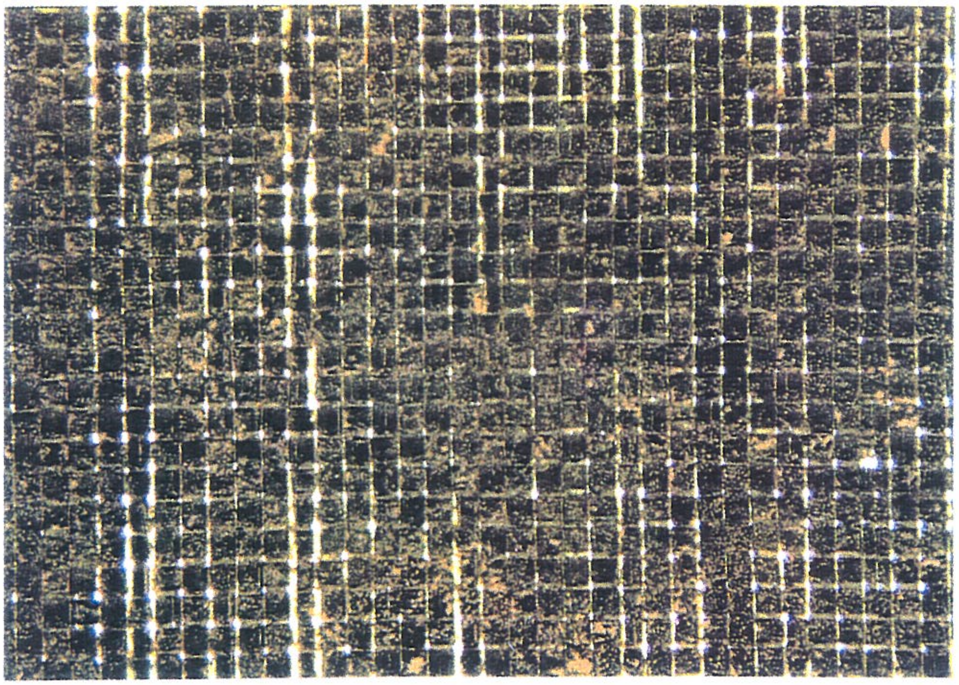

Figure 5.77 - Laboratory photograph showing typical blinding on the bottom surface of the geotextile (~2X magnification).

5.2.11 SR-502, N.E. 72nd Avenue Intersection

The site is located in the east bound lane near mile post 4.99 on SR-502, west of the town of Battle Ground, Clark County (Fig. 4.1). The roadway in this section consists of two 3.7 m travel lanes, a 3 m left turn lane, and 2.4 m shoulders. This section of highway receives mixed traffic and many heavy trucks. The roadway was widened as part of the reconstruction project. The subgrade during construction consisted of moist silts and clays, but no unusually bad soil conditions were reported. A 153 g/m^2 (4.5 oz/yd^2) needle-punched nonwoven geotextile separator (Trevira 1115) was used over the subgrade soils, and installed in June, 1986. The geotextile separator was installed under the widened sections of the highway and shoulders. Figure 5.78 shows the geotextile rolled out over the prepared subgrade surface. Figure 5.79 shows a dozer spreading the initial lift of the base material over the geotextile. The geotextile was supposedly installed according to the specifications, minimum initial lift of 300 mm, although Figure 5.79 shows at least one instance where the dozer operated on about 150 mm of base material over the geotextile separator. The initial lift was compacted with a Raygo roller.

The site was initially visited on March 24, 1992, to discuss traffic control with WSDOT maintenance personnel. The testpit limits were marked on June 2, 1992, for sawcutting and future investigation. The testpit is adjacent to the white safety line, and west of N.E. 72nd Avenue, Figure 5.80.

The testpit was excavated on June 23, 1992. The pavement surface was in good condition with no signs of distress. The geotextile was encountered approximately 76 cm below the pavement surface. The roadway section overlying the geotextile consisted of 150 to 165 mm of ACP, over 50 to 75 mm of CSTC, over 53 to 56 cm of base material consisting of sand with some subrounded gravel. Figure 5.81 shows the roadway section overlying the exposed geotextile.

Figure 5.82 shows the completely exposed geotextile and a 36 cm overlap on the east side of the excavation. The bottom surface of the exhumed geotextile is shown in Figure 5.83. Figure 5.84 shows the geotextile folded back to expose the surface of the subgrade. The surface of the geotextile was very irregular with up to 50 mm of grade change across subgrade surface. An apparent rut, due to pumping of the subgrade during construction, was found on the north side (left side of Fig. 5.85) of the excavation and accounts for most of the irregular surface. The subgrade soils consisted of moist, brown, sandy lean clay, with occasional gravels and cobbles. There were a few indentations in the geotextile due to the underlying gravels and cobbles. Figure 5.85 also shows the locations of the Shelby tube samples.

The bottom surface of the geotextile was heavily stained with orange to rust and dark brown colors, Figure 5.86 (magnified ~2X). Figure 5.87 is a photograph over a light table of the top surface of the exhumed geotextile. The geotextile was in good condition, but in several areas there appeared to be thin spots in the fabric where there were relatively few fibers. Figure 5.88 shows a close-up (magnified ~2X) of a typical thin area. Generally the geotextile appeared to be minor to moderately clogged with a few smaller areas of moderate to heavy clogging.

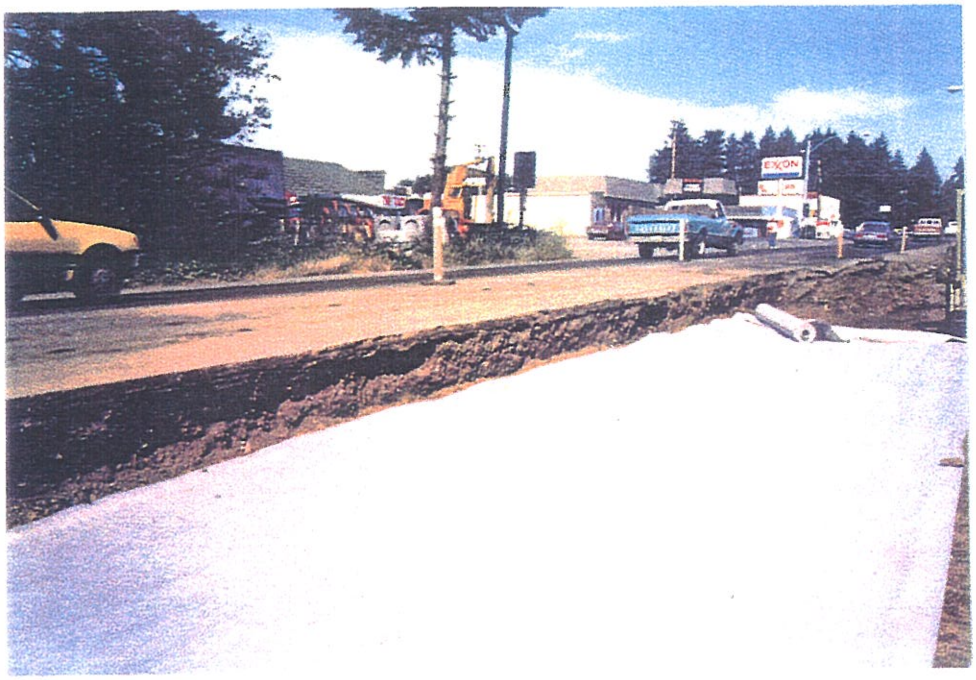

Figure 5.78 - Geotextile rolled out over prepared subgrade during construction (Courtesy of WSDOT).

Figure 5.79 - Dozer spreading the initial lift of backfill over the geotextile (Courtesy of WSDOT).

Figure 5.80 - Testpit location.

Figure 5.81 - Roadway section overlying the exposed geotextile.

Figure 5.82 - Top surface of the exposed geotextile, showing the overlap on the east side.

Figure 5.83 - Bottom surface of the exhumed geotextile.

Figure 5.84 - Geotextile folded back exposing the subgrade surface.

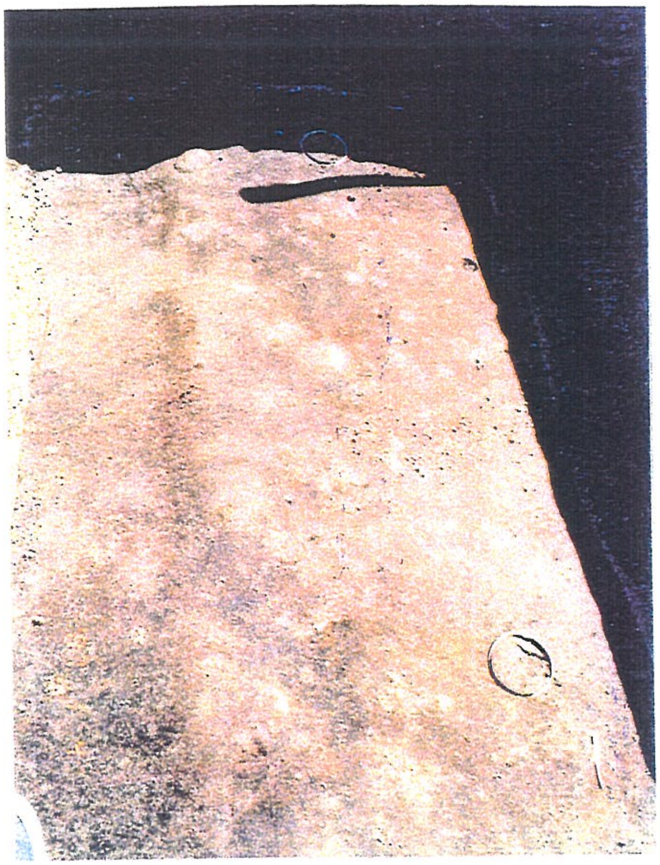

Figure 5.85 - Subgrade surface with the rut shown on the left side.

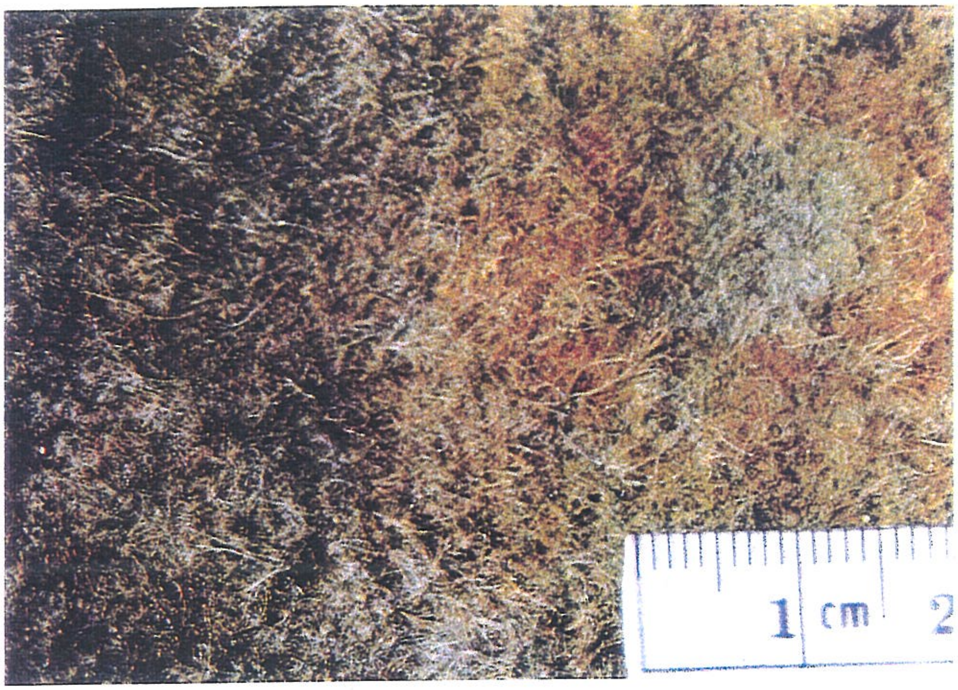

Figure 5.86 - Dark brown and rust colored staining on the bottom surface of the geotextile (magnified ~2X).

Figure 5.87 - Laboratory photograph of the geotextile over a light table.

base material used on the Coal Creek Road and Carroll Road sites, was placed as fill material for the nearby swale and the testpit happened to fall on the western limits of this fill material.

The bottom surface of the exhumed geotextile is shown in Figure 5.95. There were some areas of iron staining and other white areas which were like new and were probably sections which bridged across the large underlying rock. Figure 5.96 shows a photograph of the bottom surface of the geotextile illuminated from behind by a light table. It is interesting to note the abundance of holes towards the bottom and to the left of the photograph, which were the areas overlying the large angular rocks on the south and east sides of the testpit. The top and right side have relatively few holes and were the areas overlying the fine-grained soils which had relatively few large rocks. The geotextile was in fair to good condition over the fine-grained soil while it was in poor condition over the angular rock. The geotextile appeared to be moderately clogged with fine-grained soil particles.

Figure 5.89 - Looking east towards the excavation on Olson Road.

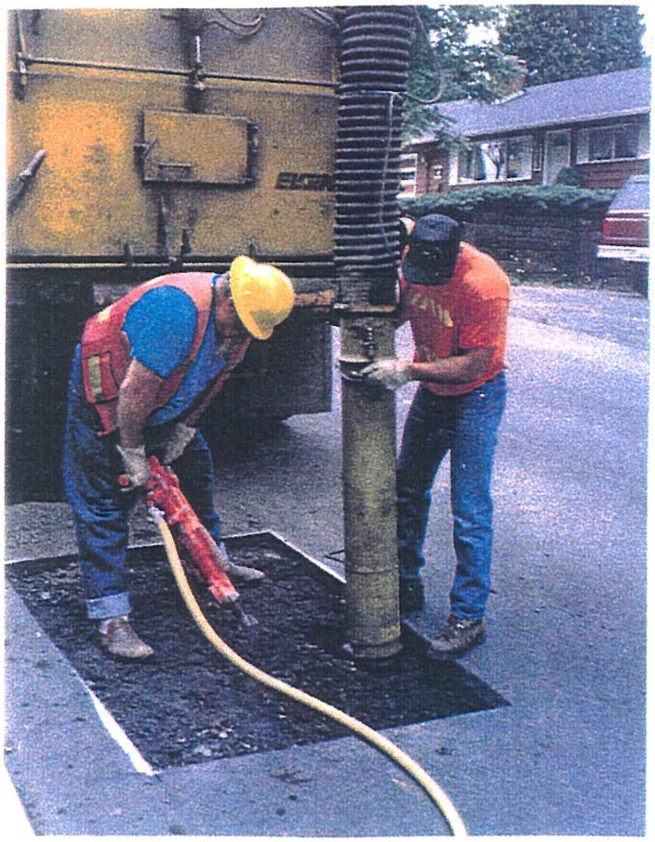

Figure 5.90 - Base being loosened with a jackhammer and being removed with the Vac-all.

Figure 5.91 - Roadway section overlying the exposed geotextile.

Figure 5.92 - Exposed geotextile. Looking west.

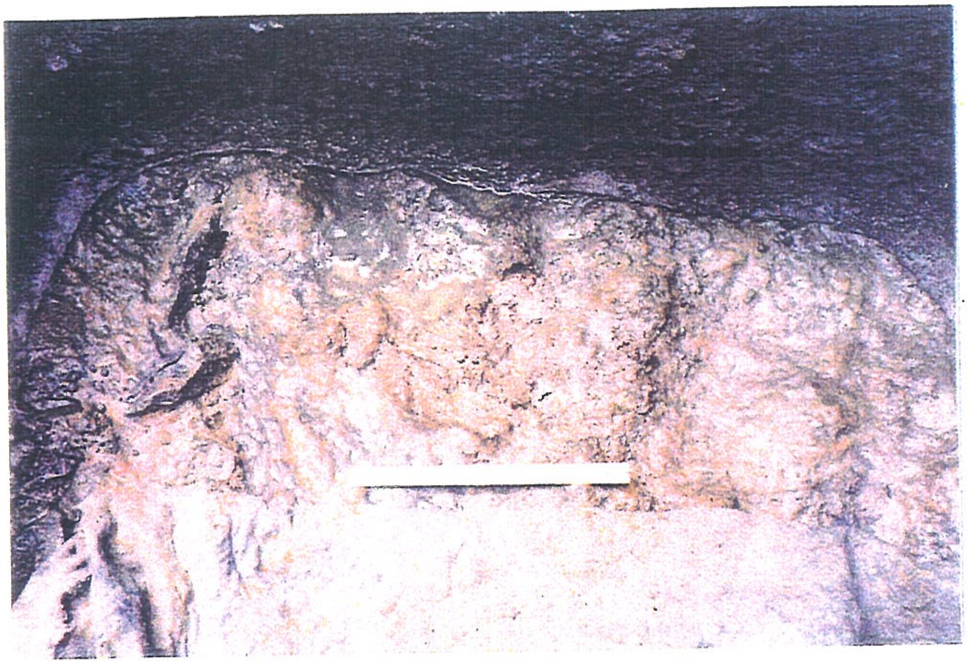

Figure 5.93 - Geotextile folded back exposing the subgrade surface, west side.

Figure 5.94 - Exposed subgrade surface. Looking west.

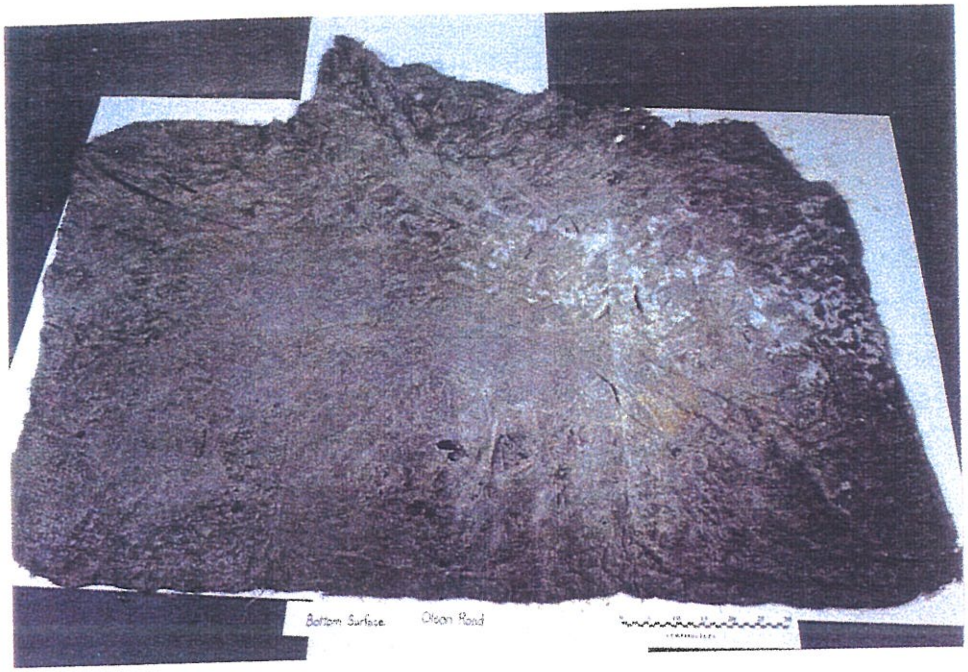

Figure 5.95 - Laboratory photograph of the bottom surface of the geotextile.

Figure 5.96 - Middle area of the bottom surface of the geotextile showing the degree of damage. The top of the photo is the north side, right is west. Illuminated from behind.

5.102 shows the geotextile folded back and the subgrade surface exposed. Also shown is moderate to heavy iron staining on the geotextile and subgrade.

The surface of the subgrade, 0 to 10 mm below the geotextile, was brown to rust colored and contained a few small gravels and some coarse sand. When taking subgrade samples the material just below the surface was much finer grained and grey in color, Figure 5.103. Figure 5.104 shows the bottom surface of the geotextile with the iron staining, and numerous indentations. The geotextile showed minor damage although it had several holes which were typically smaller than 6 mm. The bottom of the geotextile was minor to moderately blinded. Figure 5.105 shows a magnified (~2X) photograph of a typical blinded area, while Figure 5.106 shows a typical area with negligible blinding (magnified ~2X).

Figure 5.97 - Placement of base material during a recent and adjacent project.

Figure 5.98 - Spreading out the initial lift during the recent project.

Figure 5.99 - Roadway section overlying the exposed geotextile.

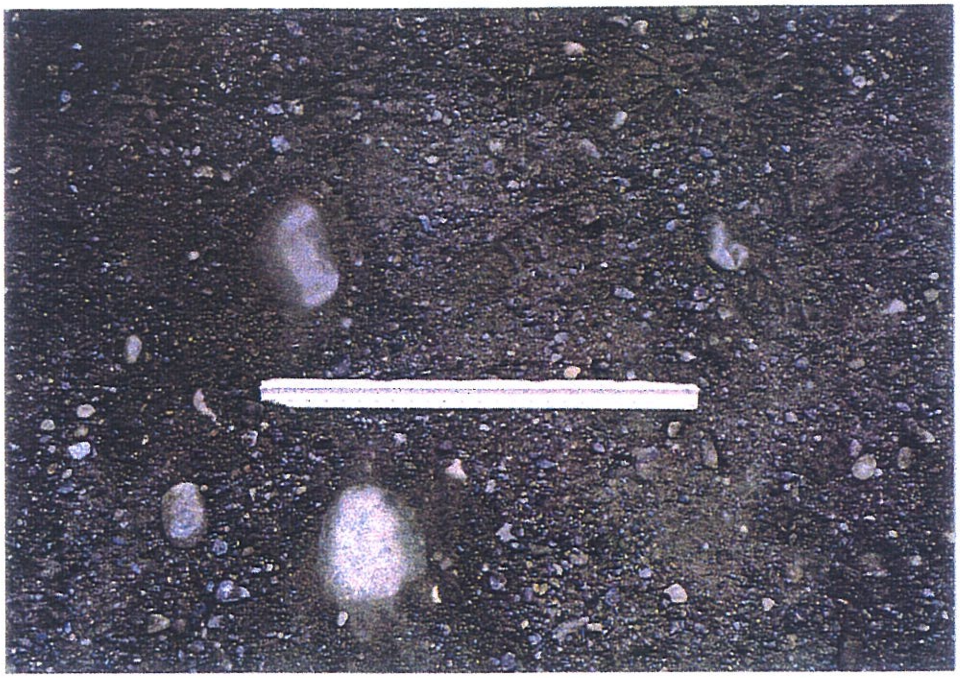

Figure 5.100 - Gravel base material overlying the geotextile.

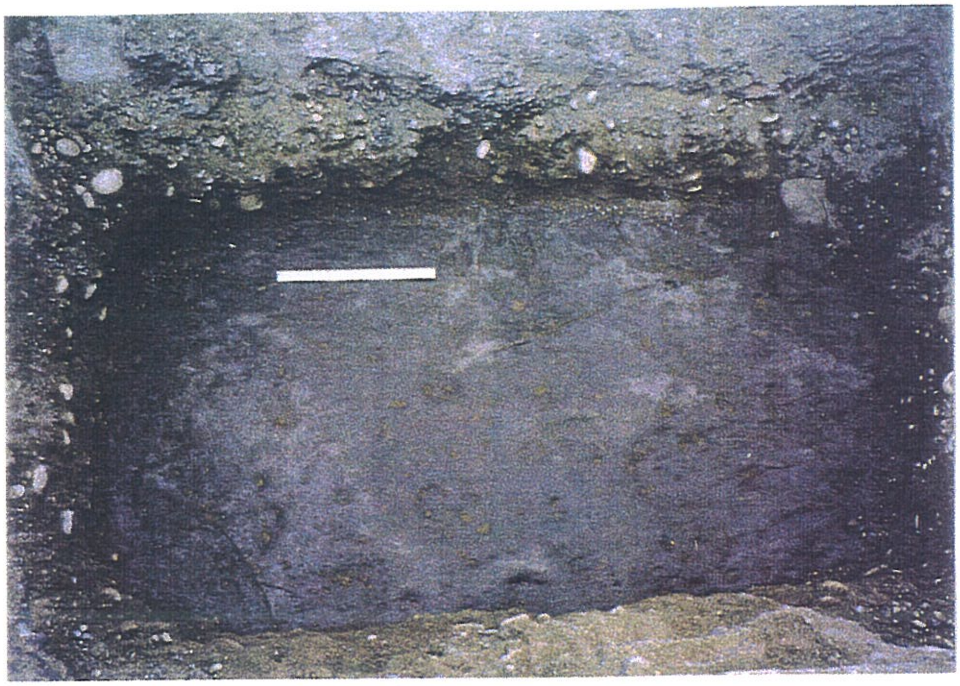

Figure 5.101 - Exposed geotextile showing the indentations from the base material.

Figure 5.102 - Geotextile folded back exposing the subgrade surface.

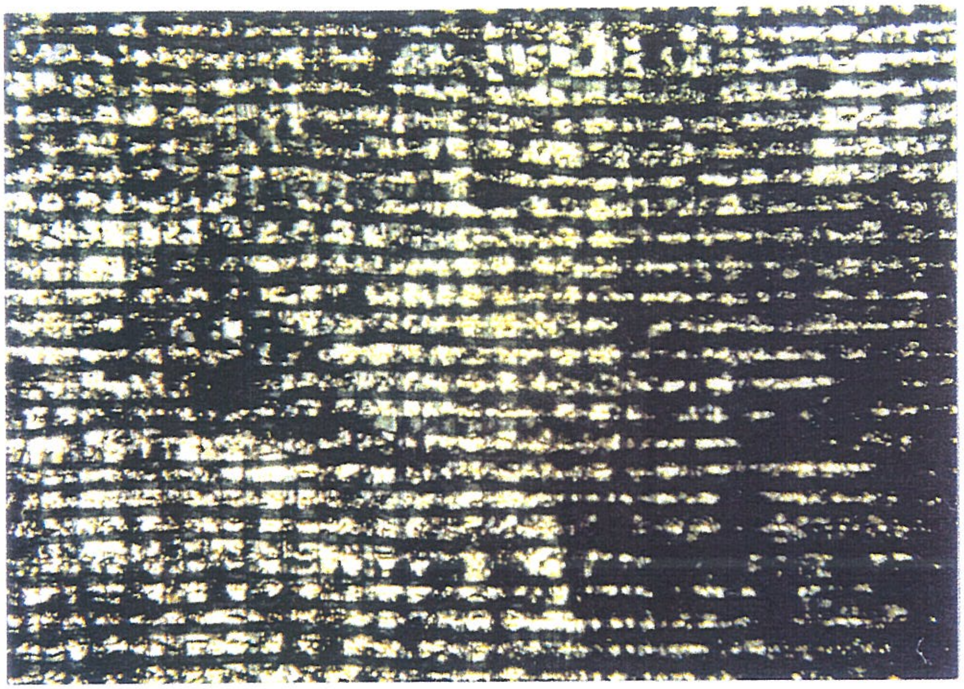

Figure 5.105 - Magnified (~2X) laboratory photograph of a typical blinded area.

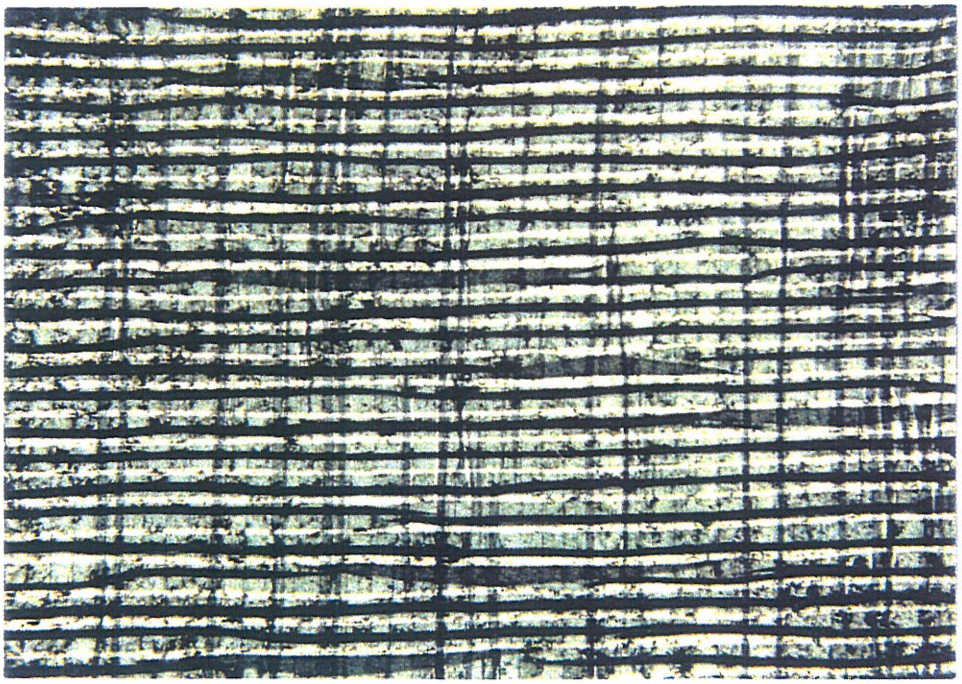

Figure 5.106 - Magnified (~2X) laboratory photograph of a typical area with little blinding.

5.3 SUMMARY OF THE SITE INVESTIGATIONS

Thirteen sites were investigated and 14 testpits were excavated. Geotextile separators were recovered in all the testpits. The 14 geotextile separators which were retrieved consisted of six woven slit-films (122 g/m^2 to 231 g/m^2), six needle-punched nonwovens (143 g/m^2 to 251 g/m^2), and two heat-bonded nonwovens (136 g/m^2). Table 5.1 summarizes the geotextile types, observations of their condition, and the installation conditions which were taken from construction records and/or verbal communications with some of the inspectors.

Seven of the 14 sites, summarized in Table 5.2, had subgrade conditions which were not ideal for an evaluation of long-term filtration characteristics. The geotextile separator at the site on SR-14 appeared to be a misapplication as it was installed over a gravel and sand embankment fill, so the long-term evaluations with regard to filtration and drainage will not be useful. Base material was mixed in with the subgrade soils at the sites on SR-546 and Carroll Road, and coarse gravel was found below part of the geotextile separator at the Olson Road site. The presence of the coarse material in these subgrade soils may have also adversely affected the long-term performance evaluation aspects of this study. A good construction application for a separator was seen at the site on SR-9 (Marsh Road), where the geotextile was installed directly over the native vegetation. Although this was a good application for the separator it was not useful for the long-term filtration evaluations, due to the filtering effects of the vegetation. The recovered geotextile on Coal Creek Road was installed over an old timber holding area and there was a high content of wood debris between the silt subgrade and the geotextile separator. The wood debris undoubtedly interfered with the long-term performance evaluations. Approximately one-half of the separator retrieved from the 49th Ave NE site had imported sandy backfill for a utility trench below it. Although these sites have less than favorable subgrade conditions for long-term filtration and drainage evaluations, they will be useful for assessing the construction damage as a function of the subgrade, base course, and construction practices.

Table 5.1 - Summary of geotextile separator installation conditions and observations.

Site Name	Date Installed	Geotextile & Weight g/m^2 (oz/yd^2)	Subgrade material	Basecourse Material	Initial Lift Thickness (cm)	Geotextile Damage
Columbia Hts Rd 1 and 1a	1990	NP NW 143 (4.2)	Lean clay	CSBC	23	Moderate to Heavy (1a) Severe (1)
Coal Creek Rd	1984	HB NW 136 (4.0)	Wood debris and silt	Angular coarse gravel/cobbles	50 to 60	Heavy
Pacific Way	1982	NP NW 153 (4.5)	Clayey sand	CSBC	33	Minor
SR-14	8/1990	W-SF 231 (6.8)	Gravel with sand	CSBC	15 to 18	Minor
SR-9 (Marsh Rd.)	8/1989	W-SF 163 (4.8)	Organics over silt	Sand with gravel	60	None
SR-546	9/1989	W-SF 149 (4.4)	Gravel with silt and sand	Sand with gravel	30	Minimal
Carroll Rd	1978/79	HB NW 136 (4.0)	Gravel with clay and sand	Angular coarse gravel/cobbles	23 to 33	Severe
SR-504	6/1988	NP NW 251 (7.4)	Silt	Sand with gravel/cobbles	60	None
49th Ave. NE	11/1988	W-SF 153 (4.5)	Sandy silt	Sandy gravel	23 to 25	Moderate
SR-16	5/1988	W-SF 149 (4.4)	Lean clay	Sandy gravel	30	None
SR-502	6/1986	NP NW 153 (4.5)	Lean clay	Sand with some gravel	30	None
Olson Rd.	1991	NP NW 204 (6.0)	Silty sand	CSBC	23	Moderate
SR-9 (Sumas)	1987	W-SF 122 (3.6)	Silt and sand	Sand and gravel	18 to 20	Minor

NP NW - Needle-punched nonwoven
HB NW - Heat-bonded nonwoven
W-SF - Woven slit-film

Table 5.2 - Sites with unfavorable subgrade conditions.

Site	**Subgrade Condition**
Coal Creek Road	Wood debris in the silt subgrade
SR-14	Sand and gravel
SR-9 (Marsh Rd.)	Vegetation matted down above the silt subgrade
SR-546	Base material intermixed in subgrade
Carroll Road	Base material intermixed in subgrade
49th Ave. NE	Utility trench sand backfill south half of excavation
Olson Road	Imported crushed rock below approximately 1/3 of geotextile

All fourteen sites were beneficial for studying the amount of construction damage and the survivability conditions for each type of geotextile separator. The retained strength of the geotextiles could also be determined for all the sites, except for testpit 1, on Columbia Heights Road, where damage to the geotextile was so severe that an adequate number of test specimens for the grab and wide width tests could not be obtained. Geotextile separators at four sites showed no signs of construction damage; these included: SR-9 (Marsh Road) SR-504, SR-16, and SR-502. Minimal or minor damage was experienced by the geotextiles at Pacific Way, SR-14, SR-546, and SR-9 (Sumas). Two geotextiles had moderate damage; 49th Avenue NE and Olson Road. The remaining four sites sustained the most damage; from moderate to heavy damage at Columbia Heights Road (testpit 1a) and Coal Creek Road, to severe damage at Columbia Heights Road (testpit 1) and Carroll Road. Although the heat-bonded nonwoven geotextiles experienced high degrees of damage, it should be remembered that they were installed under some of the highest survivability conditions. Survivability for each site is discussed in Chapter 9.

The geotextiles were also briefly examined in the field for possible blinding/clogging and also iron staining. No heavy blinding was observed on the woven geotextiles, while the nonwoven geotextiles showed varying degrees of clogging, some of which appeared to be heavy to severe (Columbia Heights Road and Carroll Road). Several geotextiles had moderate to heavy deposits of iron-oxide with the Columbia Heights Road sites having the heaviest deposits. Observations of possible blinding/clogging were made in more detail at the laboratory and are discussed in Chapter 7. Three of the sites showed signs of significant caking of fine-grained soil particles on the upper surface of the geotextiles. These sites included SR-14, 49th Ave NE, and SR-16. The degree of caking for these sites is also discussed in Chapter 7.

CHAPTER 6

FALLING WEIGHT DEFLECTOMETER (FWD) TESTS

The FWD tests were performed by WSDOT personnel as part of the site investigation and prior to the testpit excavations. The FWD tests were used to get a general idea of the subgrade conditions along sections of each roadway. As discussed previously, the FWD was used to locate "soft" subgrade areas which would be more beneficial for this study. The following two subsections will discuss the test method and the test results.

6.1 DISCUSSION OF THE TEST METHOD

The FWD is a trailer-mounted piece of testing equipment which is used to obtain pavement surface deflections. It is used to simulate a moving truck load by applying an impulse load, generally in the range of 24.5 to 71.2 kN (5,500 to 16,000 lb), with a maximum range of 6.7 to 106.8 kN (1,500 to 24,000 lb) for the Dynatest Model 8000, for a duration of about 25 to 30 ms. The weights are hydraulically raised and then dropped, from a height up to 38 cm onto a 30.5 cm diameter loading plate resting on a thick rubber pad which is in contact with the pavement surface. The pavement surface deflections are measured by monitoring up to seven velocity transducers (geophones) which are placed at various positions out from the applied load. One of the transducers is placed in the loading plate directly under the applied load (Mahoney, 1992).

The output summary provided by WSDOT lists the maximum pavement deflection, area, and the estimated subgrade modulus. The maximum pavement deflection is measured at the middle of the loading plate. The higher the maximum surface deflection, the lower the resistance that the pavement structure has in carrying traffic loads. The area is a parameter which combines the surface deflections from four transducers. These four deflections are measured at the middle of the load plate, and at 30 , 61, and 91 cm from the middle of the load plate. The lower the area parameter the more the pavement structure is acting like the subgrade material. The subgrade modulus is estimate from regression equations which are independent of the thickness of the pavement structure (Mahoney, 1992).

The output summary values provided by WSDOT were normalized to a 40 kN (9,000 lb) load and adjusted for pavement thickness and temperature. The subgrade modulus was based on the deflection at the sensor located 61 cm from the middle of the load plate.

6.2 FWD TEST RESULTS

FWD tests were performed within 15 m of the testpits at 11 of the 14 sites. The results of the tests for each site resulted in varying subgrade modulii along the roadway. The intent was to use the FWD results to locate potential "soft" spots which would be more beneficial for the purpose of this study. The soft areas were the lowest subgrade modulii recorded during the FWD tests for a particular site. After the soft spots were identified then the testpits were located on or as close to the soft subgrade areas as possible. The FWD tests were not used to verify the location of the geotextiles; they were solely used to identify soft subgrade conditions. The results of the FWD test closest to the respective testpit are shown in Table 6.1. The units shown in Table 6.1 for the deflection, area, and subgrade modulus are the same as the values from the output summaries provided by WSDOT.

As indicated, no tests were performed in the vicinity of the sites on SR-9 (Marsh Rd), Carroll Road, and SR-9 (Sumas). The original testpit location on Carroll Road did have FWD tests performed there, but the testpit had to be relocated after the fabric was not found. The high subgrade modulus for the SR-14 site was due to the sand and gravel subgrade material, while the high value for the SR-546 site may be due to the presence of crushed rock mixed in with the subgrade soil. The other high value at the SR-16 site was probably the result of a thicker base due to an overexcavated area, which was not accounted for during the FWD test.

As should be expected, the Columbia Heights Road site had the highest deflection, and the lowest area, as well as a low subgrade modulus. This of course could be attributed to the thin ACP and base layers, and the clayey subgrade soils.

Table 6.1 - Summary of the FWD test results.

Site	Backfill Thickness cm	ACP Thickness mm	Maximum Deflection mils	Area in^2	Subgrade Modulus ksi
Columbia Heights Rd (Testpits 1 and 1a)	30	35	80	14	8
Coal Creek Rd.	85	115	25	24	9
Pacific Way	45	130	22	20	12
SR-14	15	250	8	23	29
SR-9 (Marsh Rd.) [1]	No Tests	Performed			
SR-546 [2]	(50)	(280)	(10)	(26)	(18)
Carroll Road [3]	No Tests	Performed			
SR-504	80	180	18	23	13
49th Ave NE	28	90	29	18	11
SR-16	80	195	10	25	19
SR-502	60	160	17	22	15
Olson Road	35	65	74	16	7
SR-9 (Sumas) [1]	No Tests	Performed			

[1] No tests were performed because the testpit was located in a specific area.

[2] FWD tests were performed about 15 m to the north in the westbound lane.

[3] FWD tests were performed at the original testpit location, but no fabric was found there. Therefore, the testpit location was moved although no FWD tests were performed in the new location.

CHAPTER 7

GEOTEXTILE OBSERVATIONS - LABORATORY

7.1 INTRODUCTION

A detailed examination was performed in the laboratory on all the retrieved geotextile samples in an attempt to quantify the amount of physical damage and the degree of blinding and clogging to which the samples have been subjected. Iron staining and caking was also noted because it was prevalent on some of the fabrics. Qualitative descriptions were used to describe the overall condition of each geotextile separator.

Physical damage to the geotextile samples was in the form of abrasions and holes. Abrasions to individual filaments or tapes were common to most of the geotextile samples, but they would have been very difficult and time consuming to quantify, therefore abrasions were not included in the damage survey. Only holes, which include cuts and punctures, in the geotextile's structure were counted in the damage survey.

Blinding and clogging of the geotextile samples were also evaluated. Blinding is defined as the blockage of pore openings by soil particles on the surface of geotextiles, thus reducing the permeability of the fabric. Blinding can occur immediately when the geotextile in placed on a subgrade surface. Clogging occurs when soil particles enter into the structure of a geotextile and become trapped there, thus reducing the permeability of the fabric. In this study, the term caking is used to describe the blockage of pore openings on the upper surface of woven geotextiles. Although blinding can occur on both nonwoven and woven geotextiles, in this study it was only prevalent on woven fabrics. Therefore, for this study the term blinding will only used to describe the blockage of pore openings on the bottom surface of woven geotextiles. Clogging can also affect the performance of both nonwoven and woven geotextiles, but in this study it appeared to effect the nonwoven geotextiles the most. Therefore, the term clogging will only be used in conjunction with nonwoven geotextiles. The terms blinding, caking, and clogging are illustrated in Appendix E.

Although blinding or clogging of geotextiles can be caused by silt, clay, and fine sands, chemical precipitates such as iron-oxide can also decrease pore openings. In this study iron-oxide precipitates were found in varying degrees on some of the geotextile samples. Nonwoven samples appeared to be stained while the woven samples tended to have iron-oxide precipitate deposits on them. It was beyond the scope of this project to try to determine the amount of pore space reduced by the iron-oxide precipitates. Therefore, the estimates and descriptions of the degree of blinding or clogging includes iron staining, but does not distinguish between it and pore space reduced by soil particles.

7.2 DISCUSSION OF OBSERVATION TECHNIQUES

After each site investigation was completed, the exhumed geotextile samples were taken back to the laboratory where more detailed observations could be performed. Each geotextile sample was photographed, top and bottom, and close-up pictures were taken of pertinent areas which would document the condition of the retrieved samples.

Each geotextile sample was placed on top of a light table so that damage, blinding/clogging, caking and iron-oxide deposits could be viewed more effectively. A thin, square, wooden frame (300 mm sides) was used to divide the surface of the geotextile into separate areas so that surveys (damage, blinding, caking) could be performed. The frame was moved around on the sample so that as much of the fabric as possible would be included in the surveys. Only sections of the fabric which fully underlaid the frame were included in the surveys. Every framed area of fabric was viewed closely and all holes larger than approximately 1 mm were counted. The approximate number of holes were counted for each framed area, and the maximum and average hole sizes were also estimated. For woven geotextiles the degree of blinding was also recorded by estimating the blinded area as a percentage of the total area within each frame. The estimated degree of clogging for the nonwoven geotextile samples was done for the entire sample as a whole. If the samples appeared to have uniform blinding or clogging, then only an overall estimate was made for the entire geotextile sample. Estimates were also made on the percent area with caking and/or iron-oxide staining/deposits for each geotextile.

7.3 RESULTS OF THE LABORATORY OBSERVATIONS

The results of the laboratory observations are presented in Appendix A. Summaries of the damage and blinding/clogging surveys, as well as the iron-oxide and caking observations, will be discussed in the following subsections.

7.3.1 Damage Observations

Table 7.1 shows the results of the damage survey. The maximum number of holes for any frame and the average number of holes for all the frames for each geotextile is shown. The maximum size hole in each geotextile was recorded and an estimate was made of the average sized hole. The approximate hole area could then be found by multiplying the average sized hole by the number of holes per frame, as shown in Appendix A. The estimated average hole areas are presented in Table 7.1. The degree of damage was based on the following arbitrary percent hole area ranges:

% Hole Area	Degree of Damage
0	None
< 0.01	Minimal
0.01 - 0.05	Minor
0.05 - 1.0	Moderate
1.0 - 5.0	Heavy
> 5.0	Severe

As mentioned in Chapter 5, four of the retrieved geotextiles were not damaged, SR-9 (Marsh Rd.), SR-504, SR-16, and SR-502. The geotextile from the SR-546 site had minimal damage while minor damage was experienced by the geotextiles from Pacific Way, SR-14, and SR-9 (Sumas). Geotextiles from three sites experienced moderate damage, 49th Ave NE (Figs. 5.68 and 5.69), Olson Road (Fig. 5.96), and the section of fabric other than the overlapped area from Columbia Heights Road, testpit 1a (Fig. 5.7). The fabric from the Coal Creek Road site (Fig. 5.23) and the overlap area from Columbia Heights Road, testpit 1a (Fig. 5.7), experienced heavy damage. Severe damage was

Table 7.1 - Summary of the damage and blinding/clogging observations.

Site	Number of Holes per Frame (Max./Ave.)	Size of Holes, mm (max./Ave.)	Estimated Hole Area (%)	Degree of Damage	Percent Area Blinded or Clogged	Degree of Blinding or Clogging
Columbia Heights Rd. (1a)	368/338* 80/48	10/2-3* 15/1-3	1.75* 0.18	Heavy* Moderate	10-30* 30-70	Minor to Moderate* Moderate to Heavy
Columbia Heights Rd. (1)	-	-	-	Severe	50-75	Moderate to Heavy
Coal Creek Rd.	26/13	90/5-30	3.09	Heavy	<25	Minor
Pacific Way	37/18	3/1-2	0.03	Minor	25	Moderate
SR-14	5/2	15/2-4	0.02	Minor	10-30 [1]	Minor to Moderate
SR-9 (Marsh Rd.)	0	-	0	None	5 [2]	Minimal
SR-546	2/0.5	3/2-3	0.003	Minimal	10	Minor
Carroll Rd.	205/180	50/3-15	7.6	Severe	75-90	Severe
SR-504	0	-	0	None	50-75	Heavy
49th Ave NE	28/15	40/2-4	0.11	Moderate	25-50 [3]	Moderate
SR-16	0	-	0	None	0-10 [4]	Minimal
SR-502	0	-	0	None	10-40	Minor to Moderate
Olson Rd.	67/36	15/1-3	0.14	Moderate	30-50	Moderate
SR-9 (Sumas)	13/4	10/3-4	0.04	Minor	5-30	Minor to Moderate

* - Overlap area.

1 – Heavily caked upper surface (50-75%), severe in some places (up to 90%).

2 – 30-50% organic blinding over about 40% of the geotextile surface.

3 – 40-50% caking on the upper surface.

4 – 25-50% caking on the upper surface.

Table 7.2 - Summary of the iron staining observations.

Site	Percent Area with Iron staining	Degree of Iron staining
Columbia Heights Rd. (excavation 1a)	90 - 100	Heavy
Columbia Heights Rd. (excavation 1)	50 - 75	Heavy
Coal Creek Road	1 - 2	Minimal
Pacific Way	15 - 20	Minor
SR-14	1 - 2	Minimal
SR-9 (Marsh Rd.)	30 - 50	Moderate
SR-546	0	None
Carroll Road	< 1	Negligible
SR-504	< 1	Negligible
49th Ave NE	2 - 5	Minimal
SR-16	< 1	Negligible
SR-502	25 - 30	Moderate
Olson Road	2 - 5	Minimal
SR-9 (Sumas)	10 - 30	Minor to Moderate

The geotextile retrieved from the site on SR-546 showed had water stained patterns on the bottom surface of the geotextile (Fig. 5.48). This was the only geotextile which had obvious water staining.

CHAPTER 8
LABORATORY TESTS

8.1 INTRODUCTION

The objective of the laboratory testing program was to evaluate the retained properties of the retrieved geotextile samples. Then conclusions could be drawn with respect to the long-term performance of the geotextiles, especially filtration and drainage characteristics, as well as the degree of damage to the geotextiles.

The filtration and drainage properties of a geotextile are controlled by the number and size of the pore openings within the fabric's structure. When the pore openings are interfered with (blinding, clogging, chemical precipitates) then the hydraulic properties of the fabric are reduced. In order to evaluate the potential reduction in the hydraulic properties of the geotextiles, permittivity tests were performed on the geotextile samples.

The ability of a geotextile separator to survive the installation process will enable it to perform its intended functions (separation, filtration, drainage). If the geotextile is damaged, then the long-term performance of the geotextile may be affected. The ability of a geotextile to resist damage during construction not only depends on the construction practices, but also on the strength of the fabric. Therefore, in order to obtain information regarding the retained (or residual) strength of the geotextiles, grab tensile and wide width strength tests were performed in the laboratory. The results of the laboratory geotextile tests were compared to manufacturers' data for the installed material and to WSDOT conformance tests which were performed on fabrics from some of the sites.

Laboratory tests were also conducted on the base and subgrade soil samples primarily for classification purposes, but also to determine whether the subgrade fines were principally silt or clay and whether there may be any migration of fines up through the geotextile. The laboratory tests were performed on the geotextile and soil samples to provide supplemental information to support the laboratory observations and site investigation results.

The test methods performed on the base and subgrade soil samples are discussed in Section 8.2, while the test methods performed on the geotextile samples are discussed in Section 8.3. The results of all the laboratory tests are presented in Section 8.4. All the tests were conducted at the University of Washington's Geosynthetics and Geotechnical Laboratories.

8.2 TEST METHODS ON THE BASE AND SUBGRADE SAMPLES

8.2.1 Discussion of Test Methods

In order to characterize the properties of the base and subgrade soils; grain size distribution analyses, Atterberg Limits, and water content tests were conducted on the soil samples. Grain size distributions on the material retained on the No. 200 sieve and water content tests were performed on all the soil samples for each site. Hydrometer analyses were performed on the subgrade soil samples in order to obtain more information on the distribution of the fine-grained soil particles. Atterberg Limits were also only conducted on the subgrade soils for classification purposes and for a better understanding of the cohesive properties of the soils. All the tests were generally conducted in accordance with ASTM and/or WSDOT standard test methods.

8.2.2 Water Content Tests

Natural water contents were determined for all the samples from each site. These tests were conducted to determine the general soil-moisture profile below the ACP layer. The subgrade moisture contents could also give an indication of the degree of consolidation for each site when compared to the Atterberg Limits. The water content tests were conducted in accordance with ASTM D 2216.

8.2.3 Grain Size Distribution Analyses

Grain size distribution tests were performed on all the base and subgrade soil samples from each site. The grain size distribution analyses were primarily conducted in order to classify the soils. The soil samples were classified according to the Unified Soil Classification System, ASTM D 2487. The grain size distributions were also used to determine if any conclusions could be drawn regarding the possibility of subgrade fines migrating up through the geotextile and into the base material. Only the coarse fraction, greater than the No. 200 sieve, was used when determining the grain size distribution of the base materials, while a hydrometer analysis was included when the subgrade soils were analyzed. Hydrometer analyses were necessary for determining the distribution of the fine-grained portion of the subgrade soils. No hydrometer tests were performed on the base materials because they typically had less than 10 percent passing the No. 200 sieve, and that which did pass the No. 200 sieve was assumed to be silt size. The tests were conducted in accordance with ASTM D 422, with the exception that a sieve No. 100 was included in the sieve stack sequence. No constant temperature bath or constant temperature room was used for the hydrometer analyses. The temperature of the solution was recorded at each time interval during the hydrometer analyses.

8.2.4 Atterberg Limits

The limits were conducted only on the subgrade soil samples. They were used in classifying the samples, and they were compared with the natural moisture contents in order to evaluate the subgrade conditions at the time the sites were investigated. Atterberg limits were conducted in accordance with ASTM D 4318.

8.3 GEOTEXTILE TEST METHODS

8.3.1 Discussion of Test Methods

Three laboratory tests were performed on the retrieved geotextile samples in order to evaluate their retained properties. Permittivity tests were conducted to evaluate the long-term drainage characteristics of the geotextile samples and to assess the degree of blinding/clogging for each sample. Grab tensile and wide width strength tests were performed on the geotextile samples to evaluate the retained strengths of the samples. The results of the retained strength tests were also used to evaluate the degree of damage sustained by the geotextile separator during installation and subsequent use of the roadways.

8.3.2 Permittivity Tests

The permittivity tests were conducted in accordance with ASTM D 4491, although the apparatus (permeameter) at the University of Washington varies significantly from the one shown in ASTM D 4491 and the one used by WSDOT. The permeameter used at the WSDOT laboratory consists of a falling head apparatus with an electronic system which records the time of each test. The University of Washington has a constant head permeameter, "STS geotextile permeameter" design (Christopher, 1983), and a schematic of this permeameter is shown in the Phase I report (Page, 1990). This apparatus meets the requirements stated in ASTM D 4491 because it (1) is able to provide a constant head of water on the geotextile sample, (2) can be converted to be used as a falling head apparatus, although the one at the University of Washington is presently fixed for constant head tests only, and (3) is not the controlling agent for flow during the test, even with very thin needle-punched nonwoven geotextile samples which have high flow rates.

Since the permittivity tests were conducted on exhumed samples with varying degrees of blinding or clogging, the constant head test method was deemed to be the best test method available. Several of the retrieved samples had high permeabilities which tended to wash the test specimens during the permittivity tests. Falling head tests would probably tend to wash the soil from the test specimens faster than the constant head tests. The procedures for conducting the permittivity test is presented in Appendix C.

There are three common ways in which cross-plane flow through a geotextile has been reported; flow rate (Q), permittivity (Ψ), and permeability (k). Permittivity is thought to be the proper way to report the cross-plane flow for geotextiles. Permeability is still used by some people although there is some question as to its validity since it is very dependent on the thickness of each geotextile. The permittivity is calculated by dividing the flow rate per cross-sectional area by the head on the geotextile. The permeability is simply found by multiplying the permittivity by the nominal thickness of the geotextile. The equations are as follows:

$$\text{Flow Rate, } Q = \frac{qR_t}{TA} \quad (\text{liters/min/m}^2)$$

$$\text{Permittivity, } \Psi = \frac{Q}{h} = \frac{qR_t}{hTA} \quad (\text{sec}^{-1})$$

$$\text{Permeability, } k = \Psi t \quad (\text{cm/sec})$$

where:

T = time for flow (q), sec,
A = cross-sectional area of sample area, mm^2,
h = head of water on the sample, mm,
t = nominal thickness of the sample, cm.

q = quantity of flow, mm^3, $q = d(a_1 - a_2)$,
d = water level drop in permeameter, mm,
a_1= inside area of the standpipe, mm^2,
a_2= area within outside perimeter of air supply tube, mm^2.

R_t = temperature correction factor, $R_t = \frac{u_t}{u_{20^c}}$,
u_t = water viscosity at test temperature, millipoises,
u_{20^c} = water viscosity at 20°C, millipoises.

If the temperature can be assumed to be constant during the test runs, which it usually is, then the only two variables which are not constants are the water level drop, d, and the time for the flow (q) to occur, T. These two variables are measured during the permittivity test. Since the University of Washington's permeameter does not have an electronic measuring system, then a stop watch, a good eye, and a quick finger must be used. As discussed in Appendix C, the start of the test requires a finger to be lifted from the top of the air supply tube while simultaneously starting the stop watch. The test ends when the finger is placed back over the air supply tube while simultaneously stopping the stop watch. The water level drop is recorded by sighting across the meniscus in the standpipe and reading the scale at the beginning and the end of the test and finding the difference.

Error is introduced by using these techniques. First, error is introduced by sighting across the meniscus to obtain the beginning and ending water levels. The water levels were recorded to the nearest 1 mm, which introduces an error of ± 0.5 mm for each reading or up to 1 mm total possible error for each test. Second, it is not possible to start or stop the stop watch at the exact moment the finger is removed or placed on the air supply tube. This introduces more error, possibly up to 0.1 seconds each time, for a total of 0.2 seconds of possible error per test. These possible errors and other minor idiosyncrasies in the test procedure and apparatus accounts for an error of less than ± 3 percent for the typical permittivity calculation. This error decreases as the permittivity of the geotextile samples decreases (i.e., a longer test time for the same water level drop).

To make sure the washing process did not unduly disturb the structure of the fabrics being tested, test specimens from five control samples were tested and washed in the same manner as the retrieved test specimens. The results of the tests performed on the control specimens are presented in section 8.4.3.

The purpose of the permittivity tests was to get a general idea of the percent increase in the drainage characteristics of the geotextile samples after being washed. The percent increase in the permittivity was determined by comparing the unwashed versus the washed test values. The manufacturers' and WSDOT's values were not used to determine percent increases in the permittivity due to the inherent differences in the distribution of pore spaces in any fabric type. To get the exact value of the manufacturer's or WSDOT's permittivity results was not the purpose of this test.

8.3.3 Grab Tensile Tests

Grab tensile tests were performed on all the retrieved samples except for the severely damaged geotextile from Columbia Heights Road, testpit 1. The grab tensile test was selected because it is a good index test for measuring the strength properties of the geotextiles and it has been in use for years prior to the oldest site excavated (Carroll Road, 1978/79). Grab tensile tests are also used by WSDOT as a conformance test for geotextiles used in separation applications. WSDOT conformance tests were performed on the geotextile separators at five of the 14 excavated sites prior to installation. All the laboratory tests were conducted at the University of Washington's Geosynthetics Testing Laboratory. The tests were conducted in accordance with ASTM D 4632 and WSDOT Test Method No. 916, except that the test specimens were soaked for 24 hours prior to being tested saturated surface dry. Six test specimens were cut from the geotextile sample retrieved from each site and tested to determine their retained tensile strength value. Percent retained strengths could then be found for each geotextile sample by comparing the laboratory tested averaged values to the manufacturers' typical values and/or WSDOT conformance test results.

8.3.4 Wide Width Strength Tests

Wide width strength tests were also performed on all the retrieved geotextile separator samples, except for the severely damaged geotextile from Columbia Heights Road, testpit 1. These tests were also performed at the University of Washington and were in accordance with ASTM D 4595 and WSDOT Test Method No. 917. Six tests were performed on the exhumed sample from each site and they were also soaked for 24 hours prior to being tested saturated surface dry. No wide width strength tests were included in the WSDOT conformance tests for the geotextiles which were investigated. Only limited published manufacturer's data was available.

8.4 SUMMARY OF LABORATORY TEST RESULTS

8.4.1 Grain Size Distribution Analyses Results

The results of the grain size distribution analyses are presented in Appendix B, Figures B.1 through B.14. Each figure represents the soil samples, base course and subgrade, taken from a particular testpit. Also indicated on the figures are the percent passing the No. 200 sieve for each test. At least two samples were taken from the material from above the geotextile separators. A sample was taken from 0 to 50 mm above the geotextile in all the testpits, and a second sample was taken from the middle or near the top of the same base material. In testpits where there was a top course present, an additional sample of that material was also taken. Although only two samples were taken from the base material it was thought that this would be enough to get an indication of the possible change in fines content. The purpose of the grain size distributions from each site was to classify the soils and also to possibly draw conclusions regarding upward migration of fines through the geotextile separator from the subgrade soils.

Only four of the 14 testpits showed a higher percentage of fines from 0 to 50 mm above the separator in the base material. These testpits were at the SR-14, Carroll Road, SR-16, and SR-9 (Sumas) sites. The fines content ranged from 0.9 to 3.1 percent more than the fines in the samples taken from higher up in the base material. It is interesting to note that of the four testpits which had an increase in fines content in the base course material immediately above the geotextile, three of them involved woven slit-film fabrics, and the other involved the severely damaged fabric from the Carroll Road site. The geotextile separators from the SR-14 and SR-16 sites also had significant caking on top of the geotextile. The other ten testpits all showed a decrease, between 0.3 and 3.6 percent, in the fines content from 0 to 50 mm above the separator.

It is expected that there would be a small difference in the fines content from samples taken at random in any material. The percent differences in the fines content discussed above could almost have been expected. In the case of geotextile separator applications, one might expect a slightly higher content in the fines from 0 to 50 mm above the geotextile rather than from higher up in the base material. This is because normal construction operations may cause the fines to settle downward due to vibrations and/or the spraying of water to increase the moisture content for compaction purposes, although in some cases the fines may also move upward due to flooding of the base material and then compaction. The fact that ten of the testpits showed decreases in fines content 0 to 50 mm above the geotextile may suggest insensitive sampling techniques or simply inherent differences in the fines contents from each truck load when placed.

The increases in the fines content at the four sites cannot be directly attributed to upward migration of fines through the geotextile separators from the subgrade soils, although there is evidence of both caking and higher fines content at two of the sites.

8.4.2 Atterberg Limit and Water Content Test Results

The results of the Atterberg Limit and water content tests are also shown on Figures B.1 through B.14 in Appendix B. Atterberg Limits were performed only on the subgrade samples and were primarily for classification purposes only. The Atterberg Limits could also be used in conjunction with the natural moisture contents of the samples to get a rough approximation of the consolidation characteristics of the subgrade soils. Table 8.1 lists the liquid limits (LL), plastic limits (PL), and the natural moisture contents (w_n) of subgrade soil samples.

The samples from the Coal Creek Road site had a high content of wood debris and the sample from the south side was entirely wood debris. The high organic contents account for the high water content values. Both the SR-14 and the 49th Ave NE (south) samples were imported nonplastic (NP) fill materials. The low natural water contents for the SR-546 and Carroll Road samples are due to the high content of coarse material larger than the No. 40 sieve which is used in the Atterberg Limit tests.

Table 8.1 - Subgrade soil test results.

SITE	LL	PL	w_n (%)
Columbia Heights Rd. (testpit 1a)	36	22	23.1
Columbia Heights Rd. (testpit 1)	39	22	26.1
Coal Creek Rd. (north)	43	33	41
(south)	NP	NP	137
Pacific Way	44	20	24.7
SR-14	NP	NP	14.7
SR-9 (Marsh Rd.)	35	25	24.3
SR-546	40	33	9.7
Carroll Rd.	37	19	7.2
SR-504	54	33	43.7
49th Ave. NE (south)	NP	NP	5.6
(north)	26	22	22.4
SR-16	31	20	24.0
SR-502	28	19	20.8
Olson Rd.	NP	NP	15.2
SR-9 (Sumas) 0-13 mm BG	27	20	16.7
13-75 mm BG	23	21	17.9

BG - Below the Geotextile.

8.4.3 Permittivity Test Results

The results of the permittivity tests are presented in Tables C.1 through C.13 of Appendix C. The results are shown not only as permittivity, Ψ, but also as flow rate, Q, and permeability, k. The permeability values were calculated by multiplying the permittivity values by the nominal thickness of the geotextile. The thicknesses of the geotextiles were based on WSDOT conformance tests, if any, or the manufacturers' typical values for the year in which the geotextiles were installed. All thicknesses were typical values except for the Olson Road site which was the manufacturer's test value for the lot number installed. The thicknesses are shown in Table C.15 of Appendix C.

The purpose of the permittivity tests was to estimate the degree of blinding/clogging which the samples have been subject to. To accomplish this the samples were first tested as close to their undisturbed conditions as possible. As stated in the test procedures, Appendix C, five successive test runs were performed on each unwashed specimen and then the specimen was washed, and five additional test runs were performed. The estimated degree of blinding/clogging resulted from a comparison of the unwashed versus the washed tests, and the percent increase in permittivity due to the washing could then be calculated.

The percent increase in the permittivity is only an approximation. There are several limitations to performing a comparison like this. The unwashed test specimens were disturbed although care was taken to limit the amount of disturbance. The geotextile samples were disturbed when they were first removed from the testpits and placed in the plastic bags. Although the samples were sealed in plastic bags to preserve their moisture content, they still tended to dry out, especially the woven samples which had little moisture in them to begin with. The drying out of the samples greatly effected the silt particles on the woven samples and they could be easily dislodged, such as when the samples were removed from the storage bags as well as other additional handling. When the test specimens were cut from the geotextile samples, additional disturbance occurred. Further disturbance occurred when the test specimens were soaked in water prior to testing and again when they were placed in the permeameter and eventually submerged by the water in the standpipe. Thus, the fine-grained particles, especially silt, could be easily dislodged from the specimens. Also, the woven samples tended to lose their blinded particles much faster and easier than the clogged nonwoven samples. Therefore, the results of the unwashed permittivity tests should not necessarily be considered representative of the minimum field permittivity value for that sample because of the reasons stated above.

The results of the permittivity tests are summarized in Table 8.2. Washed versus unwashed tests were used for determining the degree of blinding/clogging. The unwashed specimens were supposed to represent the maximum amount of blinding and/or clogging which the geotextile sample had been subjected. The first run for each unwashed test was in all cases the lowest value, as should be expected, since the sample tends to cleanse itself with each subsequent test run. The washed tests were an attempt to show what the original permittivity values were when the geotextile was installed, although it was impractical to remove all the clogged soil particles from between the fibers of the fabric. The percent increase in the permittivity, as shown in Table 8.2, was calculated from the average of the washed test results compared to the first unwashed test run. The results of the unwashed tests for each specimen were not averaged because they increased with each run, and as stated above, the first run was considered the maximum amount of blinding/clogging that the sample had been subjected to.

The manufacturers' typical values and WSDOT conformance test result values, if any, are included in Table 8.2. Several of the retrieved geotextile samples had washed permittivity averages which were comparable to WSDOT's or the manufacturers' values. For example, the tests performed on the samples from Columbia Heights Road, Coal Creek Road, Pacific Way, SR-504, and SR-502 all had washed permittivity averages which compared well with respect to the manufacturers' typical values. The washed test results for the samples from SR-546 and 49th Ave NE compared well with WSDOT conformance test results. The other three sites which had WSDOT conformance test results, SR-14, SR-9 (Marsh Rd.), and SR-16, had washed permittivity averages which were lower. The Carroll Road and Olson Road sites had washed permittivity test results which were much lower than the manufacturers' values. The samples from Carroll Road were probably still somewhat clogged even after washing. The manufacturers' permittivity values for the geotextiles from SR-546 and SR-16 were significantly lower than the washed permittivity results and WSDOT conformance test values.

Table 8.3 summarizes the average percent increases in permittivity for each site. The samples are grouped together in terms of the fabric types. The percent increase ranges for the needle-punched nonwovens (86 - 317 percent) and the woven slit-films (17 - 350 percent) agree reasonably well. Although the needle-punched nonwovens visually appeared to be quite clogged, when compared to the blinding of the woven slit-films, they still performed well in the permittivity tests. It was surprising to see both the heat-bonded nonwovens having the greatest increases in washed permittivities and how well their average permittivity increases agreed with each other (588 and 592 percent).

Table 8.2 - Summary of permittivity test results.

Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Specimen Number	Laboratory Results			Manufacturer's Certified Value Ψ (sec^{-1})	WSDOT Results Ψ (sec^{-1})
			Unwashed 1st test run Ψ (sec^{-1})	Washed (average) Ψ (sec^{-1})	% increase in Ψ		
Columbia Hts Road	Needle-punched Nonwoven 143 (4.2)	1	0.432	1.434	232	1.90	-
		2	0.545	2.004	268		
		3	1.138	2.139	88		
		4	0.704	2.095	198		
				Average	197		
Coal Creek Road	Heat-bonded Nonwoven 136 (4.0)	1	0.210	0.982	368	0.80	-
		2	0.146	2.055	1308		
		3	0.082	0.562	585		
		4	0.538	1.120	108		
				Average	592		
Pacific Way	Needle-punched Nonwoven 153 (4.5)	1	1.130	1.831	62	1.74	-
		2	0.747	1.787	139		
		3	0.440	1.384	215		
		4	0.836	1.627	95		
				Average	128		
SR-14	Woven Slit-film 231 (6.8)	1	0.0075	0.0566	655	0.15	0.1293
		2	0.0188	0.0596	217		
		3	0.0113	0.0525	365		
		4	0.0209	0.0541	159		
				Average	349		
SR-9 (Marsh Rd)	Woven Slit-film 163 (4.8)	1	0.0686	0.1032	50	0.15	0.163
		2	0.0204	0.0784	284		
		3	0.0580	0.0889	53		
		4	0.0473	0.1005	112		
				Average	125		

Table 8.2 (continued) - Summary of permittivity test results.

Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Specimen Number	Laboratory Results: Unwashed 1st test run Ψ (sec^{-1})	Laboratory Results: Washed (average) Ψ (sec^{-1})	Laboratory Results: % increase in Ψ	Manufacturer's Certified Value Ψ (sec^{-1})	WSDOT Results Ψ (sec^{-1})
SR-546	Woven Slit-film 149 (4.4)	1	0.1446	0.1540	7	0.05	0.1764
		2	0.1596	0.1815	14		
		3	0.0820	0.1120	37		
		4	0.1564	0.1733	11		
				Average	17		
Carroll Road	Heat-bonded Nonwoven 136 (4.0)	1	0.045	0.387	760	0.80	-
		2	0.014	0.122	771		
		3	0.079	0.412	422		
		4	0.045	0.224	398		
				Average	588		
SR-504	Needle-punched Nonwoven 251 (7.4)	1	0.669	1.288	93	1.63	-
		2	0.875	1.552	77		
		3	0.697	1.261	81		
		4	0.874	1.696	94		
				Average	86		
49th Ave NE	Woven Slit-film 153 (4.5)	1	0.0299	0.0902	202	0.2	0.0914
		2	0.0101	0.0681	574		
		3	0.0236	0.0775	228		
		4	0.0531	0.2641	397		
				Average	350		
SR-16	Woven Slit-film 149 (4.4)	1	0.119	0.198	66	0.05	0.4743
		2	0.219	0.318	45		
		3	0.270	0.359	33		
		4	0.079	0.185	134		
				Average	70		

Table 8.2 (continued) - Summary of permittivity test results.

Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Specimen Number	Laboratory Results			Manufacturer's Certified Value Ψ (sec^{-1})	WSDOT Results Ψ (sec^{-1})
			Unwashed 1st test run Ψ (sec^{-1})	Washed (average) Ψ (sec^{-1})	% increase in Ψ		
SR-502	Needle-punched Nonwoven 153 (4.5)	1	0.584	1.713	193	1.74	-
		2	0.307	1.454	374		
		3	0.273	1.244	356		
		4	0.524	1.636	212		
				Average	284		
Olson Road	Needle-punched Nonwoven 204 (6.0)	1	0.504	1.744	246	2.18	-
		2	0.583	1.568	169		
		3	0.236	1.656	602		
		4	0.468	1.644	251		
				Average	317		
SR-9 (Sumas)	Woven Slit-film 122 (3.6)	1	0.0614	0.1898	209	0.0525	-
		2	0.0378	0.0933	147		
		3	0.0691	0.1615	134		
		4	0.0592	0.1203	103		
				Average	148		

Table 8.3 - Average percent increase in the permittivity (Ψ) for each sample.

Fabric Type	Site Name	Weight g/m^2 (oz/yd^2)	Range of Ψ Percent Increase Values	Average Ψ Percent Increase
Needle-punched Nonwovens	Columbia Hts Road	143 (4.2)	88-268	197
	Pacific Way	153 (4.5)	62-215	128
	SR-504	251 (7.4)	77-94	86
	SR-502	153 (4.5)	193-374	284
	Olson Road	204 (6.0)	169-602	317
Heat-bonded Nonwovens	Coal Creek Road	136 (4.0)	108-1308	592
	Carroll Road	136 (4.0)	398-771	588
Woven Slit-films	SR-14	231 (6.8)	159-655	349
	SR-9 (Marsh Rd.)	163 (4.8)	50-284	125
	SR-546	149 (4.4)	7-37	17
	49th Ave NE	153 (4.5)	202-574	350
	SR-16	149 (4.4)	33-134	70
	SR-9 (Sumas)	122 (3.6)	103-209	148

In order to check how the washing process might have affected the permittivity test samples, five control tests were performed. Five different and new fabric types were selected and tests were performed in the same manner as the retrieved specimens were tested. Thus, the new control specimens were tested unwashed and then they were washed and tested again to observe the differences in the permittivity values. The results of the control tests are presented in Table C.14 of Appendix C. The results are summarized in Table 8.4.

Table 8.4 - Summary of the control specimen permittivity (Ψ) test results.

Specimen	Fabric Type and Weight g/m^2 (oz/yd^2)	Average Ψ (sec^{-1}) Unwashed	Average Ψ (sec^{-1}) Washed	% Change in Ψ after washing
1	Heat-bonded nonwoven 136 (4.0)	1.4349	1.5024	+4.7
2	Needle-punched nonwoven 214 (6.3)	2.1600	2.3020	+6.5
3	Needle-punched nonwoven 407 (12.0)	1.2348	1.2383	+0.3
4	Woven slit-film 204 (6.0)	0.1595	0.1575	-1.3
5	Woven slit-film 163 (4.8)	0.0925	0.0935	+1.1

The percent changes in permittivity for control specimens 3, 4, and 5, in Table 8.4, are small and fairly insignificant when compared to the percent increases shown in Table 8.3. The percent changes for control specimens 1 and 2 were 4.7 percent and 6.5 percent, respectively, and are small when compared to the values of similar fabrics in Table 8.3. Slight changes in the structure of the yarns of each specimen may result from the washing process. Also, just taking the specimens out and placing them back in the permeameter will likely change the permittivity values to some extent. This is because when the specimens are placed back in the permeameter, they will likely be clamped with a slightly different fabric area being tested and due the inherent differences in the pore space openings of each fabric the permittivity values may change a little. Therefore, the washing procedures had negligible influence on the results of the permittivity tests.

8.4.4 Grab Tensile Test Results

The results of the grab tensile tests are presented in Appendix D. Table 8.5 summarizes the results of the grab tensile tests. Six grab tensile tests were performed on each retrieved sample for all the sites except for the severely damaged geotextile from the Columbia Heights Road (testpit 1) site. The six test specimens from each sample were randomly selected so that the actual average strength of the samples could be determined. The retained strength values does not discriminate against any type of degradation (i.e. physical, chemical, biological, etc.) to which the geotextiles may have been subjected. The laboratory test results presented in Table 8.5 are the averages of the six tests performed on each retrieved geotextile. The manufacturers' typical values and WSDOT conformance test results, if any, are also presented in Table 8.5. The percent strength retained was determined for both the manufacturers' and WSDOT values. The retained strength is intended to indicate the average strength of the retrieved geotextiles after a period of time under the roadways. The percent retained strengths, as shown in Table 8.5, are the result of comparing the laboratory average value to the manufacturers' and/or WSDOT values.

In the following comparisons, the percent retained strengths using WSDOT test results were given priority over the manufacturer's typical values because the WSDOT test results should be more indicative of the fabrics original strength. The results indicate

Table 8.5 - Summary of grab tensile test results.

Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Laboratory Results	Manufacturer's Typical Values		WSDOT Test Results	
		Grab Tensile kN (lb)	Grab Tensile kN (lb)	% Grab Retained	Grab Tensile kN (lb)	% Grab Retained
Columbia Hts Rd.	NP NW 143 (4.2)	0.374 (84.0)	0.601 (135)	62	–	–
Coal Creek Rd.	HB NW 136 (4.0)	0.384 (86.4)	0.645 (145)	60	–	–
Pacific Way	NP NW 153 (4.5)	0.477 (107.3)	0.579 (130)	83	–	–
SR-14	W-SF 231 (6.8)	1.131 (254.3)	1.558 (350)	73	1.687 (379)	67
SR-9 (Marsh Rd)	W-SF 163 (4.8)	1.085 (244.0)	1.024 (230)	106	1.024 (230)	106
SR-546	W-SF 149 (4.4)	1.015 (228.0)	1.024 (230)	99	1.077 (242)	94
Carroll Road	HB NW 136 (4.0)	0.127 (28.7)	0.645 (145)	20	–	–
SR-504	NP NW 251 (7.4)	0.969 (217.9)	1.202 (270)	81	–	–
49th Ave NE	W-SF 153 (4.5)	0.550 (123.6)	0.890 (200)	62	1.086 (244)	51
SR-16	W-SF 149 (4.4)	0.813 (182.8)	1.024 (230)	80	0.863 (194)	94
SR-502	NP NW 153 (4.5)	0.443 (99.5)	0.579 (130)	77	–	–
Olson Rd.	NP NW 204 (6.0)	0.698 (157.0)	1.055 (237)	66	–	–
SR-9, Sumas	W-SF 122 (3.6)	0.501 (112.6)	0.668 (150)	75	–	–

NP NW - Needle-punched nonwoven **HB NW - Heat-bonded nonwoven** **W-SF - Woven Slit-film**

that three sites, SR-9 (Marsh Rd.), SR-546, and SR-16 retained virtually all of their original strength (>94%). The samples from Pacific Way, SR-504, SR-502, and SR-9 (Sumas) also appear to have survived reasonably well with retained strengths greater than 70 percent. As would be expected, the sites with moderate to severe damage, as discussed in Chapter 7, had the lowest (< 70) percent retained values. These sites were Columbia Heights Road (testpit 1a), Coal Creek Road, Carroll Road, 49th Ave NE, and Olson Road. The only exception was the fabric from the SR-14 site which only retained 67 percent of its strength although it only experienced minor damage. Abrasions may have played a roll in the lower retained strength since the fabric was installed under an angular base material. The sample from Carroll Road retained only 20 percent of its strength while the others retained between 50 and 66 percent of their original strengths.

8.4.5 Wide Width Strength Test Results

The results of the wide width tests are presented in Appendix D and they are summarized in Table 8.6. Six wide width strength tests were also performed on each retrieved geotextile sample for all the sites except for the severely damaged geotextile from the Columbia Heights Road (testpit 1) site. The six test specimens from each sample were also randomly selected so that the actual average strength of the samples could be determined. The retained strength values does not discriminate against any type of degradation (i.e. physical, chemical, biological, etc.) to which the geotextiles may have been subjected. The laboratory test results presented in Table 8.6 are the averages of the six tests performed on each retrieved geotextile. No WSDOT wide width conformance tests were performed on the originally installed geotextiles for any of the sites. The manufacturers' seldom publish wide width test data for geotextiles intended for separator applications. Therefore, no manufacturers' or WSDOT values are presented in Table 8.6 and percent retained strength values could not be determined. However, there was information available for three of the sites; Columbia Heights Road, SR-504, and Olson Road. The published wide width data for these sites was 10.9 kN/m, 17.1 kN/m, and 14.4 kN/m, respectively. These values result in percent retained strengths of 43, 89, and 71 percent, respectively.

Table 8.6 - Summary of wide width strength test results.

Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Laboratory Test Results	
		Average Strength kN/m (lb/in)	Average % Elongation
Columbia Hts Road	NP NW 143 (4.2)	4.7 (26.7)	37.2
Coal Creek Road	HB NW 136 (4.0)	4.8 (27.3)	26.6
Pacific Way	NP NW 153 (4.5)	5.1 (29.0)	74.4
SR-14	W-SF 231 (6.8)	25.5 (145.5)	12.6
SR-9 (Marsh Rd.)	W-SF 163 (4.8)	28.3 (161.4)	22.7
SR-546	W-SF 149 (4.4)	24.7 (140.9)	23.6
Carroll Road	HB NW 136 (4.0)	2.4 (13.7)	7.5
SR-504	NP NW 251 (7.4)	15.3 (87.5)	49.3
49th Ave NE	W-SF 153 (4.5)	13.6 (77.7)	9.2
SR-16	W-SF 149 (4.4)	20.1 (114.6)	16.4
SR-502	NP NW 153 (4.5)	7.0 (39.7)	37.5
Olson Road	NP NW 204 (6.0)	10.2 (58.1)	42.0
SR-9 (Sumas)	W-SF 122 (3.6)	12.3 (70.3)	13.4

NP NW - Needle-punched nonwoven
HB NW - Heat-bonded nonwoven
W-SF - Woven Slit-film

CHAPTER 9

ANALYSIS OF THE SITE INVESTIGATIONS AND TEST RESULTS

Fourteen geotextile separators were recovered from testpits at 13 sites in western Washington. The 14 geotextile separators which were retrieved consisted of six woven slit-films (122 to 231 g/m²), six needle-punched nonwovens (143 to 251 g/m²), and two heat-bonded nonwovens (136 g/m²). The geotextile types and installation conditions are summarized in Tables 4.1 and 5.1. Information with respect to survivability and/or filtration and drainage was obtained, and an analysis of the site investigations, laboratory tests, and general observations are presented in the following sections. Although the focus of the study was directed towards the short-term (survivability) and long-term (filtration/drainage) performance of the separators and their effect on the long-term pavement performance, two additional topics will also be discussed: subgrade conditions and durability of the geotextiles.

9.1 SUBGRADE CONDITIONS

During construction, the subgrades at all the sites, except the SR-502 site, supposedly consisted of soft silts and clays. The SR-502 site reportedly had silty soils, but no unusually bad conditions. Although all the subgrades consisting of silt and/or clay were soft during construction, they were well consolidated at the time of the site investigations. No high water table levels were encountered in any of the testpits.

A few of the sites had subgrade conditions which were not ideal for evaluating the long-term performance of the separators. Two sites, SR-547 and Carroll Road, had base material mixed in with the subgrade soils. The subgrade soils in the testpit on Coal Creek Road consisted primarily of wood debris, although silty soils were more prevalent on the north side of the testpit. The subgrade soils in the testpit on SR-14 consisted of sands and gravels, while approximately one-half of the testpit at the 49th Ave NE site consisted of a sandy trench backfill material. Although the testpit at the SR-9 (Marsh Rd.) site had a silty subgrade, it was covered with a mat of grasses and small plants.

The subgrade encountered in testpit 1, on Columbia Heights Road, was obviously soft during construction. The evidence of the large ruts in the subgrade and the "mushroomed" clay intrusions into the base course, through rips in the geotextile, suggested that poor subgrade conditions existed during construction. But with time, the subgrade consolidated so that at the time of the investigation, the subgrade unconfined strength using the pocket penetrometer was generally greater than 400 kPa (~4 tsf).

Although the subgrade soil at the Carroll Road site had base material mixed in with it, there continued to be a history of bad performance prior to the installation of the geotextile separator. Apparently, additional layers of aggregate which were added to the unpaved roadway continually became contaminated with fines from the subgrade soils. This situation persisted until the separator was installed and the roadway paved. The separator may have aided in the consolidation process of the subgrade while preventing further subgrade soil intrusion into the base material. Also paving the surface would reduce any adverse effects of atmospheric conditions (rainfall, humidity, etc.). Similar conditions were encountered at the SR-546 site.

The consolidated conditions of the subgrades may have been due to (1) the time of the year in which they were excavated (a dry period), (2) the overburden pressure from the roadway, (3) the drainage of surface waters away from the roadway, (4) decreased infiltration of rainfall because of the paved surface, and (5) a combination of any of these reasons.

Table 9.1 list the sites which had native soils directly under the separator. Included in this table are the native soils found at the SR-9 (Marsh Rd.), 49th Ave NE (north side), and Coal Creek Road (after sieving out the organics) sites. The purpose of Table 9.1 is to show how WSDOT's required AOS value for separators compares to actual subgrade soils which required a separator. The D_{85} values for each subgrade soil were determined from the grain size distribution curves shown in Appendix B. Also included in Table 9.1 is the recommended maximum AOS value for nonwovens ($AOS \leq 1.8 \cdot D_{85}$) from Christopher and Holtz (1989). They suggested for wovens an $AOS \leq D_{85}$. In either case, wovens or nonwovens, they suggested an $AOS \leq 0.3$ mm. Task Force 25 (1989) recommended an $AOS \leq 0.3$ mm, for all fabrics, for soils with greater than 50 percent passing the No. 200

US sieve. WSDOT currently requires an AOS ≤ 0.42 mm for all soil conditions and for any type of fabric.

Table 9.1 - Subgrade soil D_{85} values.

Site	Percent Passing the No. 200 Sieve	D_{85} (mm)	$1.8 \cdot D_{85}$ (mm)
Columbia Heights Rd. (testpit 1)	94	0.05	0.09
Columbia Heights Rd. (testpit 1a)	96	0.053	0.095
Coal Creek Road	84	0.08	0.14
Pacific Way	49	0.20	0.36
SR-9 (Marsh Rd.)	56	0.30	0.54
SR-504	96	0.054	0.1
49th Ave NE (north side)	56	0.85	1.5
SR-16	98	0.039	0.07
SR-502	65	0.21	0.38
SR-9 (Sumas) grey subgrade soil	59	0.14	0.25

As can be seen, all the D_{85} values, except for the 49th Ave NE site, which was a sandy silt, fall well below WSDOT's required value. For the SR-9 (Marsh Rd.) site, WSDOT's conformance tests had AOS results of 0.31, 0.35, and 0.46 mm for the woven fabric, all of which do not meet either Christopher and Holtz (1989) or Task Force 25 (1989) recommended values. If these soils are typical of the subgrade soils encountered in western Washington, and require the use of geotextile separators, then the current WSDOT required AOS value should be reevaluated. Based on the native subgrade soils encountered in this study, an AOS value of 0.3 mm for all fabrics, or 0.5 mm for nonwovens and 0.3 for wovens, would be consistent with the data.

9.2 SURVIVABILITY

The subgrade, base, initial lift thickness, and construction equipment used (if known), were described for all the sites in Chapter 5 and summarized in Table 5.1. To assess the survivability conditions which existed at each site during the time of construction, Task Force 25's (1989) guidelines were used. The estimated survivability levels are shown in Table 9.2 along with most of the construction information from Table 5.1.

As shown in Table 9.2, the only site which had a "not recommended" survivability level was the site on Carroll Road. Not only was there angular crushed rock in the subgrade and a relatively thin vibratory compacted initial lift used, but the trucks dumped large angular base material directly on the fabric and they were permitted to travel directly on the fabric, with no cover, while placing the initial lift. The contractor at the Coal Creek Road site also end-dumped the large crushed rock directly onto the fabric, but very thick initial lifts were used and the subgrade consisted of organic debris. This site had an estimated high survivability rating. The other sites having estimated high survivability ratings were the Columbia Heights Road, SR-14, and Olson Road sites. The Columbia Heights Road site might have actually had a very high (or not recommended) survivability condition due to the amount of rutting which was found in testpit 1, and the relatively thin compacted initial lifts which were used. All the other sites were given medium survivability ratings due to thick initial lifts, rounded backfill material, and/or higher initial subgrade strengths.

Table 9.2 - Summary of survivability levels (Task Force 25, 1989), installation conditions, and geotextile damage.

Site Name	Geotextile & Weight g/m^2 (oz/yd^2)	Subgrade material	Basecourse Material	Initial Lift Thickness (cm)	Geotextile Damage	Estimated Survivability Level
Columbia Hts Rd (testpit 1a)	NP NW 143 (4.2)	Lean clay	CSBC	23	Moderate to Heavy	High
Columbia Hts Rd (testpit 1)	NP NW 143 (4.2)	Lean clay	CSBC	23	Severe	High
Coal Creek Rd	HB NW 136 (4.0)	Wood debris and silt	Angular coarse gravel/cobbles	50 to 60	Heavy	High
Pacific Way	NP NW 153 (4.5)	Clayey sand	CSBC	33	Minor	Medium
SR-14	W-SF 231 (6.8)	Gravel with sand	CSBC	15 to 18	Minor	High
SR-9 (Marsh Rd.)	W-SF 163 (4.8)	Organics over silt	Sand with gravel	60	None	Medium
SR-546	W-SF 149 (4.4)	Gravel with silt and sand	Sand with gravel	30	Minimal	Medium
Carroll Rd	HB NW 136 (4.0)	Gravel with clay and sand	Angular coarse gravel/cobbles	23 to 33	Severe	Not Recommended
SR-504	NP NW 251 (7.4)	Silt	Sand with gravel/cobbles	60	None	Medium
49th Ave. NE	W-SF 153 (4.5)	Sandy silt	Sandy gravel	23 to 25	Moderate	Medium
SR-16	W-SF 149 (4.4)	Lean clay	Sandy gravel	30	None	Medium
SR-502	NP NW 153 (4.5)	Lean clay	Sand with some gravel	30	None	Medium
Olson Rd.	NP NW 204 (6.0)	Silty sand	CSBC	23	Moderate	High
SR-9 (Sumas)	W-SF 122 (3.6)	Silt and sand	Sand and gravel	18 to 20	Minor	Medium

NP NW - Needle-punched nonwoven HB NW - Heat-bonded nonwoven W-SF - Woven slit-film

9.2.1 Damage

The degree of damage experienced by the separators varied greatly, although there were no real surprises when the survivability conditions were taken into account. A damage survey was performed on each of the recovered fabrics, and the results were discussed in Chapter 7. Most of the damage sustained by the geotextiles was in the form of punctures which occurred due to both, base aggregate penetration into the subgrade and/or penetration of angular gravels, from the subgrade, up into the base material.

The recovered 143 g/m^2 needle-punched nonwoven geotextile from testpit 1a on Columbia Heights Road was the only fabric which sustained significant damage which was not in the form of punctures. As shown in Figures 5.7 and 5.8, the damage was in the form of small (2-3 mm average diameter), round holes. These holes came from the overlying aggregate and occurred at the aggregate/fabric contact points. The majority of the holes occurred on the part of the overlap where the 143 g/m^2 fabric was on top of the thicker 200 g/m^2 fabric. It appears that the thicker underlying fabric acted as a stiffer upper layer which prevented the overlying aggregate from penetrating into the soft subgrade material. Therefore, at the contact points between the aggregate and lightweight fabric the aggregate would apparently vibrate around under dynamic stresses caused by construction equipment and/or vehicles during the in-service use of the roadway. Thus, instead of punctures, the vibrating aggregate caused damage in the form of small round holes. On the other end of the testpit without the underlying thicker fabric, the 143 g/m^2 fabric had numerous indentations which resulted from the overlying aggregate trying to penetrate into the soft subgrade. Apparently the elongation characteristics of the geotextile prevented holes from occurring while still performing the separation function. The aggregate in this area was unable to move around due to their imbedded position in the subgrade.

The separators from the Carroll Road and Columbia Heights Road (testpit 1) sites had severe damage but they were installed under not recommended and high (or possibly even not recommended) survivability conditions, respectively. Two other separators experienced heavy damage. They were from the Columbia Heights Road (testpit 1a) and the Coal Creek Road sites, both of which were installed under high survivability conditions. The heaviest weight (231 g/m^2) woven fabric was installed under high survivability conditions at the SR-14 site, and it experienced minor damage. This was the only woven fabric installed under high survivability conditions. The only other two separators which experienced significant damage, that being moderate, were the from the 49th Ave NE and Olson Road sites, which were installed under medium and high survivability conditions, respectively. The geotextile from the Olson Road site was the heaviest weight (204 g/m^2) nonwoven fabric installed under higher survivability conditions.

It is interesting to note that the four geotextiles which had no damage were all installed with 30 cm minimum initial lift thicknesses and with subrounded gravel and sand backfill material. No geotextile installed under an angular cover material experienced less than minor damage. The fabric at the SR-546 site (149 g/m^2 woven slit-film) was installed under a 30 cm initial lift of subrounded base material and experienced only minimal damage.

Five of the recovered geotextile separators were installed under similar medium survivability conditions, with 30 cm or greater initial lift thicknesses and subrounded gravel and sand base materials: SR-9 (Marsh Rd.), SR-546, SR-504, SR-16, and SR-502. All of these geotextiles survived very well with minimal or no damage. The fabric from SR-546 site sustained minimal damage which likely resulted from the gravel which was in the subgrade. The other four sites all had silt and/or clay subgrades.

The 122 g/m^2 woven geotextile separator from the SR-9 (Sumas) site also had a subrounded gravel and sand backfill, but an 18 to 20 cm initial lift thickness was placed over it. This lightweight separator survived the medium construction survivability conditions reasonably well, with only minor damage. Although this was a lightweight woven fabric, the installation conditions probably would not have damaged a similar lightweight nonwoven fabric (opinion). This is contrary to Page's (1990) conclusion that no lightweight (118 g/m^2) nonwoven fabric should be used in separation applications regardless of backfill type or initial lift thickness. It is the author's opinion that no lightweight separator (< 200 g/m^2) should be used under angular backfill with initial lift thicknesses less than 45 cm. However, in most cases the same lightweight separators could probably be used under medium site survivability conditions with rounded backfill materials and initial lift thicknesses greater than 30 cm. The only other two separators installed under medium survivability conditions (Pacific Way and 49th Ave NE sites) sustained minor and moderate damage, respectively.

Four recovered geotextiles were installed under similar high survivability conditions, which included 15 to 23 cm initial lift thicknesses of angular base material: Columbia Heights Road (testpits 1 and 1a), SR-14, and Olson Road. However, these fabrics came from testpits with significantly different subgrade conditions which likely accounted for the variety of damage sustained by the fabrics. The fabric from the SR-14 site, which had a dense sand and gravel subgrade, sustained minor damage. The fabric from the Olson Road site was installed over a subgrade which had coarse angular gravel on top of part of it, sustained moderate damage. The geotextile from the Columbia Heights Road site was installed over soft pumping clays and it sustained moderate to severe damage.

The only heavier weight separators (>200 g/m^2) which were installed under high survivability conditions were at the SR-14 (231 g/m^2 woven slit-film) and Olson Road (204 g/m^2 needle-punched nonwoven) sites. These separators sustained minor and moderate damage, respectively. The four lighter weight fabrics (<150 g/m^2) which were installed under high and not recommended survivability conditions sustained moderate to severe damage. This would suggest that separators with weights less than 240 g/m^2 and installed under high site survivability conditions will sustain damage to some degree and separators with weights less than 200 g/m^2 should not be considered at all for use in high survivability conditions.

9.2.2 Retained Strength

The damage survey performed in Chapter 7 and summarized in Figure 9.1 shows the results of the retained grab tensile strength (Table 8.5) as a function of percent hole area (Table 7.1) for the 13 tested fabrics. The trends showed decreasing retained strength of the fabric with increasing damage, as should be expected. Since the data was plotted on a semi-log graph, the zero percent hole area was assigned to the 0.001 logarithmic value for presentation purposes.

The results shown in Figure 9.1 are similar to those found by Koerner and Koerner (1988 and 1990). They plotted their results as a function of the number of holes greater than 6 mm, rather than the percent hole area. Thus, a hole 30 mm in diameter would have the same credit as a hole 6 mm in size. It would seem to be more meaningful to plot the percent retained strength as a function of the percent hole area of each fabric. The holes included in the estimate should also be much smaller than 6 mm since in the case of woven fabrics, many slit tapes are approximately 1 mm wide, and therefore a 6 mm wide hole would include six slit tapes. The results shown in Figure 9.1 include holes down to approximately 1 mm in size. This appeared to be more meaningful, since a fabric can be heavily damaged with holes less than 6 mm in size. A good example is the fabric from Columbia Heights Road (testpit 1a), where the average sized hole was 2 to 3 mm; yet the fabric was heavily damaged in some areas.

Although the damage is plotted differently as compared to Koerner and Koerner (1988 and 1990) the results are still similar.

It is interesting to note, that of the four fabrics which had no damage, the two woven fabrics had higher percent retained strengths as compared to the two needle-punched nonwoven geotextiles. Although the heat-bonded nonwovens had the highest percent hole areas, the fabric from the Coal Creek Road site had reasonable retained strength values which could be partially attributed to the fact that most of the holes in the fabric were quite large and the test specimens were not taken in those areas. The fabric from the Carroll Road site had numerous very uniform holes and the retained strength values are quite indicative of its present condition.

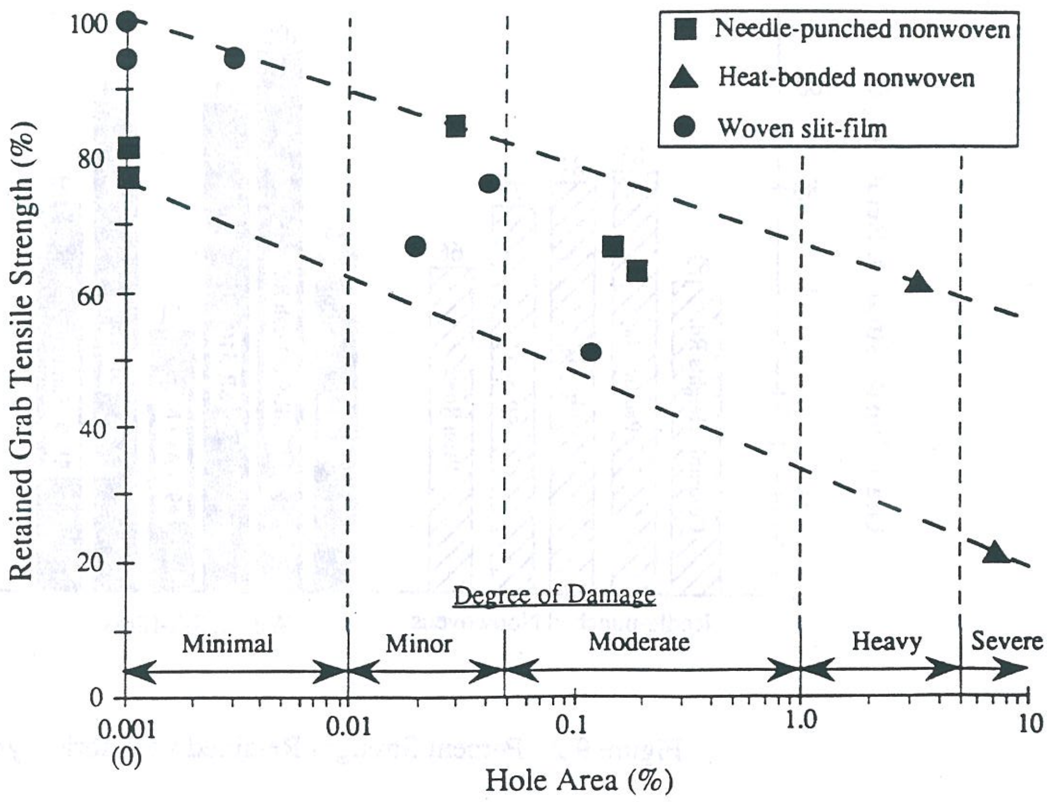

Figure 9.1 - Percent Retained Strength vs. Percent Hole Area.

The average percent retained strength for each fabric was also plotted as a function of the type of fabric, as shown in Figure 9.2. As can be seen in this figure, the retained strength values for the needle-punched nonwovens and the woven slit-films as somewhat similar, although the woven fabrics had the three highest retained strengths. Also shown are the two low retained strength values for the heat-bonded fabrics. The estimated survivability levels for each site at the time of installation (Table 9.2) must also be taken into account when assessing the short-term performances of the fabrics.

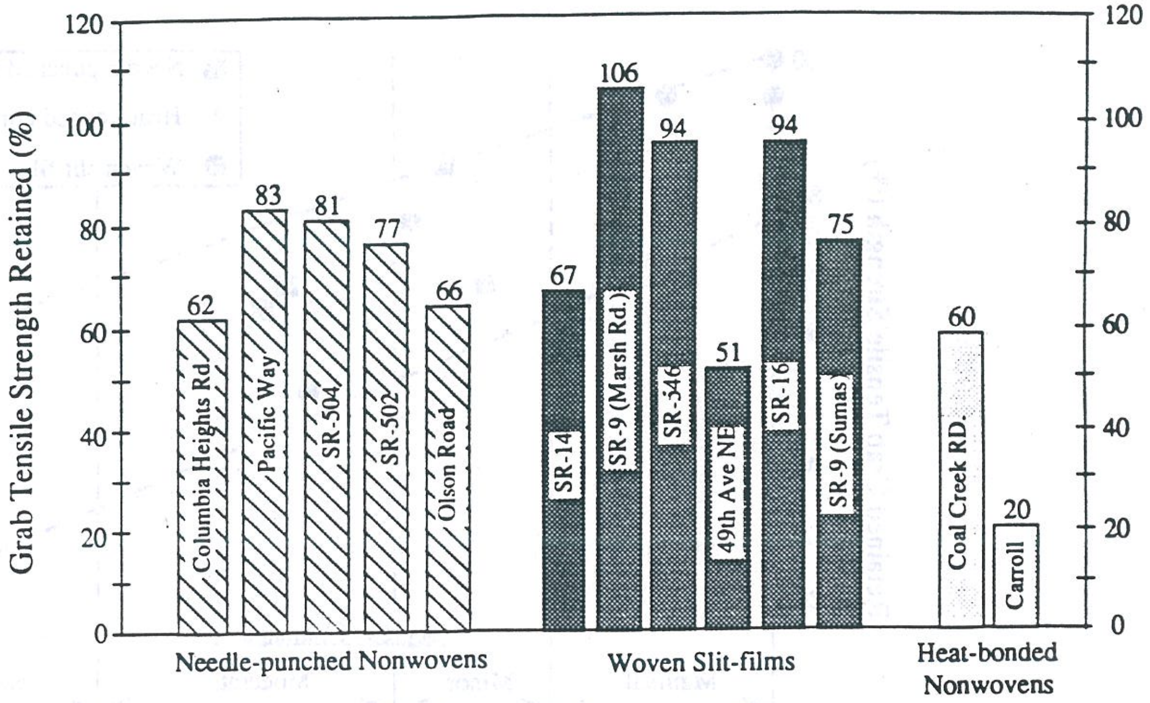

Figure 9.2 - Percent Strength Retained vs. Fabric Type.

It is interesting to note that of the seven fabrics which had greater than 70 percent retained strengths, six of them were installed under rounded to subrounded base materials. The only exception was the fabric which was recovered from the Pacific Way site. Even the fabrics from SR-546, which had gravels in the subgrade, and SR-9 (Sumas), which had a thin initial lift, still retained a relatively high percentage of their strengths. However, all the sites which had an angular aggregate placed over the fabric also had the thinner initial lifts. In any event, this may indicate that the type of base aggregate is more important than the initial lift thickness, and therefore both must be designed for. Paulson (1990) reached similar conclusions.

Although the elongations at failure, which were recorded during the grab tensile strength tests, were not included in the summary tables in Chapter 8, they are provided in Appendix D. The results indicated that the woven slit-films retained between 47 and 81 percent of their original elongations (which were assumed to be the manufacturers' typical values). The two undamaged woven slit-films, from the SR-9 (Marsh Rd.) and SR-16 sites, had 106 and 94 percent retained strengths respectively, but only 68 and 66 percent retained elongations, respectively. This could indicate potential brittle behavior with time for the polypropylene woven fabrics. All of the needle-punched nonwoven fabrics, except for the Pacific Way fabric, retained between 55 to 81 percent of their original elongation values. The Pacific Way fabric retained over 100 percent of its original elongation. The two undamaged needle-punched nonwoven fabrics from the SR-504 and SR-502 sites had 81 and 77 percent retained strengths, respectively, and 72 and 55 percent retained elongation values, respectively. The two heat-bonded nonwovens from the Coal Creek Road and Carroll Road sites, which were heavily damaged, had 60 and 20 percent retained strengths, respectively, and 52 and 23 percent retained elongations, respectively.

9.3 FILTRATION/DRAINAGE

9.3.1 Washed Permittivity Test Results

Permittivity tests were conducted in the laboratory to obtain information on the general blinding/clogging characteristics of the recovered geotextiles. The results of the permittivity tests are summarized in Figure 9.3. In this figure, the results are presented as percent permittivity increase after washing versus the type of geotextile. As can be seen, the needle-punched nonwovens and the woven slit-films had similar performances. The two needle-punched nonwovens with the greatest increases, from the SR-502 and Olson Road sites, were installed over lean clay and silty sand subgrades, respectively. The woven fabrics with the greatest washed permittivity increases had a significant amount of caking on the fabrics. Both of the heat-bonded nonwovens showed the highest increases in the washed permittivities. Even the heat-bonded fabric overlying the organic debris at the Coal Creek Road site had a high washed permittivity increase. This would indicate that the heat-bonded nonwovens were more susceptible to clogging than the other fabrics.

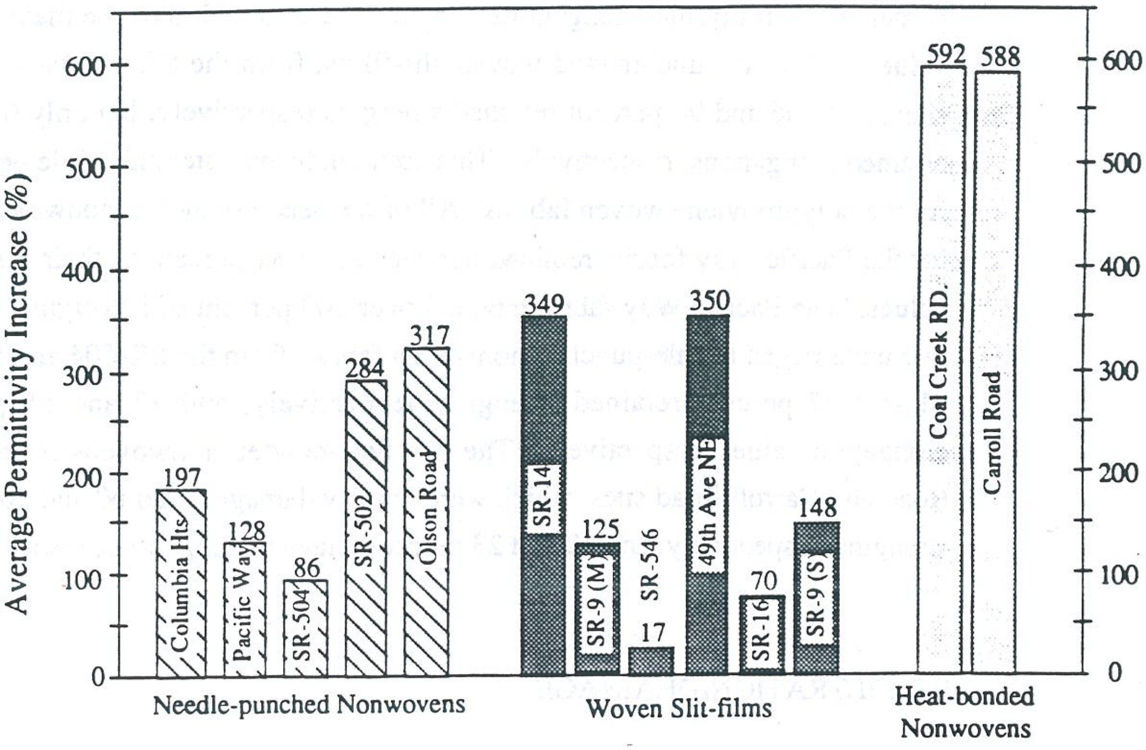

Figure 9.3 - Average Percent Permittivity Increase (after washing) vs. Fabric Type.

9.3.2 Blinding/Clogging

Although the woven slit-films and needle-punched nonwoven fabrics had similar average percent increases (Fig. 9.3), the wovens had lower increases because they were disturbed the most prior to testing. Observations indicated that the wovens were most susceptible to blinding. However during the course of handling, after they were exhumed and prior to testing, a great deal of the blinded particles (generally silt) fell off the fabric, especially after they lost even a small amount of moisture. Also, just removing the woven slit-films from the subgrade probably stripped most of the blinded particles away from the fabric. On the contrary, the needle-punched nonwovens were most susceptible to clogging and little material was lost while handling the fabric, because the soil particles were trapped within the fibers of the geotextile. Thus, the permittivity values for the needle-punched nonwovens were probably good indicators of their undisturbed hydraulic characteristics, while the permittivity values for the woven slit-films were only indicative of the material which remained on the fabric. This would indicate that only small pore space reductions, by blinding, clogging, or caking, can significantly drop the permeability of the woven slit-film geotextiles to well below WSDOT's required minimum value of 0.005 cm/sec (discussed in subsection 9.3.5).

Page (1990) had similar conclusions with respect to blinding of woven slit-film fabrics. As shown in Table 2.6, he found one woven slit-film (Fallon to Palouse) to be severely blinded with fine soil particles. This fabric had washed permittivity increases up to almost 5,000 percent, and the average washed permittivity increase of the three tests was close to 2,000 percent.

Generally the nonwoven geotextiles were clogged, rather than blinded. Some of the needle-punched fabrics visually appeared to be moderately to severely clogged (e.g. Columbia Heights Rd., Carroll Road, SR-504, Olson Road), as shown in Table 7.1. However, the needle-punched nonwovens had washed permittivity increases around 300 percent or less, and the permeabilities of the fabrics were still quite high. The two heat-bonded nonwovens appeared to be the most susceptible to detrimental clogging because of the higher, almost 600 percent, washed permittivity increases, and their permeabilities are lower to begin with.

Clogging of the fabrics occurred at the contact points of the base aggregate and the subgrade at the Carroll Road and Olson Road sites. There were several instances where there were clean or relatively clean spots on the fabric in between aggregate/soil contact points. At the Olson Road site the clean spots occurred where the fabric bridged across some of the large rocks on the subgrade surface, thus preventing contact with the subgrade soils.

9.3.3 Caking

There were three sites which had woven slit-film fabrics with a significant amount of caking on the upper surface of the geotextiles: SR-14, 49th Ave NE, and SR-16. The laboratory observations (Table 7.1) indicated that these sites had 10-30, 25-50, and 0-10 percent blinding, respectively, while having 50-75, 40-50, and 25-50 percent caking, respectively. The results from the permittivity tests definitely indicates that caking on the fabrics also prevents the flow of water through the pores. This occurred even though the fabrics were placed in the permeameter in such a way as to simulate upward flow from the subgrade through the geotextile. The results would indicate that both blinding (as well as clogging) and caking can diminish the permittivity of woven slit-films.

The grain size analyses did not indicate conclusive evidence of subgrade fines migration up through the geotextile separators at any of the sites. However, as mentioned previously, the grain size analyses for four of the sites did indicate small increases in the fines content in the base material immediately above the geotextile. Significant caking was discovered on the surface of three woven slit-film geotextiles, although there was also no conclusive evidence that the caking was the result of subgrade fine migration. Two of the sites, SR-14 and SR-16, which had significant caking also had higher fines contents in the base material immediately above the separator. The fines may have been deposited on the top surface of the geotextile during construction. Rathmayer (1980) also noted fines on top of fabrics during his field investigations. Laier and Brau (1986) and Tsai et al. (1993) found evidence of fines migration up through woven slit-film fabrics during their investigations. Although there was no conclusive evidence of subgrade fines migration up through the geotextiles, it cannot be ruled out that caking on the woven slit-films may be the result of subgrade fines migrating up through these woven fabrics due to their larger pore openings.

Although the subgrade soils at the SR-14 site consisted of gravel with sands, it was gap-graded, with 13 percent passing the No. 200 sieve. Carroll (1983) found gap-graded soils to be susceptible to piping which can lead to fabric clogging. But in the case of woven slit-films, the pore sizes may be too large to prevent the soils from passing through them when piping occurs, and the fines could then be deposited on the surface of the fabric.

9.3.4 Iron Staining

Iron staining was prevalent at several of the sites, as indicated in Table 7.2. Iron staining was most obvious and more wide spread on the needle-punched fabrics (e.g. Columbia Heights Rd., Pacific Way, SR-502). Although the needle-punched fabrics might appear to suffer greater reductions in permittivity because of the wide spread staining on the fabrics, they probably do not. This is because the needle-punched nonwoven fabrics have more pore spaces due to their three-dimensional structure and the iron stains appear to be just "stains" on and within the fabric and do not indicate significant reductions in the pore sizes. However, with respect to the woven slit-film fabrics (SR-9 at Marsh Road, and SR-9 in Sumas) the iron stains were actually iron deposits which could generally be found around or even covering the pore openings. Although the impact of iron staining on the permeability of the fabrics was not assessed in this study, observations indicate that permeabilities of the woven slit-films would be impacted the most.

9.3.5 Comparisons to WSDOT's Permeability Requirements

When reviewing the permeability values for the unwashed and washed permittivity test results in Appendix C, one trend became quite apparent. All of the unwashed tests for the woven slit-films, except for the fabric from SR-546, had permeability values lower than WSDOT's required minimum value of 0.005 cm/s. And even several of the washed tests were still lower than WSDOT's minimum value. Some of the unwashed test results for the woven slit-film fabrics were close to an order of magnitude below WSDOT's minimum value. The only woven slit-film fabric which had water staining on the bottom surface of the geotextile was from the SR-546 site. This also happened to be the only fabric with unwashed permeabilities higher than WSDOT's minimum value, and it had the smallest percent increase in permittivity after washing. The only other fabric to have unwashed test results with permeabilities lower than WSDOT's minimum value was the heat-bonded nonwoven geotextile from the Carroll Road site. All of the needle-punched nonwovens had permeability values much higher than WSDOT's minimum value even when tested unwashed (clogged).

9.4 DURABILITY

Although fabric durability was not one of the objectives of this study, a few observations were made regarding the durability of the recovered geotextiles. In general, all the fabrics appear to have performed well with no indications of chemical or biological degradation. The iron staining which existed on several of the fabrics did not appear to have affected the fabrics' strength properties, although any such effects could not be distinguished from the mechanical damage.

One concern regarding the durability with respect to retained strength was when the two undamaged needle-punched nonwovens (SR-504 and SR-502), rather than the two undamaged woven slit-films, had significantly lower values (Figs. 9.1 and 9.2). The two needle-punched nonwovens were composed of polyester fibers, while the two woven fabrics had polypropylene slit tapes. The lower retained strength values for these two nonwoven polyester fabrics may be due to hydrolysis. The fabric from the SR-504 site was very wet when uncovered, although there was no standing water on the subgrade surface in the testpit. The fabric from the SR-502 site was moist, but not wet. The fabric from the SR-502 site did have significant iron staining on the bottom surface, while the fabric from the SR-504 site had negligible iron staining. On the other hand, as discussed in Section 9.2.2, the two woven slit-film polypropylene fabrics had significantly lower retained elongations at break which may indicate potential brittle behavior with time.

9.5 SEPARATION

All of the recovered geotextiles appeared to be performing their intended separation function well. With the possible exception of the three woven slit-films which had significant caking on their upper surfaces, no subgrade fines migration was found at any of the sites. Even the most damaged geotextiles (e.g. Columbia Heights Road and Carroll Road) still separated the subgrade fines from the overlying base aggregate.

The clay intrusions found in testpit 1 on Columbia Heights Road were the result of subgrade soils pumping up through large tears in the needle-punched nonwoven fabric, rather than fines migration through the fabric structure or through punctures in the fabric.

During construction, the fabric was overstressed by rutting to the point where the deformations exceeded the fabrics elongation potential and therefore the fabric ripped in several areas. The clayey subgrade soils were then able to penetrate up through the tears in the fabric under the pumping action caused by wheel loads of the construction equipment. The clay intrusions then consolidated on top of the separator. There was no evidence of fines migration through the fabric in the areas between the tears.

Although heat-bonded nonwoven fabric from the Carroll Road site was severely damaged, it still successfully separated the subgrade soils from the base aggregate. This site had a history of bad performance prior to the installation of the separator.

Based on the evidence from the investigated sites, it is apparent that damaged geotextiles are still able to perform the required separator application. The geotextile was needed at most of the sites as a construction aide. However, it seemed that once the subgrades stiffened up due to consolidation, then the need for the separator became less critical since subgrade intrusion was less of a problem. If the investigated sites were susceptible to fluctuating groundwater conditions, then the more damaged geotextiles may not perform as well, especially in the long-term.

9.6 PAVEMENT PERFORMANCE

All of the pavements except for the Columbia Heights Road site were in good condition at the time of the site investigations.

The pavement surface at the Columbia Heights Road site had several areas which showed signs of premature failure in the form of fatigue cracking and minor rutting. The ACP in this are was only 35 mm thick (it was to receive an additional asphalt concrete layer shortly after the site investigation was completed), and the base material was approximately 30 to 35 cm thick. For the soft subgrade conditions which existed at the time of construction, the roadway section in this area may not have been adequate to support the traffic loads without prematurely failing.

The two testpits on Columbia Heights Road provided information which would support the conclusion that the thin pavement section on the soft subgrade was the source of the problem rather than the damaged geotextiles. The fact that the intact geotextile separator was under the fatigue cracked pavement area, while the severely damaged separator was under the pavement surface which was in good condition tends to be contradictory. But it shows that the severely damaged separator in this case was not the root of the problem.

REFERENCES

Allen, T.M. (1991) "Determination of long-term tensile strength of geosynthetics: A State-of-the-Art review", *Proceedings of the Geosynthetics '91 Conference*, Atlanta, Vol. 1, pp. 351-379.

Andersson, O., and Jonsson, B. (1984). “A laboratory model study of a plastic fabric at the subgrade-subbase interface”, Department of Highway Engineering, Royal Institute of Technology, Stockholm, Sweden, Bulletin 1984:2, 36 pp.

Ayres, D.J. and McMorrow, J.C. (1980). "Discussion - The filtration behavior of construction fabrics under conditions of dynamic loading", *Geotechnique*, Vol. 30, No. 1, pp. 87-88.

Barksdale, R.D., Brown, S.F. and Chan, F. (1989). "Potential benefits of geosynthetics in flexible pavement system", *National Cooperative Highway Research Program*, Report 315, TRB.

Bell, A.L., McCullough, L.M., and Snaith, M.S. (1982). "An experimental investigation of sub-base protection using geotextiles", *Proceedings of the 2nd International Conference on Geotextiles*, Vol. 2, Las Vegas, pp. 435-440.

Billing, J.W., Greenwood, J.H., and Small, G.D. (1990). "Chemical and mechanical durability of geotextiles", *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*, The Hague, Vol. 2, pp. 621-626.

Bonaparte, R., Ah-Line, C., and Charron, R. (1988). "Survivability and durability of a nonwoven geotextile", *Geosynthetics for Soil Improvement*, Geotechnical Special Publication No. 18, ASCE, pp. 68-91.

Brandl, H. (1982). "Separation function and bearing capacity of non-woven fabrics in special geotechnical practice", *Proceedings of the 2nd International Conference on Geotextiles*, Vol. 2, Las Vegas, pp. 441-446.

Brorsson, I. and Eriksson, L. (1986). "Long-term properties of geotextiles and their function as a separator in road construction", *Proceedings of the 3rd International Conference on Geotextiles*, Vienna, Vol. 1, pp. 93-98.

Carroll, R.G. (1983). "Geotextile filter criteria", *Transportation Research Record 916*, Transportation Research Board, pp. 46-53.

Christopher, B.R. and Holtz, R.D. (1985). *Geotextile Engineering Manual*, U.S. Federal Highway Administration, Washington D.C., Report FHWA-TS-86/203, 1044 pp.

Christopher, B.R. and Holtz, R.D. (1989). *Geotextile Design and Construction Guidelines*, National Highway Institute, U.S. Federal Highway Administration, Washington D.C., Report FHWA-HI-90-001, 305 pp.

Christopher, B.R. and Holtz, R.D. (1991). "Geotextiles for subgrade stabilization in permanent roads and highways", *Proceedings of the Geosynthetics '91 Conference*, Atlanta, Vol. 2, pp. 701-713.

Cicoff, G.A. and Sprague, C.J. (1991). "Permanent road stabilization: low cost pavements, structures and lightweight geotextiles", *Fifth International Conference on Low-Volume Roads*, Transportation Research Board, Vol. 2, pp. 294-310.

Colin, G., Mitton, M.T., Carlsson, D.J. and Wiles, D.M. (1986). "The effect of soil burial exposure on some geotechnical fabrics", *Geotextiles and Geomembranes*, Vol. 4, No. 1, pp. 1-8.

Dawson, A. (1986). "The role of geotextiles in controlling sub-base contamination", *Proceedings of the 3rd International Conference on Geotextiles*, Vienna, Vol. 2, pp. 593-598.

Deberadino, S. (1992). "Permeability or permittivity? What should be specified?", *Geotechnical Fabrics Report*, Innerview, November, pg. 52.

Dierickx, W. and van der Sluys, L. (1990). "Research into the functional hydraulic properties of geotextiles", *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*, The Hague, Vol. 1, pp. 285-288.

Elias, V. (1990). "Durability/corrosion of soil reinforced structures", U.S. Federal Highway Administration, Report No. FHWA-RD-89-186, 163 pp.

Giroud, J.P. (1981). "Designing with geotextiles", *Materiaux et Constructions*, Vol. 14, No. 82, pp. 257-272.

Giroud, J.P. and Noiray, L. (1981). "Geotextile-reinforced unpaved road design", *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 107, No. GT9, pp. 1233-1254.

Hausmann, M.R. (1987). "Geotextiles for unpaved roads - A review of design procedures", *Geotextiles and Geomembranes*, Vol. 5, No. 3, pp. 201-233.

Hoare, D.J. (1982). "A laboratory study into pumping clay through geotextiles under dynamic loading", *Proceedings of the 2nd International Conference on Geotextiles*, Las Vegas, Vol. 2, pp. 423-428.

Holtz, R.D. and Sivakugan, N. (1987). "Design charts for roads with geotextiles", *Geotextiles and Geomembranes*, Vol. 5, No. 3, pp. 191-199.

Ingold, T.S. and Crowcoft, P. (1984). "The notion of geotextiles as separators in roads", *Ground Engineering*, January, pp. 27-34.

Jorenby, B.N. and Hicks, R.G. (1986). "Base course contamination limits", *Transportation Research Record 1095*, Transportation Research Board, pp. 86-101.

Koerner, R.M. (1990). Designing with Geosynthetics, 2nd edition, Prentice Hall Inc., Englewood Cliffs, N.J., 652 pp.

Koerner, R.M. and Ko, F.K. (1986). "Laboratory studies on long-term drainage capability of geotextiles", *Proceedings of the 2nd International Conference on Geotextiles*, Las Vegas, Vol. 1, pp. 91-95.

Koerner, R.M. and Koerner, G.R. (1988). "A qualification and assessment of installation damage to geotextiles", *Geosynthetic Research Institute*, Report No. 2, Drexel University, 56 pp.

Koerner, G.R. and Koerner, R.M. (1990). "The installation survivability of geotextiles and geogrids", *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*, The Hague, Vol. 2, pp. 597-602.

Koerner, R.M. and Wayne, M.H. (1989). "Geotextile specifications for highway applications", U.S. Federal Highway Administration, Report No. FHWA-TS-89-026, 86 pp.

Kothari, V.K. and Das, A. (1992). "Compressional behavior of nonwoven geotextiles", *Geotextiles and Geomenbranes*, Vol. 11, No. 3, pp. 235-253.

Lafleur, J., Rollin, A.L. and Mlynarek, J. (1990). "Clogging of geotextiles under pumping loads", *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*, The Hague, Vol. 1, pp. 189-192.

Laier, H. and Brau, G. (1986). "The use of geotextiles in road constructions under intensive dynamic loading", *Proceedings of the 3rd International Conference on Geotextiles*, Vienna, Vol. 4, pp. 995-1000.

Lawson, C.R. (1982). "Filter criteria for geotextiles: Relevance and use", *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 108, No. GT10, pp. 1300-1317.

Mahoney, J.P. (1992). Pavement Design Course Lecture Notes, CETS 424, University of Washington, 302 pp..

McGown, A., Kabir, M.H. and Murray, R.T. (1982). "Compressibility and hydraulic conductivity of geotextiles", *Proceedings of the 2nd International Conference on Geotextiles*, Las Vegas, Vol. 1, pp. 167-172.

McMorrow, J. (1990). "Filtering action of nonwoven geotextiles under dynamic loading", *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*, The Hague, Vol. 1, pp. 233-238.

Mlynarek, J., Lewandowski, J.B., Rollin, A.L., and Bolduc, G. (1991). "Soil-geotextile system interaction", *Geotextiles and Geomembranes*, Vol. 10, No. 2, pp. 161-176.

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APPENDIX A

Geotextile Observations - Laboratory Results

Geotextile Observations - Laboratory Results

A discussion of the laboratory observations on the recovered geotextile samples and a summary of the results are presented in Chapter 6. The results of all the observations made on the recovered samples are presented in Tables A.1 through A.14. Only comments are presented for the samples which did not need quantitative surveys performed.

Table A.1 - Geotextile laboratory observations for Columbia Heights Road, testpit 1.

Comments:

1. Geotextile was severely damaged.
2. Most of the damage was in the form of rips/tears rather than punctures.
3. The tears were generally parallel to the direction of rutting which occurred during construction.
4. Clay intrusions from the subgrade mushroomed up through the tears and consolidated in the form of ridges on top of the upper surface of the geotextile.
5. The geotextile appeared to be moderately to heavily clogged.
6. The bottom surface of the geotextile appeared to be 50-75% iron stained.

Table A.2 - Geotextile laboratory observations for Columbia Heights Road, testpit 1a.

Trial Number	Number of Holes per Frame	Hole Size, mm (Maximum/Average)	Estimated % Hole Area
1*	368	8/2-3	1.9
2*	308	10/2-3	1.6
			Average 1.75
3	42	5/1-2	0.08
4	80	4/1-2	0.15
5	60	15/2-3	0.32
6	55	15/2-3	0.29
7	30	10/2-3	0.16
8	19	10/1-3	0.06
			Average 0.18

Comments:

1. The fabric under the overlap on the east side of the excavation was a thicker material (~6 oz/yd^2).
2. Many more holes on the overlapped area.
3. Holes are typically quite rounded, especially on the overlap side.
4. Several large wrinkles in the geotextile.
5. Heavy iron staining (90-100%) on the entire bottom surface.
6. Overall geotextile appears to be 30-70% clogged and about 10-30% clogged on the overlap.
7. Parallel lineations in the structure of the geotextile, probably due to manufacturing.
8. Numerous angular indentations in the geotextile from the base course.

* Overlapped area above the thicker geotextile

Table A.3 - Geotextile laboratory observations for Coal Creek Road.

Trial Number	Number of Holes per Frame	Hole Size, mm (Maximum/Average)	Estimated % Hole Area
1	4	35/10	0.34
2	23	25/5-15	1.94
3	5	10/3-5	0.07
4	6	7/2-4	0.05
5	3	3/2-3	0.02
6	26	70/10-30	8.79
7	25	70/10-30	8.45
8	15	90/10-30	5.07
			Average 3.09

Comments:

1. Most of the larger holes were on the north end of the sample where there were a few larger chunks of wood and more pronounced base rock punctures.
2. Holes were typically very angular (sharp edges).
3. Geotextile appeared to be less than 25% clogged.
4. Minimal iron staining (1-2%) on the bottom surface, heavy in one spot (8 by 12 cm)

Table A.4 - Geotextile laboratory observations for Pacific Way.

Trial Number	Number of Holes per Frame	Hole Size, mm (Maximum/Average)	Estimated % Hole Area
1	37	3/1-2	0.07
2	22	3/1-2	0.04
3	12	2/1-2	0.02
4	12	3/1-2	0.02
5	13	3/1-2	0.02
6	11	3/1-2	0.02
7	14	3/1-2	0.03
8	19	2/1-2	0.04
			Average 0.03

Comments:

1. Holes were relatively small.
2. Holes were generally rounded.
3. Several areas with dark orange iron stains with dark brown rings around them. Two of the large stains were approximately (1) 6 by 30 cm, and (2) L-shape, 25 by 44 cm. 15-20% iron staining overall.
4. The geotextile appeared to be about 25% clogged, but some areas were up to 50% clogged.

Table A.5 - Geotextile laboratory observations for SR-14.

Trial Number	Number of Holes per Frame	Hole Size, mm (Max./Average)	Estimated % Hole Area	% Caking on Top Surface
1	1	3	0.01	50-75
2	0	-	0	50-75
3	0	-	0	75-90
4	1	1	<0.01	50-75
5	5	3/1-2	0.01	50-75
6	4	15/5	0.08	20-40
7	2	4/4	0.03	50+
8	0	0	0	50-75
9	3	2/1-2	0.01	30-50
10	2	3/2-3	0.01	50+
11	1	2	<0.01	75+
12	2	6/4	0.03	75+
13	4	10/3-4	0.04	50+
14	4	8/2-4	0.03	50
15	3	4/2-3	0.02	50
			Average 0.02	

Comments:

1. Bottom surface was generally about 10-30% blinded.
2. Top surface was heavily caked (50-75%) with fine soil particles, with some areas up to 90% caked.
3. Minimal (1-2%) iron precipitate deposits, although they were concentrated at the pore spaces.

Table A.6 - Geotextile laboratory observations for SR-9 (Marsh Rd.).

Comments:

1. No holes. Geotextile was in very good condition.
2. The bottom surface appeared to be less than 5% blinded with silt particles.
3. There was about 30-50% organic blinding over 40% of the bottom surface.
4. Moderate (30-50%) iron deposits in and around the areas with organic blinding, minimal elsewhere.
5. Several wrinkles on the west side of the geotextile.
6. There were few indentations in the geotextile, and they were not that pronounced.

Table A.7 - Geotextile laboratory observations for SR-546.

Comments:

1. Only 4 holes, 2-3 mm in diameter.
2. Geotextile in good condition.
3. Many small (2-10 mm) indentations in the geotextile from the subgrade.
4. There was generally uniform blinding (~10%) on the bottom surface of the geotextile.
5. No iron precipitate deposits.

Table A.8 - Geotextile laboratory observations for Carroll Road.

Trial Number	Number of Holes per Frame	Hole Size, mm (Maximum/Average)	Estimated % Hole Area
1	175	50/3-10	6.3
2	166	40/3-10	5.9
3	181	50/3-15	12.4
4	170	40/3-15	11.6
5	190	50/3-10	6.8
6	165	45/3-10	5.9
7	185	35/3-10	6.6
8	186	40/3-10	6.6
9	205	30/3-10	7.3
10	180	30/3-10	6.4
			Average 7.6

Comments:

1. Holes were very uniform throughout the sample's surface.
2. Holes were typically very angular (sharp edges).
3. Most areas between the holes appeared to be 75-90% clogged, while some other areas were 0-10% clogged.
4. Negligible (<1%) iron staining.

Table A.9 - Geotextile laboratory observations for SR-504.

Comments:

1. No holes. Geotextile in very good condition.
2. Numerous rounded indentations in the geotextile from the base material.
3. Geotextile appeared to be about 50-75% clogged, but with fine sand particles.
4. Negligible (<1%) iron staining.

Table A.10 - Geotextile laboratory observations for 49th Ave. NE.

Trial Number	Number of Holes per Frame	Hole Size mm (Max./Ave.)	Estimated Hole Area (%)	% Blinded on Bottom Surface	% Caking on Top Surface
1	7	2/1-2	0.01	25-40	75
2	7	3/2	0.02	20-30	50-75
3	10	6/2	0.03	20-30	50-60
4	12	40/2-6	0.16	50-75	50
5	21	20/2-5	0.22	50	30-50
6	6	5/2	0.02	30-40	50
7	14	4/2	0.05	30-50	30-40
8	28	15/3-4	0.29	25-30	40-50
9	25	10/2-3	0.13	50-60	40-50
10	18	35/3-4	0.19	50	40-50
			Average 0.11		

Comments:

1. 20-50% blinding on the bottom surface and 40-50% caking on the top surface.
2. Many indentations, some of which opened up the weaves, but did not tear the tapes.
3. Minimal (2-5%) iron precipitate deposits.

Table A.11 - Geotextile laboratory observations for SR-16.

Comments:

1. No holes. Geotextile in good condition.
2. Bottom surface of the geotextile was typically 5-10% blinded, but 0-10% overall.
3. Negligible (<1%) iron deposits.
4. There was a lot of caking (25-50%) on the top surface.
5. Some smaller indentations.

Table A.12 - Geotextile laboratory observations for SR-502.

Comments:

1. No holes. Geotextile in good condition.
2. Several thin areas in the geotextile where there were no holes, but the fabric had fewer filaments.
3. The overall geotextile appeared to be 10-40% clogged, but some areas appeared to be 50-75% clogged.
4. Moderate (25-30%) iron staining overall, with heavy staining in a few local areas.
5. Numerous indentations from the overlying base material.

Table A.13 - Geotextile laboratory observations for Olson Road.

Trial Number	Number of Holes per Frame	Hole Size, mm (Maximum/Average)	Estimated (%) Hole Area
1	67	8/2-3	0.35
2	67	14/2-3	0.35
3	41	1.5/2-4	0.31
4	37	4/1-3	0.13
5	18	4/1-2	0.03
6	25	5/1-2	0.05
7	28	7/1-3	0.05
8	19	4/1-3	0.04
9	30	6/1-3	0.06
10	30	5/1-3	0.06
			Average 0.14

Comments:

1. A couple of iron-stained spots near NE area about 100 cm^2, sporadic iron-staining elsewhere.
2. Geotextile appeared to be 30-50% clogged.
3. Minimal (2-5%) iron-staining.
4. Fold and wrinkles in the geotextile on the south side.

Table A.14 - Geotextile laboratory observations for SR-9 (Sumas).

Trial Number	Number of Holes per Frame	Hole Size, mm (Max./Average)	Estimated % Hole Area	% Blinding on Bottom Surface
1	8	10/2-3	0.04	20-30
2	13	10/3-4	0.13	10-20
3	2	4/4	0.03	5-10
4	3	7/4	0.04	10-20
5	2	5/4	0.03	20-30
6	2	3/3	0.02	5-10
7	1	4	0.01	5-10
8	3	10/4	0.04	10-20
			Average 0.04	

Comments:

1. Many indentations in the geotextile. Two were up to 90 mm diameter and 15 mm deep. Indentations were caused by the base material penetrating down into the subgrade.
2. About 6 small wrinkles in the geotextile.
3. Minor to moderate (10-30%) iron precipitate deposits on the bottom surface.

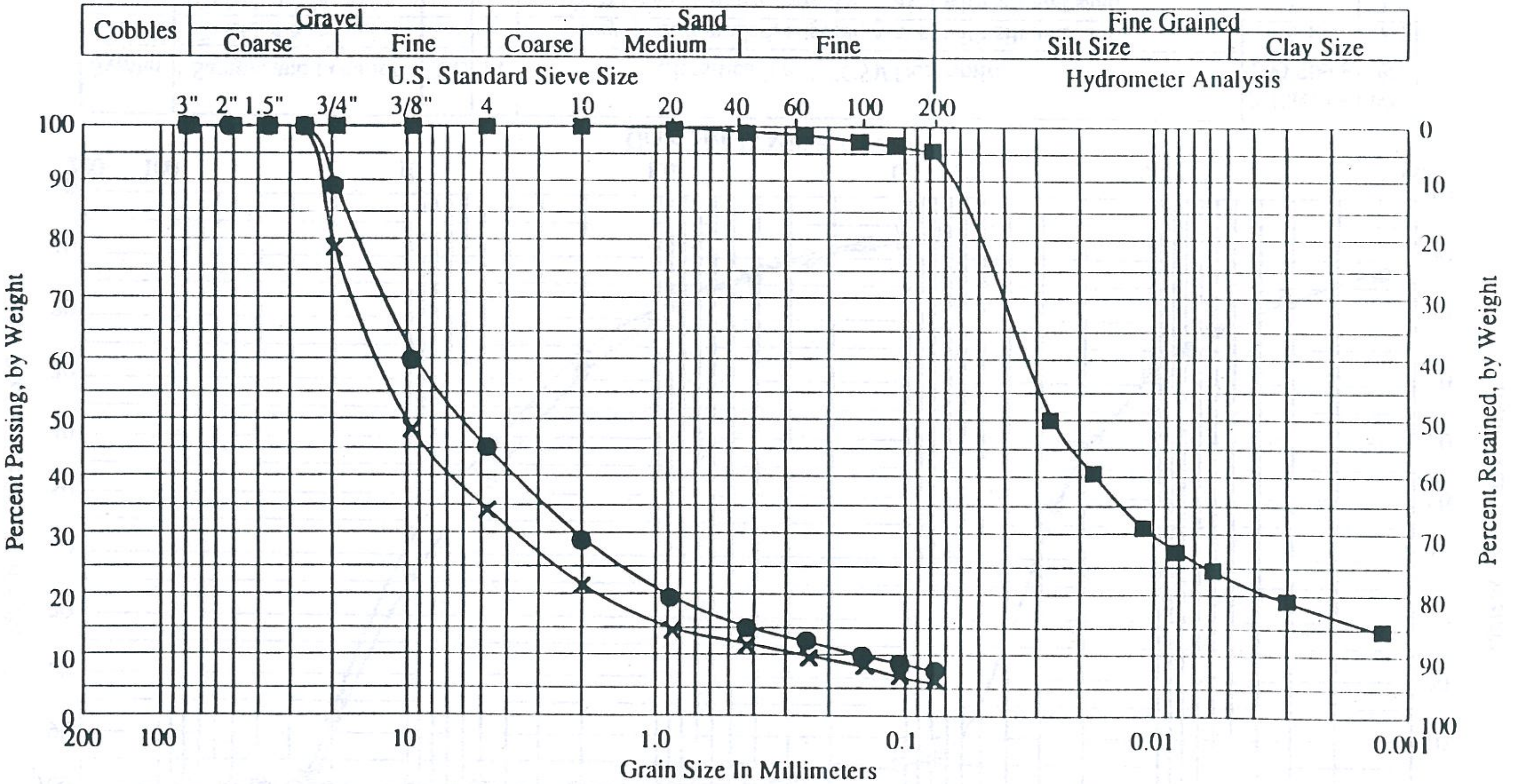
APPENDIX B

Grain Size Distribution Curves and Soil Test Results

Grain Size Distribution Curves and Soil Test Results

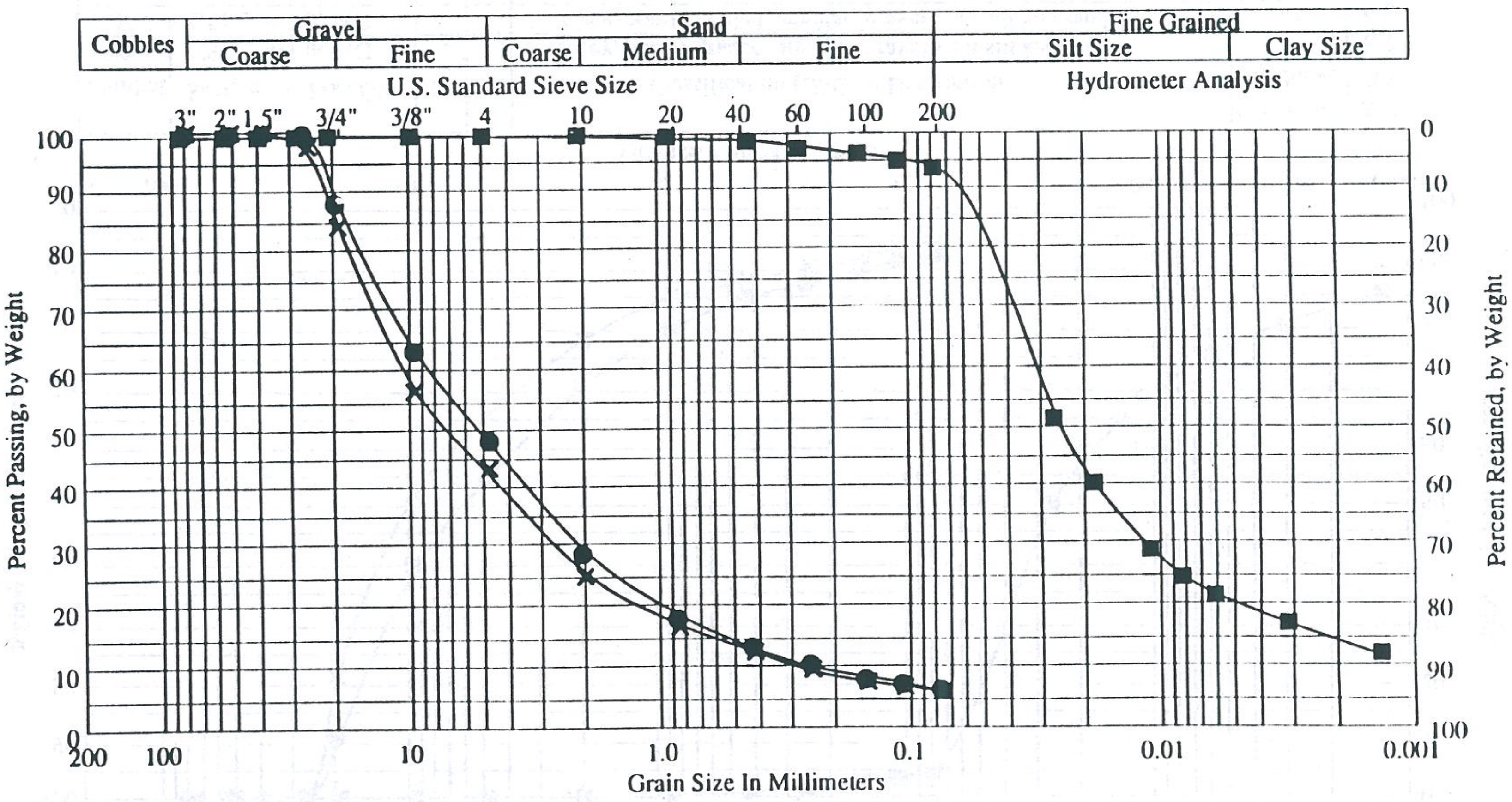
The soil testing procedures are discussed in Chapter 7, Section 7.2. The results of soil tests are discussed in Sections 7.4.1 and 7.4.2. Figures B.1 through B.14 summarize all the test results performed on the disturbed soil samples. Included in these figures are classifications and/or descriptions of the samples. The following abbreviations are used in Figures B.1 through B.14:

LL - Liquid Limit
PI - Plasticity Index
WC - Moisture Content
AG - Above geotextile
BG - Below geotextile
NP - Nonplastic
N - North
S - South



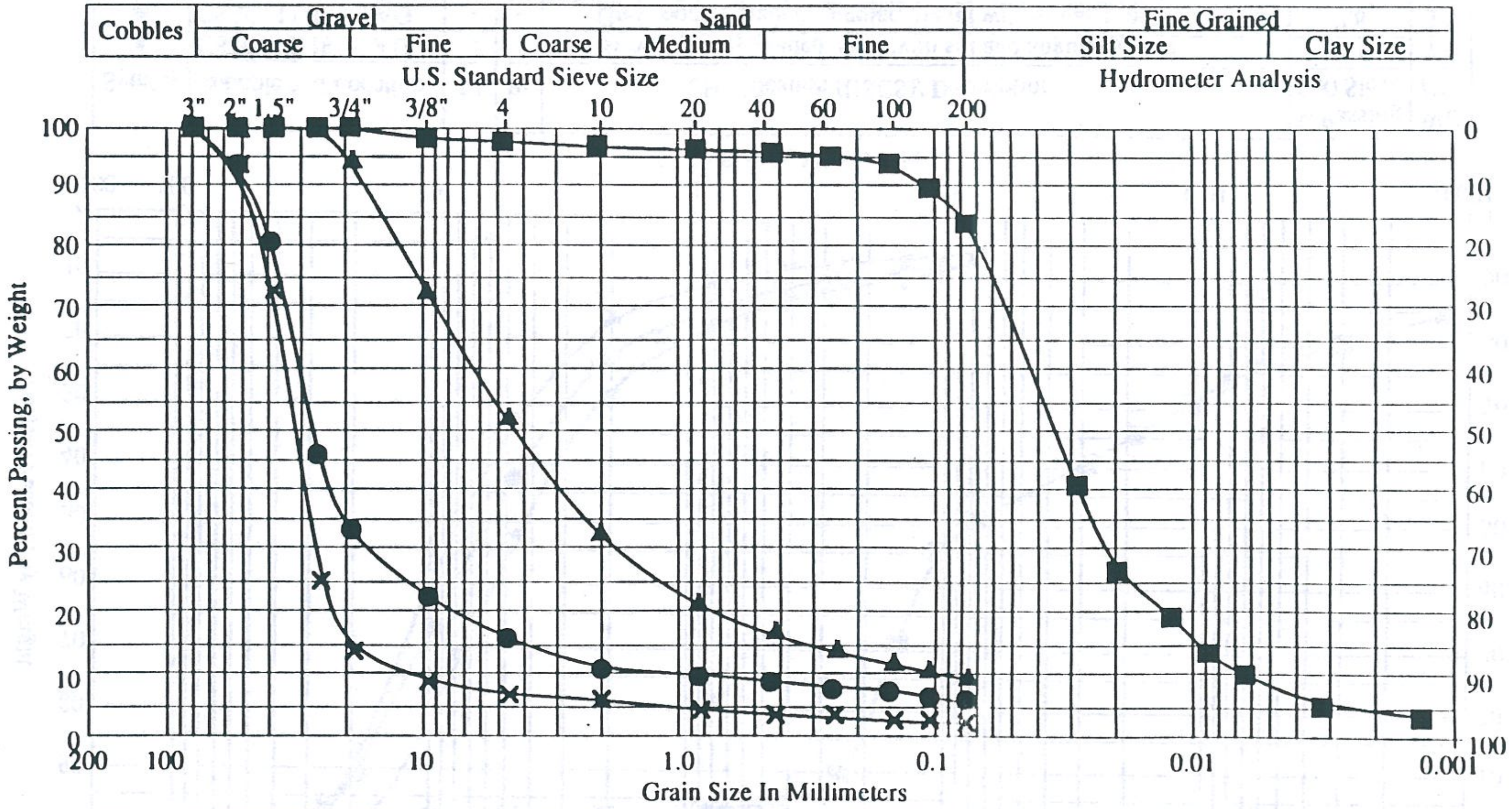
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	CSBC, 4-7 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	7.4	6.7
✕	CSBC, 0-2 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	6.1	6.8
■	Subgrade, 0-5 in. BG	36	14	Moist, reddish-brown and grey, iron-stained, lean clay (CL)	96.0	23.1

Figure B.1 - Grain Size Distribution for Columbia Heights Road, Testpit 1a.



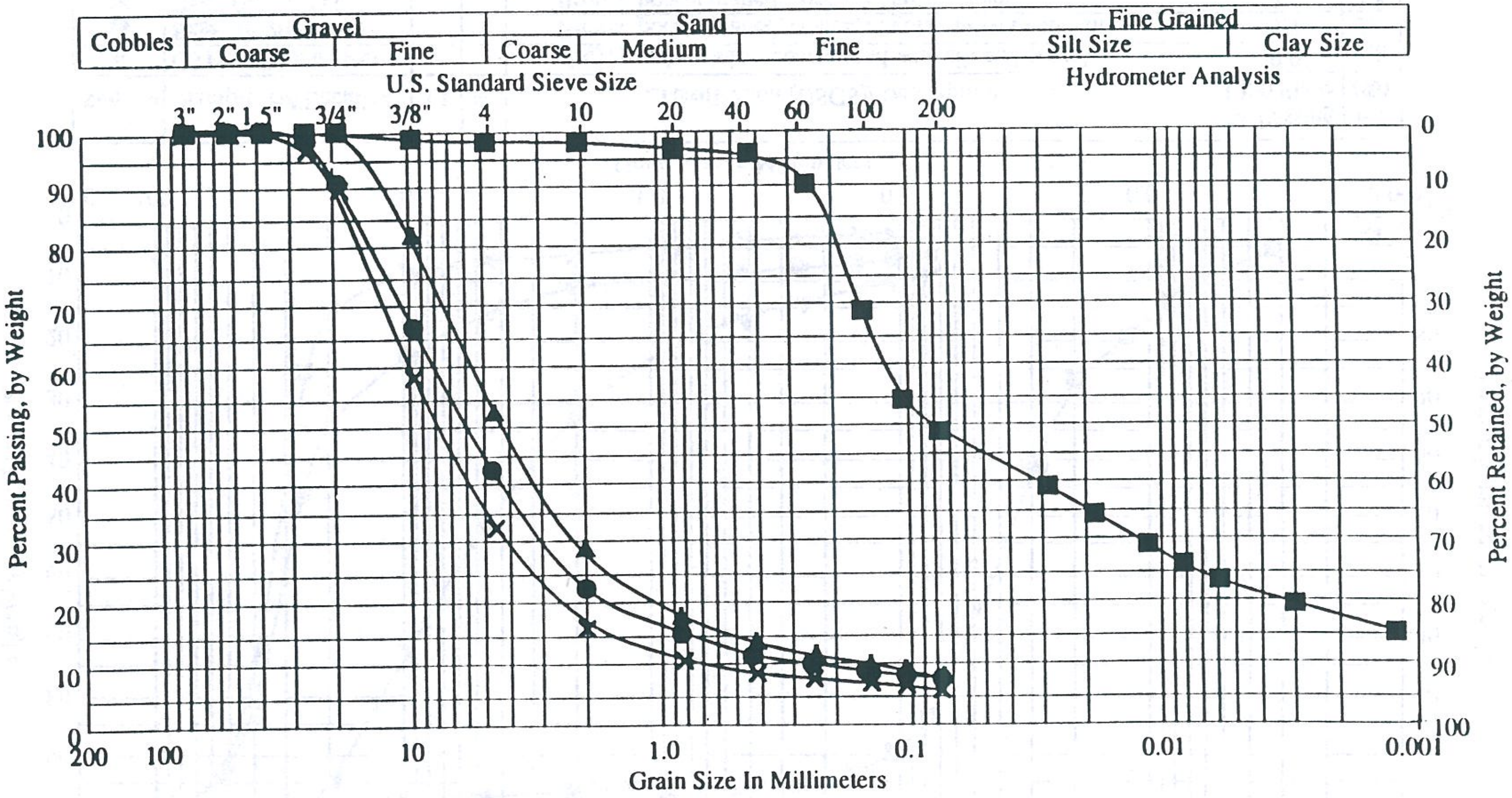
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	CSBC, 4-6 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	6.1	7.4
×	CSBC, 0-2 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	5.4	7.4
■	Subgrade, 0-4 in. BG	39	17	Moist, reddish-brown and grey, iron-stained, lean clay (CL)	93.7	26.1

Figure B.2 - Grain Size Distribution for Columbia Heights Road, Testpit 1.



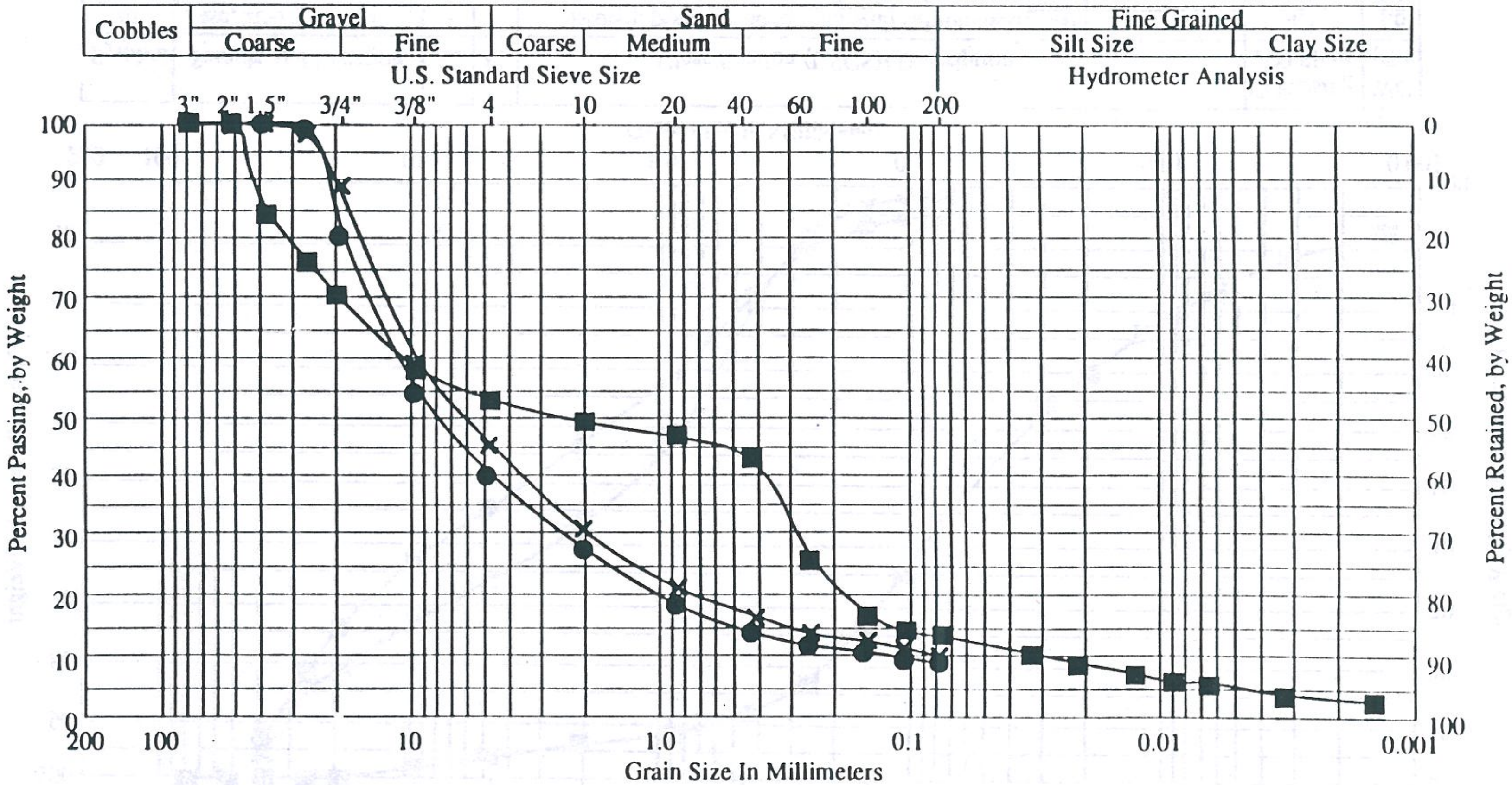
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
▲	CSTC, 27-32 in. AG	-	-	Grey, poorly graded, coarse sand with silt and gravel	9.9	5.8
●	Base, 16-20 in. AG	-	-	Brown, poorly graded, coarse, angular, gravel with silt	5.7	5.7
✕	Base, 0-2 in. AG	-	-	Brown, poorly graded, coarse, angular gravel	2.1	5.8
■	Subgrade (N), 0-3" BG	43	10	Moist, grey, silt with sand (ML) and wood debris	84.4	41
	Subgrade (S), 0-3" BG	-	-	Moist, dark brown wood debris	-	137

Figure B.3 - Grain Size Distribution for Coal Creek Road.



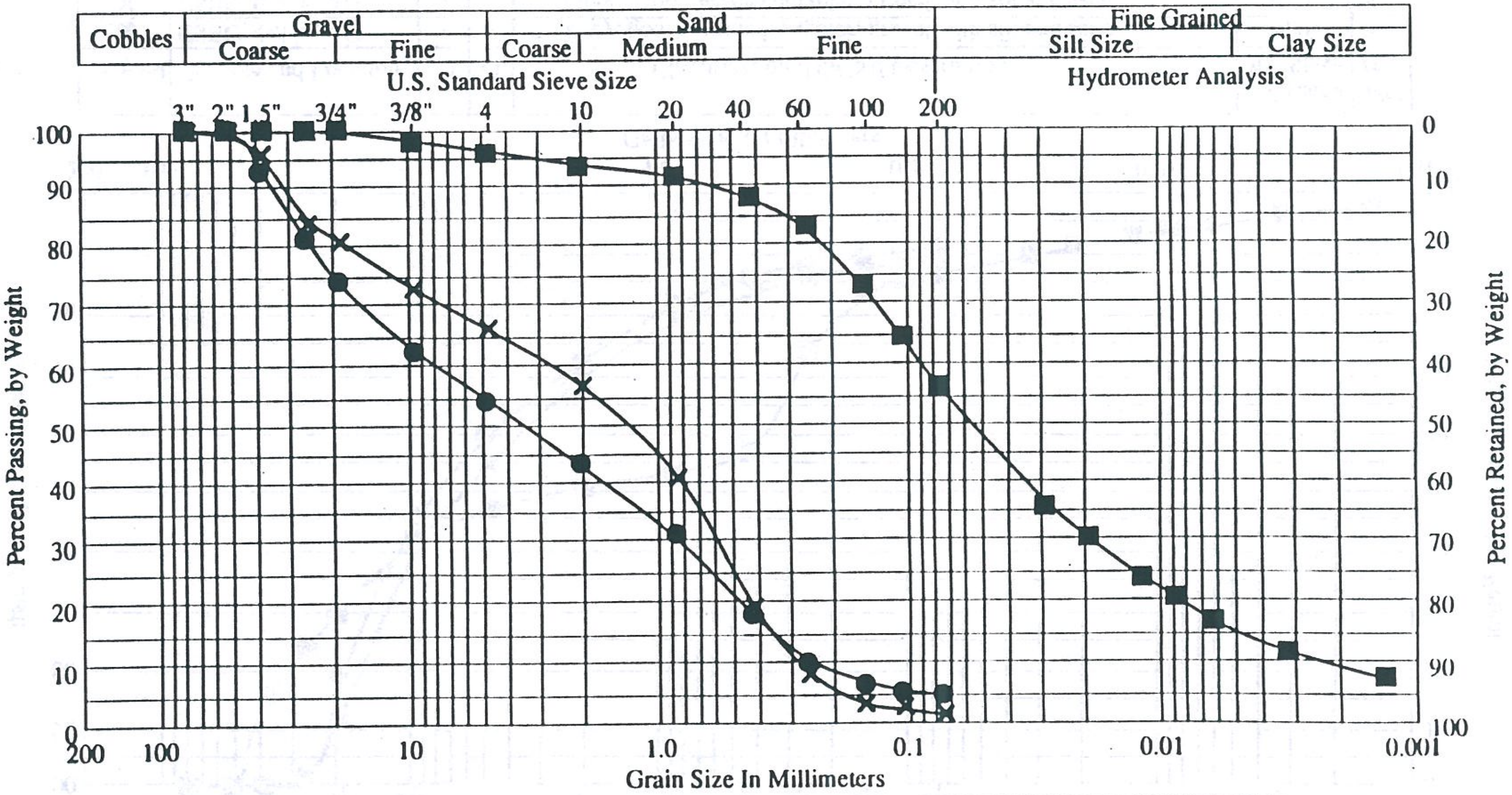
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
▲	CSTC, 16-18 in. AG	-	-	Brown, poorly graded, sand with silt and angular gravel	8.1	7.0
●	CSBC, 11-14 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	7.8	5.5
×	CSBC, 0-2 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	6.0	6.3
■	Subgrade, 0.5-4 in. BG	44	24	Moist, brown, iron-stained, clayey fine sand (SC)	48.6	24.7

Figure B.4 - Grain Size Distribution for Pacific Way.



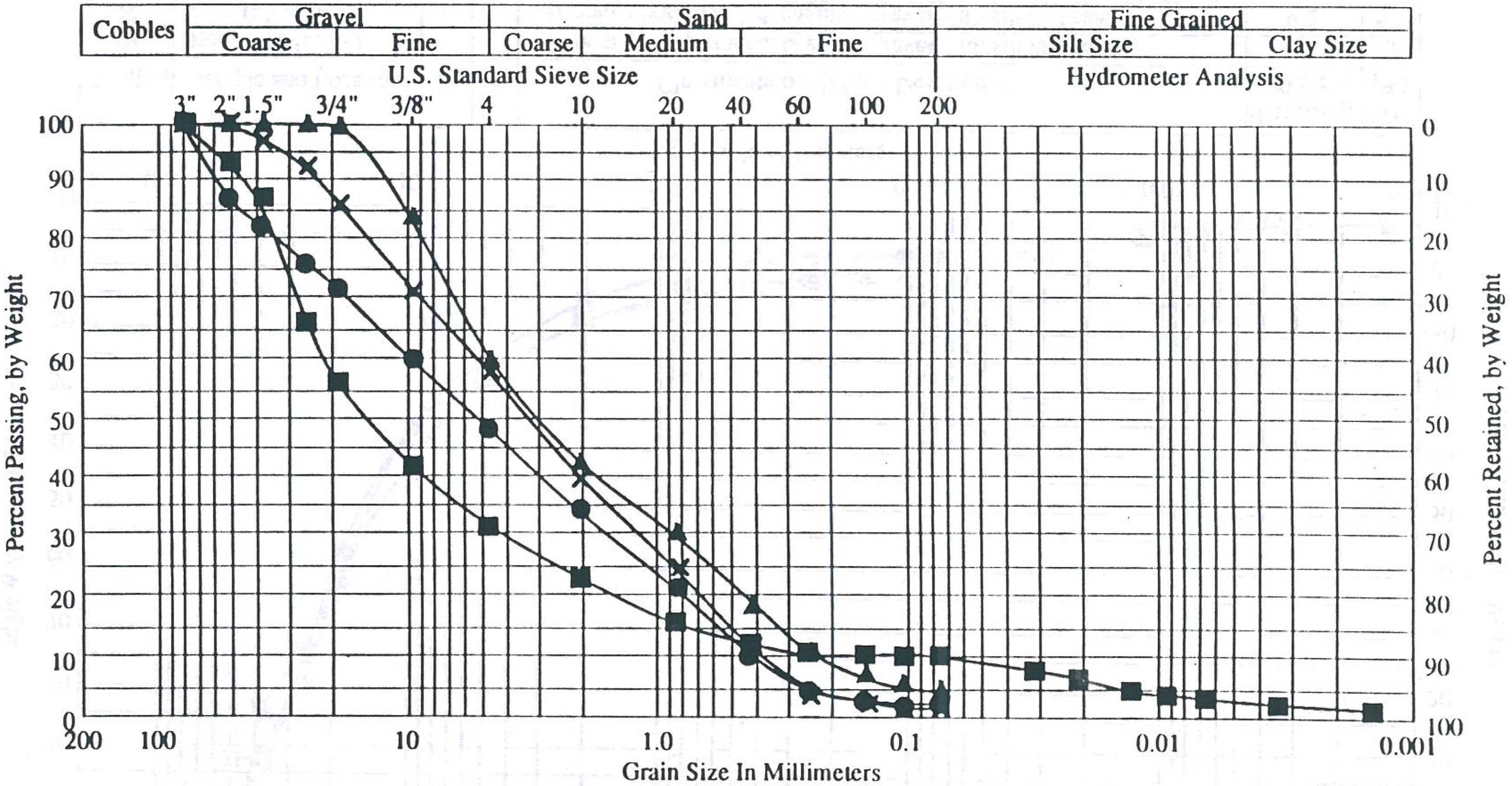
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	CSBC, 4-6 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	8.9	4.8
×	CSBC, 0-2 in. AG	-	-	Grey, poorly graded, angular, gravel with silt and sand	10.2	5.4
■	Subgrade, 0-3 in. BG	NP	-	Grey, subrounded, silty gravel with sand (GM)	13.3	14.7

Figure B.5 - Grain Size Distribution for SR-14.



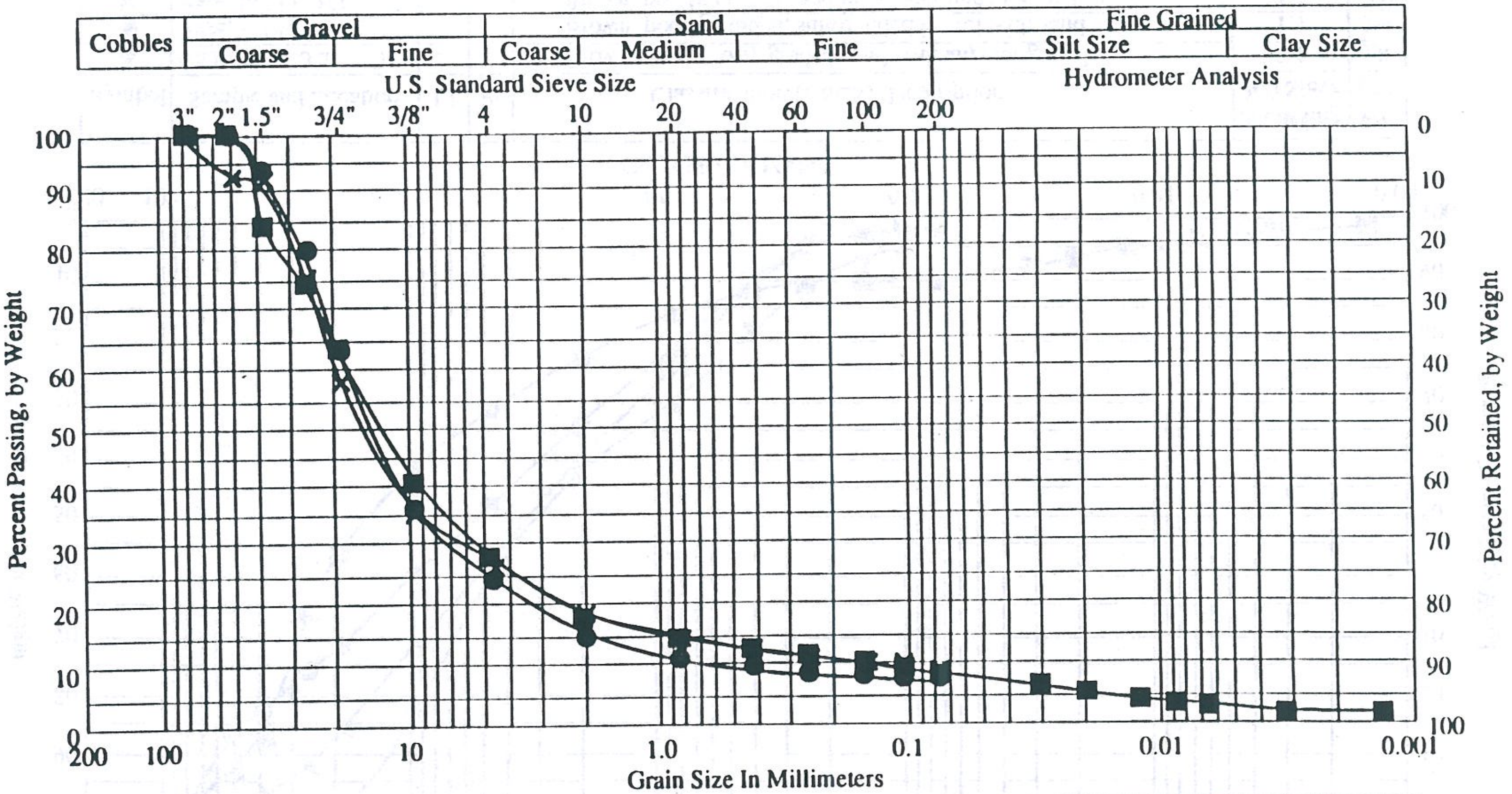
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	Base, 20-26 in. AG	-	-	Brown, poorly graded sand with subrounded gravel	4.1	3.6
X	Base, 0-2 in. AG	-	-	Brown, poorly graded sand with subrounded gravel	1.5	5.8
■	Subgrade, 0.5-4 in. BG	35	10	Moist, grey/brown, sandy silt (ML)	56.4	24.3

Figure B.6 - Grain Size Distribution for SR-9 (Marsh Road).



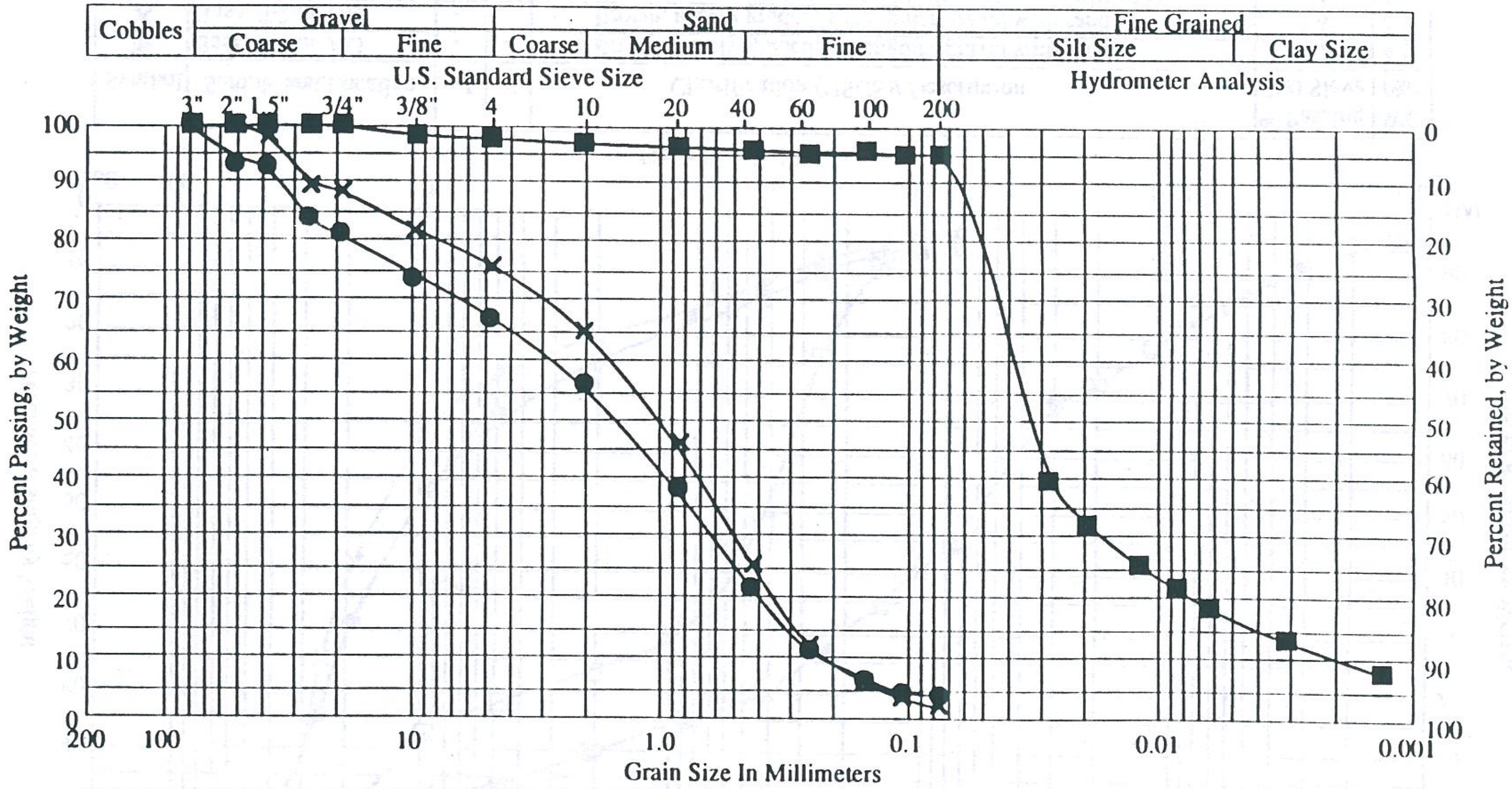
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
▲	CSTC, 17-20 in. AG	-	-	Brown/grey, poorly graded sand with angular gravel	5.4	3.8
●	Base, 9-14 in. AG	-	-	Brown, poorly graded, subrounded gravel with sand	1.7	2.9
✕	Base, 0-2 in. AG	-	-	Brown, poorly graded sand with subrounded gravel	1.4	2.9
■	Subgrade, 0-3 in. BG	40	7	Moist, dark brown, poorly graded, subrounded gravel with silt and sand (GP-GM)	9.8	9.7

Figure B.7 - Grain Size Distribution for SR-546.



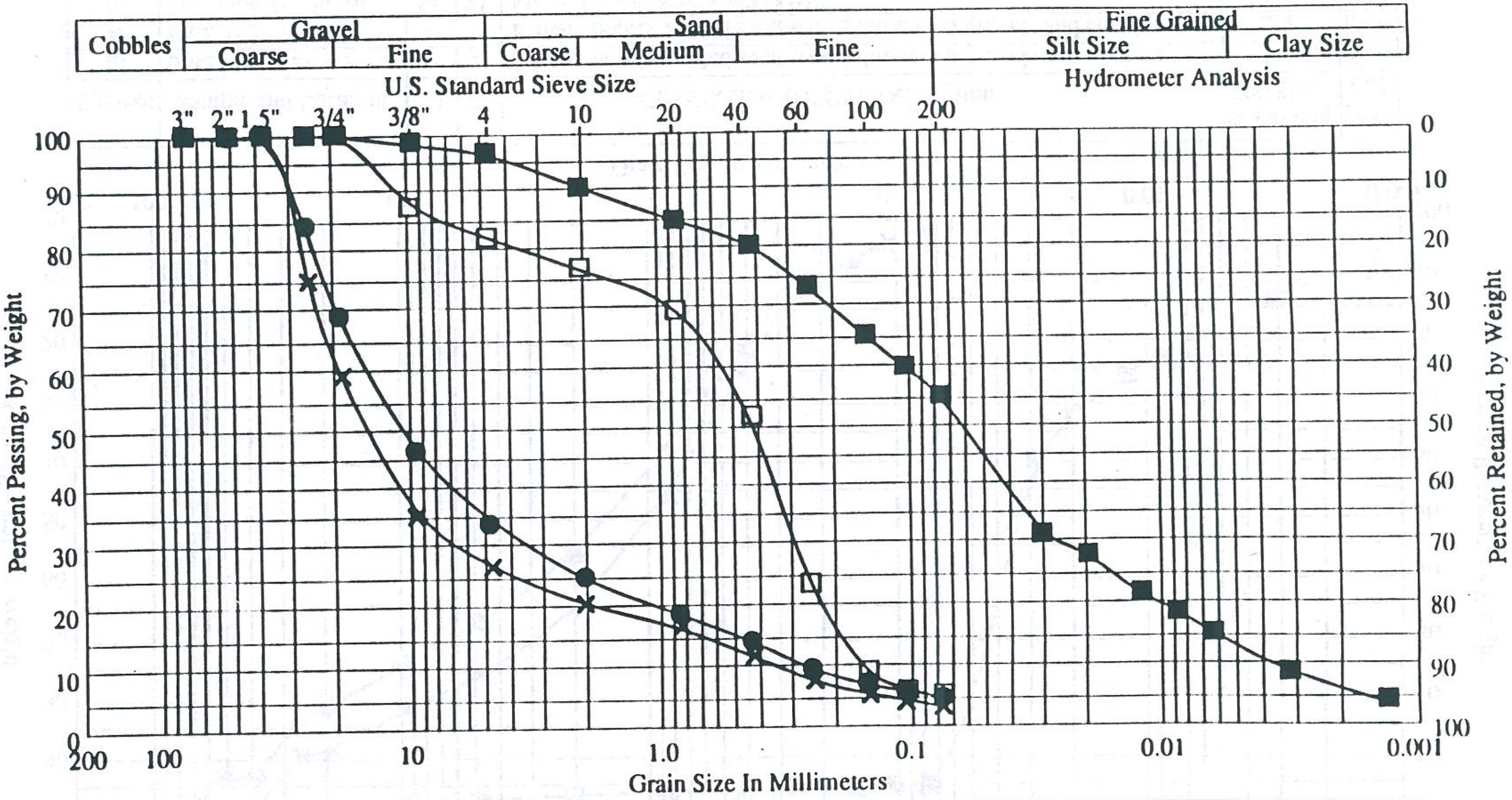
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	Base, 7-12 in. AG	-	-	Brown, poorly graded, angular, gravel with silt and sand	7.5	5.6
X	Base, 0-2 in. AG	-	-	Brown, poorly graded, angular, gravel with silt and sand	9.2	5.6
■	Subgrade, 0-3 in. BG	37	16	Brown, poorly graded, angular, gravel with clay and sand (GP-GC)	8.5	7.2

Figure B.8 - Grain Size Distribution for Carroll Road.



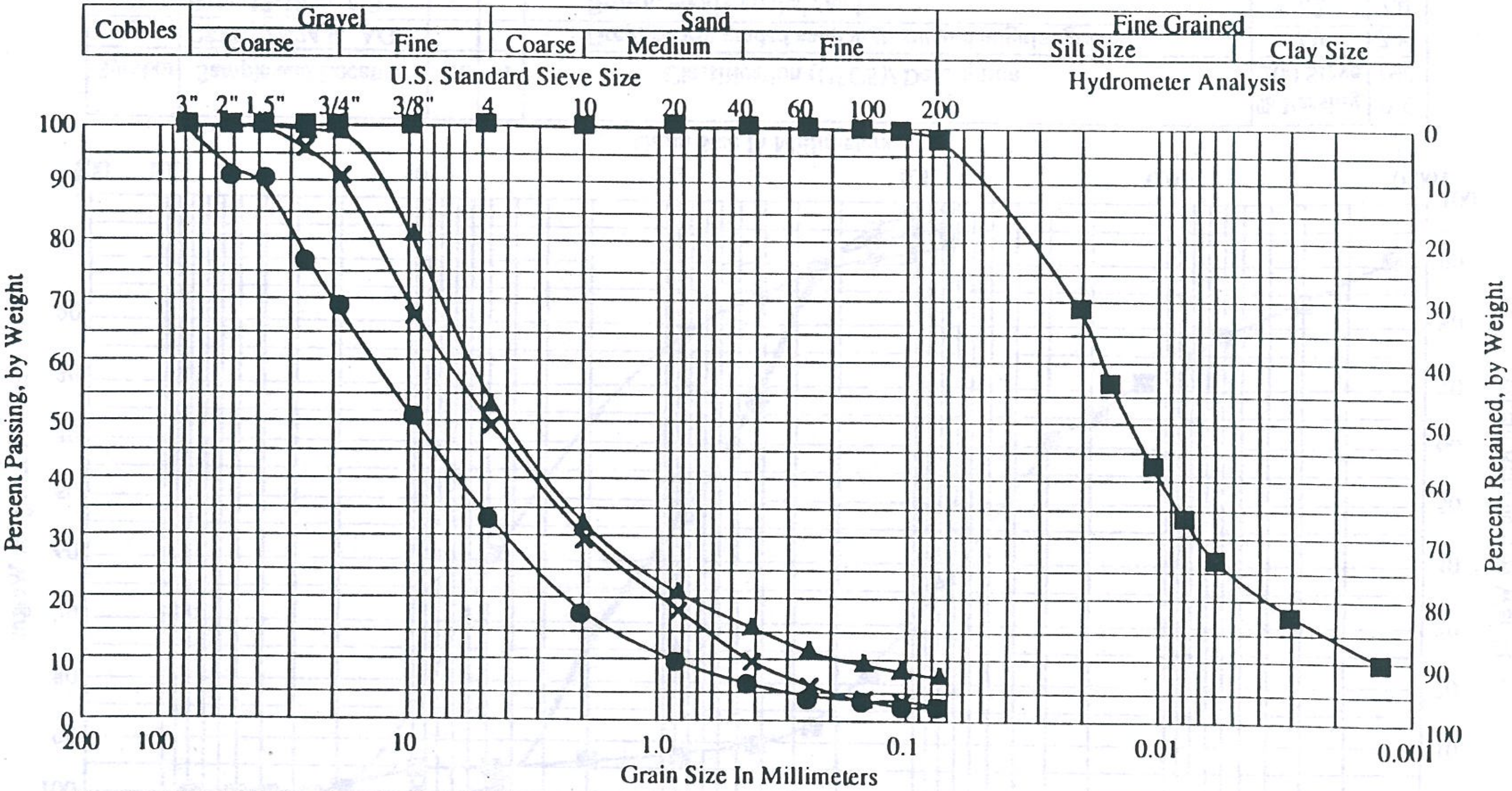
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	Base, 15-21 in. AG	-	-	Brown, poorly graded sand with subrounded gravels and cobbles	3.3	5.6
✕	Base, 0-2 in. AG	-	-	Brown, poorly graded sand with subrounded gravels and cobbles	2.7	10.0
■	Subgrade, 0-2 in. BG	54	21	Moist, brown, elastic silt (MH)	95.8	43.7

Figure B.9 - Grain Size Distribution for SR-504.



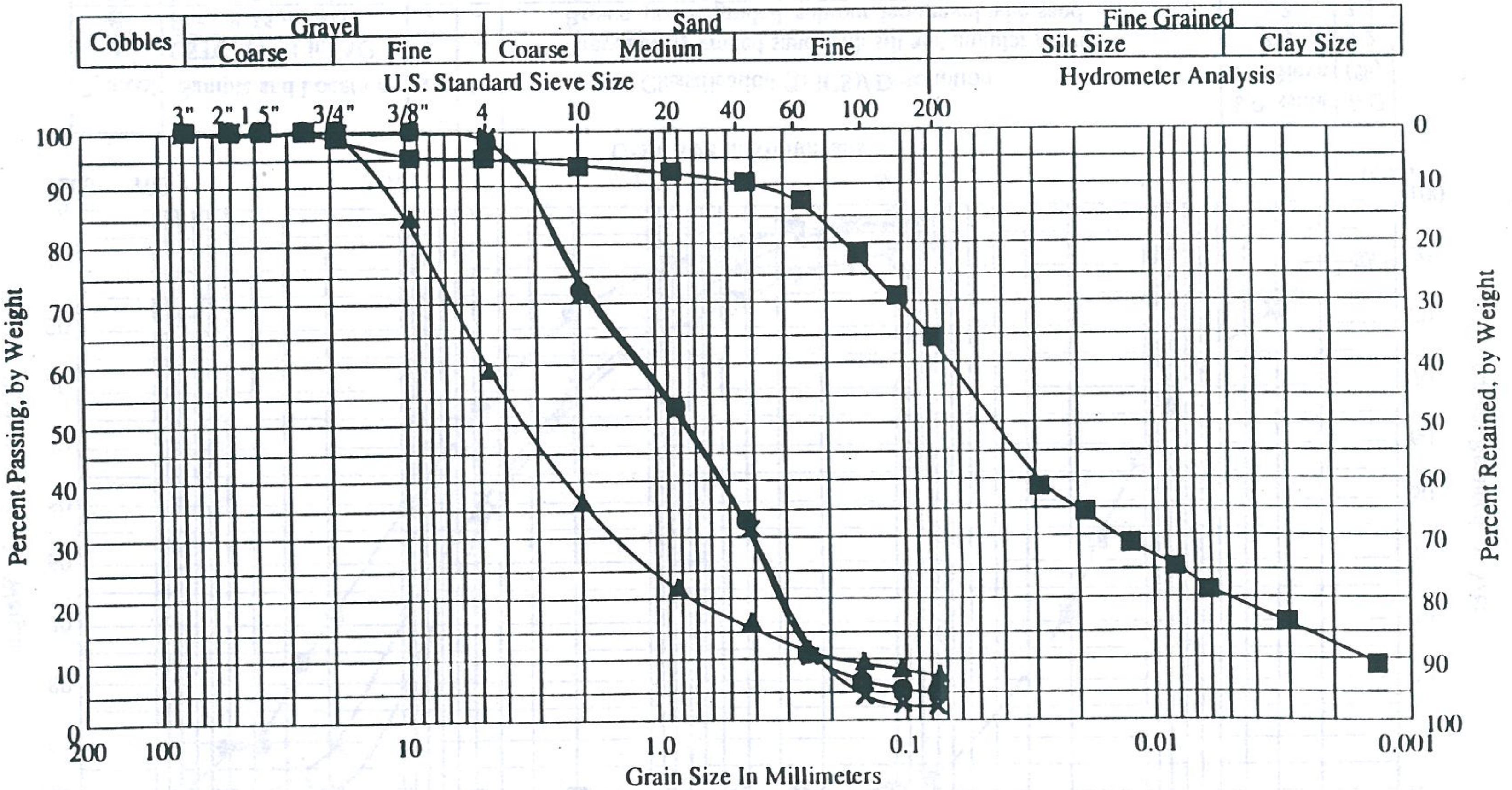
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	Base, 5-9 in. AG	-	-	Brown, poorly graded, subangular gravel with sand	4.7	4.5
X	Base, 0-2 in. AG	-	-	Brown, poorly graded, subangular gravel with sand	3.6	4.7
□	Subgrade (S), 2-6" BG	NP	-	Brown, poorly graded sand with silt and gravel (SP-SM)	5.1	5.6
■	Subgrade (N), 2-6" BG	26	4	Moist, dark brown, sandy silt (ML)	55.5	22.4

Figure B.10 - Grain Size Distribution for 49th Ave NE.



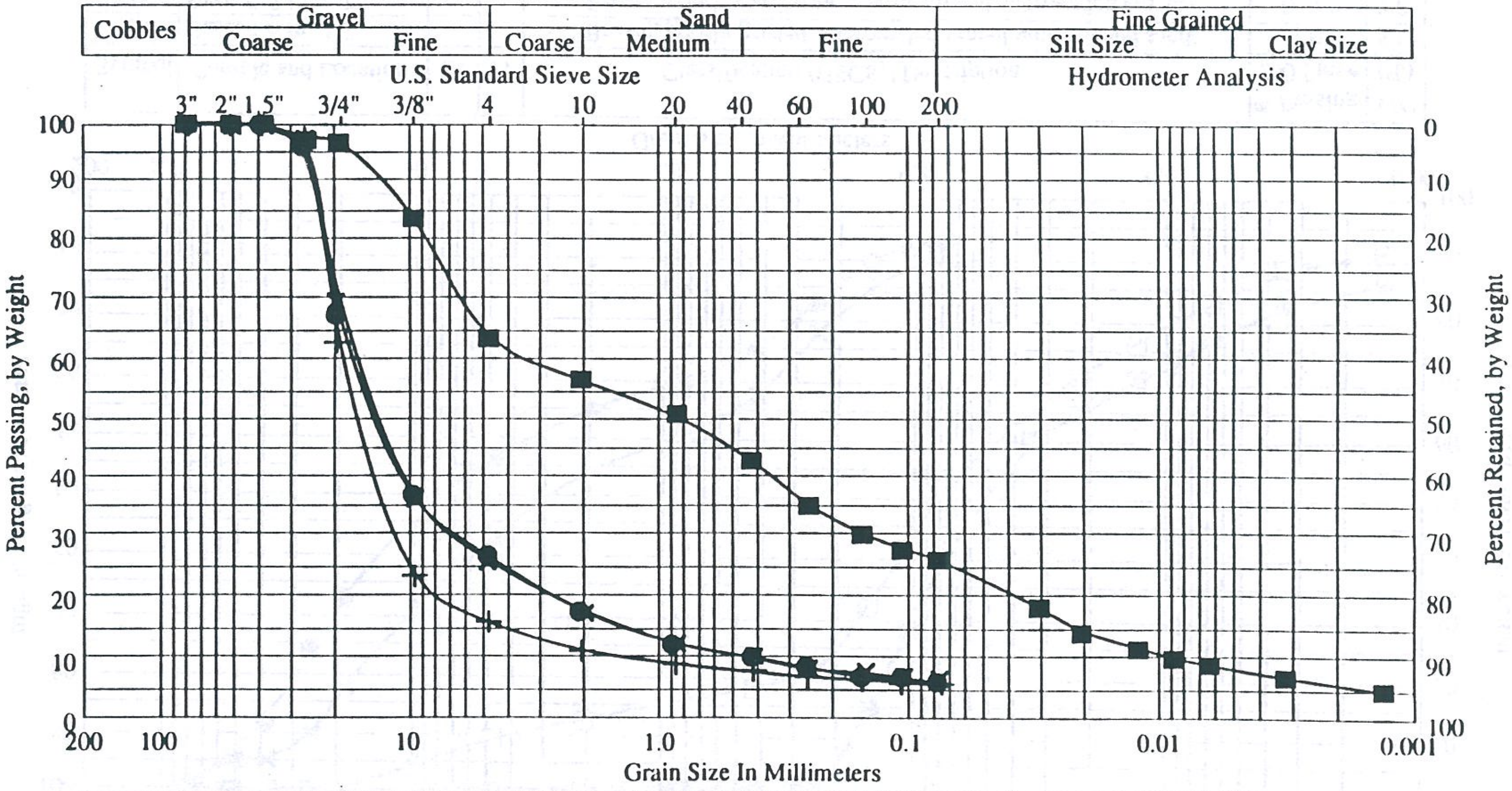
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
▲	CSTC, 27-31 in. AG	-	-	Grey, poorly graded sand with silt and angular gravel	7.6	3.2
●	Base, 9-15 in. AG	-	-	Brown, poorly graded, subrounded gravel with sand	1.7	3.2
×	Base, 0-2 in. AG	-	-	Brown, poorly graded, subrounded gravel with sand	2.6	3.8
■	Subgrade, 0.5-4 in. BG	31	11	Moist, brown, lean clay (CL)	97.6	24.0

Figure B.11 - Grain Size Distribution for SR-16.



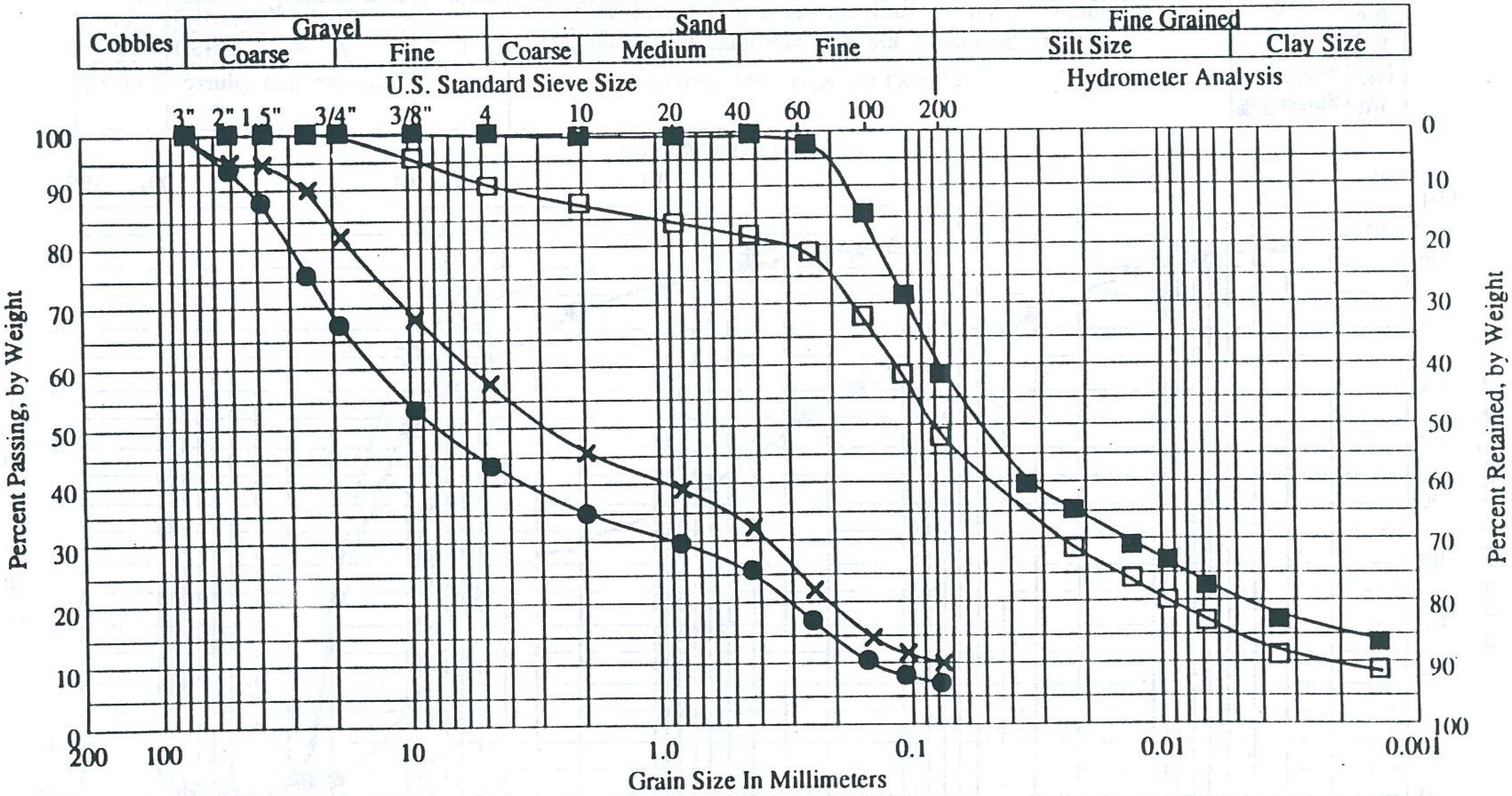
Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
▲	CSTC, 21-24 in. AG	-	-	Grey, poorly graded sand with silt and angular gravel	7.9	3.8
●	Base, 12-18 in. AG	-	-	Brown, poorly graded sand	4.2	7.0
✕	Base, 0-2 in. AG	-	-	Brown, poorly graded sand	2.8	8.1
■	Subgrade, 0-4 in. BG	28	9	Moist, brown, sandy lean clay (CL)	64.6	20.8

Figure B.12 - Grain Size Distribution for SR-502.



Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	CSBC, 4-8 in. AG	-	-	Grey, poorly graded, angular gravel with silt and sand	5.6	6.9
×	CSBC (E), 0-2 in. AG	-	-	Grey, poorly graded, angular gravel with silt and sand	5.0	8.9
+	CSBC (W), 0-2 in. AG	-	-	Grey, poorly graded, angular gravel with silt	5.2	11.1
■	Subgrade, 0-3 in. BG	NP	-	Moist, brown, silty sand with angular gravel (SM)	26.2	15.2

Figure B.13 - Grain Size Distribution for Olson Road.



Symbol	Sample and Location	LL	PI	Classification (USCS)/ Description	% Passing 200 Sieve	WC (%)
●	Base, 4-6 in. AG	-	-	Brown, poorly graded, subrounded gravel with silt and sand	7.0	5.8
×	Base, 0-2 in. AG	-	-	Brown, poorly graded sand with silt and subrounded gravel	10.1	7.0
□	Subgrade, 0-0.5 in. BG	27	7	Moist, brown, silty, clayey sand (SC-SM)	48.7	16.7
■	Subgrade, 0.5-3 in. BG	23	2	Moist, grey, sandy silt (ML)	58.5	17.9

Figure B.14 - Grain Size Distribution for SR-9 (Sumas).

APPENDIX C

Permittivity Test Procedures and Results

Permittivity Test Procedures and Results

A discussion of the permittivity test procedure is presented in Chapter 7, Section 7.3.2, and a summary of the test results is presented in Section 7.4.3. The results of the permittivity tests are presented in Tables C.1 through C.13. The results of the control tests are shown in Table C.14. The cross-plane flow through the geotextile is also reported as permeability in Tables C.1 through C.13. The geotextile thicknesses used in calculating the permeability values are presented in Table C.15.

The accuracy of the permeability/permittivity values in Tables C.1 through C.14 was to two significant figures. However, up to four significant figures are shown in the tables due to formatting of the spread sheet. Also, the units shown for the Flow Rate (l/min/m2) are liters per minute per square meter (L/min/m^2).

In general, the permittivity testing procedures were as follows:

1. Randomly select four permittivity test specimens from the exhumed geotextile sample for each site location (occasionally one or two of the test specimens, from a few samples, were selected based on observations of areas with more severe blinding or clogging).
2. Cut each test specimen into a circular shape with a diameter of approximately 5.5 cm.
3. Deair water prior to the start of the test. The deaired water was obtained from a deairing tank which was filled with misted water while under a vacuum of approximately 75 cm of mercury (Hg), for a period of at least 2 hours, but typically 24 hours.
4. Immerse each test specimen in a sealed container of deaired water for a period of 24 hours.
5. After the test specimens have soaked for the required period of time, detach the lower part of the permeameter from the standpipe by unscrewing the union joint coupling. With minimal turbulence, fill the lower part of the permeameter with

deaired water through the overflow port until water rises to the top of the lower half of the union joint and O-ring.

6. Place an unwashed test specimen on the lower part of the union joint in a way that the specimen becomes partially immersed in water and air bubbles are not trapped beneath the specimen. The bottom surface of the test specimen must be in the upward position so that the test approximates in-situ flow conditions.

7. Very carefully lift up the lower part of the permeameter and connect it to the upper part of the union joint, attached to the standpipe, and carefully tighten down the screw-down clamp. Care must be taken so that water is not spilled.

8. Once the permeameter is connected with the specimen in position, continue to fill the remainder of the lower portion of the permeameter through the outlet port until water reaches the top of the outlet port.

9. Insert a thermometer into the water at the outlet port of the permeameter and record this as the test temperature.

10. Insert a stopper in the outlet port. Observe the specimen while inserting the stopper to see if any air bubbles come up through it. If none, then continue the procedure. If air bubbles do come up from the test specimen then repeat inserting the stopper until air bubbles do not appear. Care must be taken when inserting the stopper so that the condition of the unwashed specimens are not disturbed in a way which may affect the test results (i.e. disturbing the soil particles). When testing washed specimens, rapidly insert the stopper and observe for air bubbles.

11. Slowly fill the standpipe with deaired water to approximately the 50 cm mark. The tube supplying the water should be placed down into the standpipe until it very close to, or is submerged under, the existing water level. Initially fill at a slow rate until the water level is high enough, and the water supply tube far enough away, so the test specimen will not be disturbed by a higher flow rate. This will help reduce the introduction of air bubbles or causing turbulence which can affect the performance of the specimen.

12. When the standpipe has been filled, insert the stopper with the air supply tube into the top of the standpipe.

13. Make sure the bottom of the air supply tube is 5 cm above the outlet port to ensure the required head is applied to the specimen.

14. Place a finger over the air supply tube and then remove the stopper in the outlet port.

15. Slowly allow air to go down the air supply tube by slight finger movements until a bubble comes out the bottom. Record the level of water in the standpipe as the starting point of the test.

16. Begin the test by simultaneously starting the stop watch and removing the finger from the air supply tube.

17. End the test by simultaneously stopping the stop watch and placing the finger back over the top of the air supply tube. The water level should drop approximately 30 cm or the elapsed time should be at least 60 seconds before the test is completed. Record the final water level and the elapsed time.

18. Calculate the permittivity.

19. Repeat the procedure, steps 5-18, until five runs have been completed on the unwashed specimen.

20. After the five runs on the unwashed specimen have been completed, remove the test specimen and wash it under swiftly moving water.

    - Nonwoven geotextiles: Generally a very gentle massage of the specimen is all that is needed to remove most of the clogged soil particles.
    - Woven geotextiles: The specimens can be gently rubbed with a very soft fabric to remove most of the soil particles.

    The washing process should be brief and care must be taken to avoid damage to the structure of the geotextile. It is generally impractical to remove all the soil particles.

21. Repeat the test procedure, steps 5-18, until five test runs have been completed on the washed specimen.

Table C.1 - Permittivity Test Results for the Columbia Heights Road Site, testpit 1a.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	34.5	15.09	19	0.432	1297	0.0714
Unwashed	2	34.4	12.30	19	0.529	1587	0.0873
	3	33.9	10.74	19	0.597	1791	0.0986
	4	35.8	10.85	19	0.624	1872	0.1030
	5	35.4	9.68	19	0.692	2075	0.1142
1	1	30.0	3.92	19	1.448	4343	0.2390
Washed	2	34.1	4.55	19	1.418	4253	0.2340
	3	34.4	4.56	19	1.427	4281	0.2356
	4	36.7	4.85	19	1.431	4294	0.2363
	5	37.8	4.94	19	1.447	4342	0.2389
				Average	1.434	4302	0.2368
2	1	36.6	12.71	19	0.545	1634	0.0899
Unwashed	2	32.6	9.50	19	0.649	1947	0.1072
	3	35.9	9.26	19	0.733	2200	0.1211
	4	33.8	8.00	19	0.799	2397	0.1319
	5	33.8	7.45	19	0.858	2574	0.1417
2	1	34.0	3.16	19	2.035	6105	0.3360
Washed	2	30.5	2.96	19	1.949	5847	0.3218
	3	36.3	3.29	19	2.087	6261	0.3445
	4	34.8	3.31	19	1.989	5966	0.3283
	5	36.8	3.55	19	1.961	5882	0.3237
				Average	2.004	6012	0.3309
3	1	37.3	6.20	19	1.138	3414	0.1879
Unwashed	2	34.9	5.03	19	1.312	3937	0.2167
	3	34.4	4.76	19	1.367	4101	0.2257
	4	29.6	3.94	19	1.421	4263	0.2346
	5	35.2	4.44	19	1.499	4498	0.2476
3	1	36.1	3.19	19	2.140	6421	0.3534
Washed	2	34.5	3.07	19	2.126	6377	0.3509
	3	34.7	3.11	19	2.110	6331	0.3484
	4	36.9	3.31	19	2.109	6326	0.3481
	5	40.2	3.44	19	2.210	6631	0.3649
				Average	2.139	6417	0.3532
4	1	31.8	8.54	19	0.704	2113	0.1163
Unwashed	2	34.7	8.26	19	0.795	2384	0.1312
	3	35.8	7.99	19	0.847	2542	0.1399
	4	32.5	6.84	19	0.899	2696	0.1484
	5	34.3	6.88	19	0.943	2829	0.1557
4	1	37.1	3.37	19	2.082	6247	0.3438
Washed	2	36.1	3.15	19	2.168	6503	0.3579
	3	35.2	3.14	19	2.120	6361	0.3501
	4	37.4	3.45	19	2.050	6151	0.3385
	5	35.2	3.24	19	2.055	6165	0.3393
				Average	2.095	6285	0.3459

Table C.2 - Permittivity Test Results for the Coal Creek Road Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	36.9	34.13	18	0.210	629	0.0091
Unwashed	2	36.5	27.11	18	0.261	783	0.0113
	3	37.1	25.64	18	0.281	842	0.0121
	4	37.0	24.20	18	0.296	889	0.0128
	5	36.5	23.29	18	0.304	912	0.0131
1	1	34.7	6.88	18	0.978	2934	0.0423
Washed	2	37.4	7.27	18	0.998	2993	0.0431
	3	37.5	7.39	18	0.984	2952	0.0425
	4	36.9	7.33	18	0.976	2929	0.0422
	5	37.6	7.48	18	0.975	2924	0.0421
				Average	0.982	2946	0.0424
2	1	32.9	43.59	18	0.146	439	0.0063
Unwashed	2	31.8	36.75	18	0.168	503	0.0072
	3	30.9	32.29	18	0.186	557	0.0080
	4	31.0	27.49	18	0.219	656	0.0094
	5	31.5	27.14	18	0.225	675	0.0097
2	1	34.0	3.16	18	2.086	6259	0.0901
Washed	2	30.5	2.96	18	1.998	5994	0.0863
	3	36.3	3.29	18	2.140	6419	0.0924
	4	34.8	3.31	18	2.039	6116	0.0881
	5	36.8	3.55	18	2.010	6031	0.0868
				Average	2.055	6164	0.0888
3	1	30.1	69.42	19	0.082	246	0.0035
Unwashed	2	30.9	62.76	19	0.093	279	0.0040
	3	30.5	53.59	19	0.108	323	0.0047
	4	29.9	49.76	19	0.114	341	0.0049
	5	30.9	48.42	19	0.121	362	0.0052
3	1	32.5	11.11	19	0.553	1660	0.0239
Washed	2	32.6	10.91	19	0.565	1696	0.0244
	3	32.1	10.83	19	0.561	1682	0.0242
	4	31.3	10.51	19	0.563	1690	0.0243
	5	32.5	10.82	19	0.568	1704	0.0245
				Average	0.562	1686	0.0243
4	1	33.2	11.68	19	0.538	1613	0.0232
Unwashed	2	33.6	10.51	19	0.605	1814	0.0261
	3	33.5	10.05	19	0.630	1891	0.0272
	4	34.7	10.26	19	0.640	1919	0.0276
	5	33.6	9.70	19	0.655	1966	0.0283
4	1	33.2	5.63	19	1.115	3346	0.0482
Washed	2	32.9	5.56	19	1.119	3358	0.0483
	3	32.8	5.56	19	1.116	3347	0.0482
	4	34.2	5.77	19	1.121	3363	0.0484
	5	33.3	5.59	19	1.127	3380	0.0487
				Average	1.120	3359	0.0484

Table C.3 - Permittivity Test Results for the Pacific Way Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	29.4	4.80	20	1.130	3391	0.2441
Unwashed	2	35.3	5.18	20	1.258	3773	0.2716
	3	37.7	5.08	20	1.370	4109	0.2957
	4	40.1	5.06	20	1.463	4388	0.3158
	5	38.5	4.79	20	1.483	4450	0.3203
1	1	37.7	3.66	20	1.901	5703	0.4105
Washed	2	36.1	3.72	20	1.791	5373	0.3867
	3	37.2	3.81	20	1.802	5406	0.3891
	4	37.6	3.80	20	1.826	5479	0.3943
	5	41.9	4.22	20	1.833	5498	0.3956
				Average	1.831	5492	0.3952
2	1	37.5	9.26	20	0.747	2242	0.1614
Unwashed	2	37.3	8.38	20	0.822	2465	0.1774
	3	38.6	7.34	20	0.971	2912	0.2096
	4	38.9	7.03	20	1.021	3064	0.2205
	5	37.0	6.36	20	1.074	3221	0.2318
2	1	35.4	3.71	20	1.761	5283	0.3802
Washed	2	37.4	3.86	20	1.788	5365	0.3861
	3	35.6	3.69	20	1.781	5342	0.3844
	4	36.5	3.75	20	1.796	5389	0.3879
	5	39.1	3.99	20	1.809	5426	0.3905
				Average	1.787	5361	0.3858
3	1	37.9	15.91	20	0.440	1319	0.0949
Unwashed	2	38.5	13.20	20	0.538	1615	0.1162
	3	38.6	11.17	20	0.638	1913	0.1377
	4	37.2	10.02	20	0.685	2056	0.1479
	5	38.2	9.74	20	0.724	2172	0.1563
3	1	35.4	4.69	20	1.393	4179	0.3008
Washed	2	37.4	4.95	20	1.395	4184	0.3011
	3	34.8	4.66	20	1.378	4135	0.2976
	4	37.0	4.94	20	1.382	4147	0.2985
	5	35.2	4.74	20	1.371	4112	0.2959
				Average	1.384	4151	0.2988
4	1	38.9	8.59	20	0.836	2507	0.1805
Unwashed	2	37.3	7.17	20	0.960	2880	0.2073
	3	40.9	6.84	20	1.104	3311	0.2383
	4	40.1	6.26	20	1.182	3547	0.2553
	5	38.9	5.88	20	1.221	3663	0.2636
4	1	34.7	3.99	20	1.605	4815	0.3465
Washed	2	40.0	4.31	20	1.713	5139	0.3698
	3	36.7	4.19	20	1.617	4850	0.3490
	4	33.3	3.81	20	1.613	4839	0.3483
	5	21.6	2.51	20	1.588	4765	0.3429
				Average	1.627	4882	0.3513

Table C.4 - Permittivity Test Results for the SR-14 Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1 Unwashed	1	15.0	359.99	21	0.0075	23	0.00056
	2	25.2	359.93	21	0.0126	38	0.00093
	3	25.6	360.06	21	0.0128	38	0.00095
	4	21.0	239.90	21	0.0158	47	0.00116
	5	32.3	359.99	21	0.0162	49	0.00119
1 Washed	1	36.0	117.13	21	0.0554	166	0.00408
	2	38.1	121.42	21	0.0565	170	0.00417
	3	38.1	120.84	21	0.0568	170	0.00419
	4	38.2	121.06	21	0.0569	171	0.00419
	5	38.7	122.02	21	0.0571	171	0.00421
				Average	0.0566	170	0.00417
2 Unwashed	1	31.4	300.03	21	0.0188	57	0.00139
	2	37.0	289.60	21	0.0230	69	0.00170
	3	38.0	240.02	21	0.0285	86	0.00210
	4	32.2	239.91	21	0.0242	73	0.00178
	5	32.7	180.65	21	0.0326	98	0.00240
2 Washed	1	35.2	109.52	21	0.0579	174	0.00426
	2	35.2	107.98	21	0.0587	176	0.00433
	3	35.3	105.74	21	0.0601	180	0.00443
	4	34.3	101.37	21	0.0610	183	0.00450
	5	35.1	104.84	21	0.0603	181	0.00445
				Average	0.0596	179	0.00439
3 Unwashed	1	11.3	180.80	21	0.0113	34	0.00083
	2	13.0	180.83	21	0.0130	39	0.00095
	3	14.6	180.24	21	0.0146	44	0.00108
	4	14.9	180.32	21	0.0149	45	0.00110
	5	19.2	180.38	21	0.0192	58	0.00141
3 Washed	1	30.2	107.18	21	0.0508	152	0.00374
	2	30.2	106.53	21	0.0511	153	0.00376
	3	29.9	99.99	21	0.0539	162	0.00397
	4	30.0	101.84	21	0.0531	159	0.00391
	5	30.0	100.38	21	0.0538	162	0.00397
				Average	0.0525	158	0.00387
4 Unwashed	1	20.9	180.25	21	0.0209	63	0.00154
	2	21.4	180.01	21	0.0214	64	0.00158
	3	26.9	179.91	21	0.0269	81	0.00199
	4	28.3	179.95	21	0.0283	85	0.00209
	5	31.2	180.20	21	0.0312	94	0.00230
4 Washed	1	30.6	104.10	21	0.0530	159	0.00390
	2	30.6	101.64	21	0.0542	163	0.00400
	3	30.3	100.94	21	0.0541	162	0.00399
	4	29.8	97.18	21	0.0552	166	0.00407
	5	32.7	109.26	21	0.0539	162	0.00397
				Average	0.0541	162	0.00399

Table C.5 - Permittivity Test Results for the SR-9 (Marsh Rd.) Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1 Unwashed	1	32.2	86.66	20	0.0686	206	0.00446
	2	31.2	79.67	20	0.0723	217	0.00470
	3	31.3	74.09	20	0.0780	234	0.00507
	4	31.0	73.18	20	0.0782	235	0.00508
	5	31.1	70.85	20	0.0810	243	0.00527
1 Washed	1	31.5	56.46	20	0.1030	309	0.00669
	2	30.7	54.99	20	0.1030	309	0.00670
	3	30.9	55.99	20	0.1019	306	0.00662
	4	31.0	55.06	20	0.1039	312	0.00675
	5	32.4	57.31	20	0.1043	313	0.00678
				Average	0.1032	310	0.00671
2 Unwashed	1	21.5	194.29	20	0.0204	61	0.00133
	2	25.4	179.50	20	0.0261	78	0.00170
	3	26.0	179.86	20	0.0267	80	0.00173
	4	27.7	181.16	20	0.0282	85	0.00183
	5	28.1	180.48	20	0.0287	86	0.00187
2 Washed	1	30.1	71.28	20	0.0779	234	0.00507
	2	30.1	70.67	20	0.0786	236	0.00511
	3	31.6	74.30	20	0.0785	235	0.00510
	4	31.7	74.65	20	0.0784	235	0.00509
	5	31.4	73.96	20	0.0784	235	0.00509
				Average	0.0784	235	0.00509
3 Unwashed	1	30.9	98.39	20	0.0580	174	0.00377
	2	31.6	99.84	20	0.0584	175	0.00380
	3	30.8	95.79	20	0.0593	178	0.00386
	4	30.5	92.81	20	0.0607	182	0.00394
	5	30.7	92.50	20	0.0613	184	0.00398
3 Washed	1	30.8	63.00	20	0.0902	271	0.00587
	2	34.8	72.20	20	0.0890	267	0.00578
	3	29.3	61.27	20	0.0883	265	0.00574
	4	30.4	63.20	20	0.0888	266	0.00577
	5	30.3	63.36	20	0.0883	265	0.00574
				Average	0.0889	267	0.00578
4 Unwashed	1	27.2	106.09	20	0.0473	142	0.00308
	2	27.2	100.35	20	0.0500	150	0.00325
	3	27.7	96.86	20	0.0528	158	0.00343
	4	31.1	102.43	20	0.0560	168	0.00364
	5	28.8	85.66	20	0.0621	186	0.00403
4 Washed	1	30.9	56.99	20	0.1001	300	0.00650
	2	31.4	57.79	20	0.1003	301	0.00652
	3	30.9	56.77	20	0.1005	301	0.00653
	4	30.8	56.61	20	0.1004	301	0.00653
	5	31.4	57.32	20	0.1011	303	0.00657
				Average	0.1005	301	0.00653

Table C.6 - Permittivity Test Results for the SR-546 Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	30.9	40.42	19	0.1446	434	0.0086
Unwashed	2	31.1	40.61	19	0.1448	435	0.0086
	3	31.6	40.88	19	0.1462	439	0.0087
	4	30.5	39.45	19	0.1462	439	0.0087
	5	32.7	42.06	19	0.1470	441	0.0088
1	1	30.2	36.91	19	0.1548	464	0.0092
Washed	2	31.3	38.26	19	0.1547	464	0.0092
	3	31.1	38.10	19	0.1544	463	0.0092
	4	31.1	38.28	19	0.1537	461	0.0092
	5	32.1	39.76	19	0.1527	458	0.0091
				Average	0.1540	462	0.0092
2	1	32.5	37.58	20	0.1596	479	0.0095
Unwashed	2	31.6	36.05	20	0.1618	485	0.0096
	3	31.6	35.18	20	0.1658	497	0.0099
	4	31.6	35.09	20	0.1662	499	0.0099
	5	32.4	35.79	20	0.1671	501	0.0100
2	1	32.1	32.40	20	0.1829	549	0.0109
Washed	2	32.2	32.64	20	0.1821	546	0.0109
	3	32.7	33.32	20	0.1811	543	0.0108
	4	32.8	33.45	20	0.1810	543	0.0108
	5	32.6	33.36	20	0.1804	541	0.0107
				Average	0.1815	544	0.0108
3	1	34.5	77.68	20	0.0820	246	0.0049
Unwashed	2	34.2	72.74	20	0.0868	260	0.0052
	3	32.6	68.28	20	0.0881	264	0.0053
	4	32.2	65.92	20	0.0902	270	0.0054
	5	32.0	65.77	20	0.0898	269	0.0054
3	1	31.3	50.87	20	0.1136	341	0.0068
Washed	2	30.2	49.26	20	0.1132	339	0.0067
	3	31.9	52.80	20	0.1115	335	0.0066
	4	31.4	52.22	20	0.1110	333	0.0066
	5	33.5	55.69	20	0.1110	333	0.0066
				Average	0.1120	336	0.0067
4	1	31.4	37.06	20	0.1564	469	0.0093
Unwashed	2	31.2	36.50	20	0.1578	473	0.0094
	3	32.4	37.34	20	0.1601	480	0.0095
	4	32.8	37.49	20	0.1615	484	0.0096
	5	31.4	35.90	20	0.1614	484	0.0096
4	1	31.1	32.91	20	0.1744	523	0.0104
Washed	2	31.4	33.37	20	0.1737	521	0.0104
	3	31.3	33.36	20	0.1732	520	0.0103
	4	32.0	34.05	20	0.1735	520	0.0103
	5	34.6	37.13	20	0.1720	516	0.0103
				Average	0.1733	520	0.0103

Table C.7 - Permittivity Test Results for the Carroll Road Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1 Unwashed	1	26.0	107.45	20	0.045	134	0.0019
	2	33.0	107.15	20	0.057	171	0.0025
	3	27.4	78.37	20	0.065	194	0.0028
	4	32.4	81.57	20	0.073	220	0.0032
	5	31.3	77.93	20	0.074	222	0.0032
1 Washed	1	35.6	17.27	20	0.380	1141	0.0164
	2	33.4	15.88	20	0.388	1165	0.0168
	3	34.5	16.51	20	0.386	1157	0.0167
	4	36.7	17.41	20	0.389	1167	0.0168
	5	36.0	17.06	20	0.389	1168	0.0168
				Average	0.387	1160	0.0167
2 Unwashed	1	18.7	240.14	20	0.014	43	0.0006
	2	21.1	240.02	20	0.016	49	0.0007
	3	31.2	202.87	20	0.028	85	0.0012
	4	31.2	181.03	20	0.032	95	0.0014
	5	30.5	165.45	20	0.034	102	0.0015
2 Washed	1	32.0	49.91	20	0.118	355	0.0051
	2	32.0	48.77	20	0.121	363	0.0052
	3	31.6	47.52	20	0.123	368	0.0053
	4	32.2	48.24	20	0.123	370	0.0053
	5	32.2	47.89	20	0.124	372	0.0054
				Average	0.122	366	0.0053
3 Unwashed	1	31.3	73.06	20	0.079	237	0.0034
	2	32.0	62.53	20	0.094	283	0.0041
	3	32.0	57.27	20	0.103	309	0.0045
	4	31.3	53.59	20	0.108	323	0.0047
	5	32.0	53.74	20	0.110	330	0.0047
3 Washed	1	31.7	14.35	20	0.408	1223	0.0176
	2	31.7	14.25	20	0.411	1232	0.0177
	3	33.8	15.05	20	0.415	1244	0.0179
	4	32.7	14.62	20	0.413	1238	0.0178
	5	32.3	14.39	20	0.414	1243	0.0179
				Average	0.412	1236	0.0178
4 Unwashed	1	32.4	137.46	19	0.045	134	0.0019
	2	31.9	89.56	19	0.067	202	0.0029
	3	32.3	78.22	19	0.078	234	0.0034
	4	32.6	72.16	19	0.085	256	0.0037
	5	31.3	69.19	19	0.086	257	0.0037
4 Washed	1	31.8	27.43	19	0.219	658	0.0095
	2	31.9	27.34	19	0.221	662	0.0095
	3	32.2	27.31	19	0.223	669	0.0096
	4	32.8	27.63	19	0.225	674	0.0097
	5	31.2	25.35	19	0.233	698	0.0101
				Average	0.224	672	0.0097

Table C.8 - Permittivity Test Results for the SR-504 Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	33.2	9.38	19	0.669	2008	0.1870
Unwashed	2	34.8	8.00	19	0.823	2468	0.2299
	3	35.9	7.55	19	0.899	2698	0.2513
	4	33.1	6.52	19	0.960	2881	0.2683
	5	34.4	6.47	19	1.006	3017	0.2810
1	1	35.6	5.21	19	1.292	3877	0.3611
Washed	2	35.1	5.16	19	1.287	3860	0.3595
	3	35.6	5.20	19	1.295	3885	0.3618
	4	33.8	5.02	19	1.273	3820	0.3558
	5	38.2	5.58	19	1.295	3885	0.3618
				Average	1.288	3865	0.3600
2	1	36.5	7.89	19	0.875	2625	0.2445
Unwashed	2	33.8	6.36	19	1.005	3016	0.2808
	3	35.6	6.25	19	1.077	3232	0.3010
	4	35.9	5.91	19	1.149	3447	0.3210
	5	35.8	5.72	19	1.184	3551	0.3307
2	1	36.8	4.53	19	1.537	4610	0.4293
Washed	2	35.7	4.30	19	1.570	4711	0.4387
	3	37.8	4.61	19	1.551	4653	0.4333
	4	37.1	4.50	19	1.559	4678	0.4357
	5	36.6	4.48	19	1.545	4636	0.4317
				Average	1.552	4657	0.4338
3	1	36.1	9.80	19	0.697	2090	0.1947
Unwashed	2	37.0	8.59	19	0.815	2444	0.2276
	3	36.5	7.83	19	0.882	2645	0.2463
	4	36.3	7.33	19	0.937	2810	0.2617
	5	36.1	6.98	19	0.978	2935	0.2733
3	1	36.6	5.45	19	1.270	3811	0.3549
Washed	2	36.3	5.45	19	1.260	3779	0.3520
	3	36.7	5.48	19	1.267	3800	0.3539
	4	38.2	5.79	19	1.248	3744	0.3487
	5	37.5	5.63	19	1.260	3779	0.3520
				Average	1.261	3783	0.3523
4	1	36.1	7.81	19	0.874	2623	0.2443
Unwashed	2	37.1	6.86	19	1.023	3069	0.2858
	3	35.4	5.88	19	1.139	3416	0.3182
	4	37.1	5.86	19	1.197	3592	0.3346
	5	36.3	5.36	19	1.281	3843	0.3579
4	1	39.1	4.33	19	1.708	5124	0.4772
Washed	2	38.6	4.32	19	1.690	5070	0.4722
	3	36.8	4.12	19	1.689	5068	0.4720
	4	39.5	4.40	19	1.698	5094	0.4744
	5	34.8	3.88	19	1.696	5089	0.4740
				Average	1.696	5089	0.4740

Table C.9 - Permittivity Test Results for the 49th Ave. N.E. Tacoma Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	28.4	179.89	19	0.0299	90	0.00182
Unwashed	2	31.2	168.56	19	0.0350	105	0.00214
	3	31.4	161.79	19	0.0367	110	0.00224
	4	31.5	155.54	19	0.0383	115	0.00234
	5	31.5	144.40	19	0.0413	124	0.00252
1	1	31.1	65.64	19	0.0896	269	0.00547
Washed	2	31.4	65.62	19	0.0905	272	0.00552
	3	31.4	65.84	19	0.0902	271	0.00550
	4	32.0	66.65	19	0.0908	272	0.00554
	5	34.4	72.47	19	0.0898	269	0.00548
				Average	0.0902	271	0.00550
2	1	16.0	300.22	19	0.0101	30	0.00061
Unwashed	2	17.8	300.17	19	0.0112	34	0.00068
	3	21.2	300.02	19	0.0134	40	0.00082
	4	25.5	300.09	19	0.0161	48	0.00098
	5	25.6	300.06	19	0.0161	48	0.00098
2	1	27.3	76.29	19	0.0677	203	0.00413
Washed	2	27.5	77.88	19	0.0668	200	0.00407
	3	27.3	76.35	19	0.0676	203	0.00413
	4	26.7	73.12	19	0.0691	207	0.00421
	5	27.8	76.02	19	0.0692	208	0.00422
				Average	0.0681	204	0.00415
3	1	22.5	180.07	19	0.0236	71	0.00144
Unwashed	2	26.9	179.95	19	0.0283	85	0.00172
	3	26.9	168.16	19	0.0303	91	0.00185
	4	27.1	156.01	19	0.0329	99	0.00200
	5	27.0	143.64	19	0.0356	107	0.00217
3	1	32.1	80.43	19	0.0755	226	0.00460
Washed	2	31.4	78.07	19	0.0761	228	0.00464
	3	31.4	76.28	19	0.0779	234	0.00475
	4	31.9	76.36	19	0.0790	237	0.00482
	5	32.0	76.43	19	0.0792	238	0.00483
				Average	0.0775	233	0.00473
4	1	27.2	99.35	18	0.0531	159	0.00324
Unwashed	2	25.5	86.37	18	0.0573	172	0.00349
	3	27.1	84.42	18	0.0622	187	0.00380
	4	26.6	84.91	18	0.0607	182	0.00371
	5	27.6	87.30	18	0.0613	184	0.00374
4	1	31.9	23.51	18	0.2631	789	0.01605
Washed	2	33.7	24.45	18	0.2673	802	0.01630
	3	31.8	22.74	18	0.2712	814	0.01654
	4	32.5	24.27	18	0.2597	779	0.01584
	5	31.0	23.19	18	0.2592	778	0.01581
				Average	0.2641	792	0.01611

Table C.10 - Permittivity Test Results for the SR-16 Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	33.7	52.06	20	0.119	358	0.00179
Unwashed	2	32.6	47.53	20	0.127	380	0.00190
	3	32.1	45.14	20	0.131	394	0.00197
	4	32.9	44.20	20	0.137	412	0.00206
	5	31.2	41.39	20	0.139	417	0.00209
1	1	32.9	30.34	20	0.200	600	0.00300
Washed	2	32.4	30.07	20	0.199	597	0.00298
	3	33.4	31.31	20	0.197	591	0.00295
	4	32.6	30.55	20	0.197	591	0.00295
	5	33.3	31.11	20	0.198	593	0.00296
				Average	0.198	594	0.00297
2	1	32.6	27.52	20	0.219	656	0.00328
Unwashed	2	32.1	25.91	20	0.229	686	0.00343
	3	33.4	26.02	20	0.237	711	0.00355
	4	32.6	24.95	20	0.241	723	0.00362
	5	33.4	25.56	20	0.241	724	0.00362
2	1	33.9	19.59	20	0.319	958	0.00479
Washed	2	34.0	19.81	20	0.317	950	0.00475
	3	33.6	19.53	20	0.318	953	0.00476
	4	35.0	20.27	20	0.319	956	0.00478
	5	34.1	19.78	20	0.318	955	0.00477
				Average	0.318	954	0.00477
3	1	32.5	22.23	20	0.270	809	0.00405
Unwashed	2	34.2	22.41	20	0.282	845	0.00423
	3	34.8	21.80	20	0.295	884	0.00442
	4	34.5	21.64	20	0.294	883	0.00441
	5	36.2	22.65	20	0.295	885	0.00442
3	1	34.0	17.49	20	0.359	1076	0.00538
Washed	2	32.4	16.70	20	0.358	1074	0.00537
	3	34.5	17.59	20	0.362	1086	0.00543
	4	33.5	17.27	20	0.358	1074	0.00537
	5	33.5	17.21	20	0.359	1078	0.00539
				Average	0.359	1078	0.00539
4	1	31.5	71.41	21	0.079	238	0.00119
Unwashed	2	32.3	60.92	21	0.096	287	0.00143
	3	32.4	58.32	21	0.100	300	0.00150
	4	32.5	55.27	21	0.106	318	0.00159
	5	32.0	52.05	21	0.111	332	0.00166
4	1	33.2	32.14	21	0.186	558	0.00279
Washed	2	32.9	32.52	21	0.182	547	0.00273
	3	32.8	32.52	21	0.182	545	0.00273
	4	34.2	32.49	21	0.190	569	0.00284
	5	33.3	32.52	21	0.184	553	0.00277
				Average	0.185	555	0.00277

Table C.11 - Permittivity Test Results for the SR-502 Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	33.4	10.30	21	0.584	1753	0.1261
Unwashed	2	32.8	9.13	21	0.647	1942	0.1397
	3	32.5	8.33	21	0.703	2109	0.1518
	4	32.5	7.99	21	0.733	2198	0.1582
	5	32.7	7.78	21	0.757	2272	0.1635
1	1	33.8	3.57	21	1.706	5117	0.3683
Washed	2	33.8	3.53	21	1.725	5175	0.3724
	3	33.5	3.53	21	1.710	5129	0.3691
	4	34.4	3.66	21	1.693	5080	0.3656
	5	34.5	3.59	21	1.731	5194	0.3738
				Average	1.713	5139	0.3698
2	1	33.9	19.91	21	0.307	920	0.0662
Unwashed	2	33.2	16.69	21	0.358	1075	0.0774
	3	32.9	14.13	21	0.419	1258	0.0906
	4	33.0	13.02	21	0.457	1370	0.0986
	5	33.4	12.13	21	0.496	1488	0.1071
2	1	34.5	4.32	21	1.439	4316	0.3106
Washed	2	34.2	4.20	21	1.467	4401	0.3167
	3	34.8	4.28	21	1.465	4395	0.3163
	4	31.3	3.92	21	1.439	4316	0.3106
	5	32.1	3.96	21	1.460	4381	0.3153
				Average	1.454	4362	0.3139
3	1	31.9	21.09	21	0.273	818	0.0588
Unwashed	2	32.8	18.26	21	0.324	971	0.0699
	3	32.4	16.20	21	0.360	1081	0.0778
	4	30.8	14.46	21	0.384	1151	0.0829
	5	32.4	14.10	21	0.414	1242	0.0894
3	1	33.0	4.76	21	1.249	3747	0.2697
Washed	2	31.6	4.54	21	1.254	3762	0.2707
	3	33.5	4.85	21	1.244	3733	0.2687
	4	33.8	4.92	21	1.238	3713	0.2672
	5	33.5	4.88	21	1.237	3710	0.2670
				Average	1.244	3733	0.2687
4	1	32.8	11.27	21	0.524	1573	0.1132
Unwashed	2	32.9	10.01	21	0.592	1776	0.1278
	3	33.1	9.15	21	0.652	1955	0.1407
	4	31.9	7.95	21	0.723	2169	0.1561
	5	33.3	7.76	21	0.773	2319	0.1669
4	1	34.0	3.78	21	1.620	4861	0.3499
Washed	2	32.7	3.61	21	1.632	4896	0.3523
	3	32.3	3.56	21	1.635	4904	0.3529
	4	33.6	3.66	21	1.654	4962	0.3571
	5	32.7	3.59	21	1.641	4923	0.3543
				Average	1.636	4909	0.3533

Table C.12 - Permittivity Test Results for the Olson Road Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	33.4	11.65	22	0.504	1513	0.1217
Unwashed	2	33.0	8.15	22	0.712	2137	0.1719
	3	33.8	6.96	22	0.854	2563	0.2061
	4	33.7	6.16	22	0.962	2887	0.2322
	5	31.4	5.42	22	1.019	3057	0.2459
1	1	35.3	3.55	22	1.749	5248	0.4221
Washed	2	29.6	3.02	22	1.724	5173	0.4161
	3	34.3	3.38	22	1.785	5356	0.4308
	4	34.2	3.48	22	1.729	5187	0.4172
	5	32.6	3.31	22	1.733	5198	0.4181
				Average	1.744	5232	0.4208
2	1	32.8	9.90	22	0.583	1749	0.1406
Unwashed	2	32.4	7.12	22	0.801	2402	0.1932
	3	32.6	6.34	22	0.905	2714	0.2183
	4	32.7	5.68	22	1.013	3038	0.2444
	5	34.1	5.64	22	1.064	3191	0.2567
2	1	31.2	3.51	22	1.564	4691	0.3773
Washed	2	34.0	3.75	22	1.595	4785	0.3849
	3	32.9	3.66	22	1.581	4744	0.3816
	4	34.9	3.97	22	1.546	4639	0.3732
	5	32.9	3.73	22	1.552	4655	0.3744
				Average	1.568	4703	0.3783
3	1	33.4	24.94	22	0.236	707	0.0568
Unwashed	2	32.2	13.94	22	0.406	1219	0.0981
	3	32.8	10.95	22	0.527	1581	0.1272
	4	32.8	9.19	22	0.628	1884	0.1515
	5	33.0	8.29	22	0.700	2101	0.1690
3	1	33.7	3.55	22	1.670	5010	0.4030
Washed	2	35.3	3.73	22	1.665	4995	0.4017
	3	33.7	3.64	22	1.629	4886	0.3930
	4	34.7	3.69	22	1.654	4963	0.3992
	5	34.3	3.63	22	1.662	4987	0.4011
				Average	1.656	4968	0.3996
4	1	32.7	12.29	22	0.468	1404	0.1129
Unwashed	2	32.5	8.73	22	0.655	1965	0.1580
	3	33.6	7.88	22	0.750	2250	0.1810
	4	32.3	6.94	22	0.819	2456	0.1976
	5	35.0	7.00	22	0.880	2639	0.2122
4	1	32.3	3.74	19	1.633	4900	0.3942
Washed	2	33.7	3.88	19	1.643	4928	0.3964
	3	32.9	3.81	19	1.633	4900	0.3941
	4	35.1	3.99	19	1.664	4992	0.4015
	5	34.6	3.98	19	1.644	4933	0.3968
				Average	1.644	4931	0.3966

Table C.13 - Permittivity Test Results for the SR-9 (Sumas) Site.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
1	1	30.7	90.03	21	0.0614	184	0.00234
Unwashed	2	31.7	90.06	21	0.0634	190	0.00242
	3	31.3	81.68	21	0.0690	207	0.00263
	4	31.6	80.63	21	0.0706	212	0.00269
	5	31.3	76.71	21	0.0735	221	0.00280
1	1	31.7	30.45	21	0.1876	563	0.00589
Washed	2	31.3	29.83	21	0.1890	567	0.00594
	3	32.0	30.02	21	0.1920	576	0.00603
	4	31.2	29.66	21	0.1895	569	0.00595
	5	31.4	29.64	21	0.1909	573	0.00599
				Average	0.1898	569	0.00596
2	1	31.4	149.46	21	0.0378	114	0.00144
Unwashed	2	31.5	148.42	21	0.0382	115	0.00146
	3	31.6	141.70	21	0.0402	121	0.00153
	4	30.6	134.16	21	0.0411	123	0.00157
	5	30.6	132.03	21	0.0418	125	0.00159
2	1	31.0	59.91	21	0.0932	280	0.00293
Washed	2	31.0	59.95	21	0.0932	279	0.00293
	3	31.0	59.86	21	0.0933	280	0.00293
	4	31.2	59.99	21	0.0937	281	0.00294
	5	30.8	59.58	21	0.0931	279	0.00292
				Average	0.0933	280	0.00293
3	1	32.7	85.26	21	0.0691	207	0.00263
Unwashed	2	32.3	77.94	21	0.0747	224	0.00284
	3	31.7	71.60	21	0.0798	239	0.00304
	4	31.7	69.36	21	0.0823	247	0.00314
	5	32.3	69.63	21	0.0836	251	0.00318
3	1	31.6	35.29	21	0.1613	484	0.00507
Washed	2	32.1	35.98	21	0.1607	482	0.00505
	3	30.7	34.15	21	0.1620	486	0.00509
	4	31.4	34.95	21	0.1619	486	0.00508
	5	32.2	35.90	21	0.1616	485	0.00507
				Average	0.1615	484	0.00507
4	1	31.5	95.80	21	0.0592	178	0.00226
Unwashed	2	32.1	91.70	21	0.0631	189	0.00240
	3	31.6	89.35	21	0.0637	191	0.00243
	4	31.1	86.37	21	0.0649	195	0.00247
	5	31.0	83.09	21	0.0672	202	0.00256
4	1	31.3	46.79	21	0.1205	362	0.00378
Washed	2	31.2	46.74	21	0.1203	361	0.00378
	3	32.7	48.97	21	0.1203	361	0.00378
	4	31.9	47.43	21	0.1212	364	0.00380
	5	31.7	47.87	21	0.1193	358	0.00375
				Average	0.1203	361	0.00378

Table C.14 - Permittivity Test Results for the Trial Wash (Control) Samples.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
Typar 3401 Unwashed	1	35.4	4.56	20	1.4328	4298	0.06190
	2	33.4	4.32	20	1.4270	4281	0.06165
	3	31.6	4.10	20	1.4225	4268	0.06145
	4	34.5	4.46	20	1.4277	4283	0.06168
	5	37.1	4.66	20	1.4694	4408	0.06348
Typar 3401 Washed	1	36.0	4.39	20	1.5135	4541	0.06538
	2	35.4	4.32	20	1.5124	4537	0.06534
	3	33.5	4.09	20	1.5117	4535	0.06531
	4	30.8	3.84	20	1.4804	4441	0.06395
	5	36.1	4.46	20	1.4939	4482	0.06454
				Average	1.5024	4507	0.06490
Polyfelt **TS 600** Unwashed	1	38.8	3.33	20	2.1505	6452	0.43010
	2	32.5	2.80	20	2.1423	6427	0.42846
	3	36.4	3.10	20	2.1672	6502	0.43344
	4	35.4	3.06	20	2.1352	6406	0.42704
	5	37.2	3.11	20	2.2077	6623	0.44154
Polyfelt **TS 600** Washed	1	34.1	2.69	20	2.3397	7019	0.46794
	2	36.0	2.83	20	2.3479	7044	0.46957
	3	37.1	2.98	20	2.2978	6893	0.45956
	4	33.8	2.77	20	2.2521	6756	0.45043
	5	39.4	3.20	20	2.2725	6817	0.45450
				Average	2.3020	6906	0.46040
Polyfelt **TS 800** Unwashed	1	35.5	5.34	20	1.2270	3681	0.40491
	2	34.8	5.20	20	1.2352	3706	0.40761
	3	33.7	5.00	20	1.2440	3732	0.41052
	4	35.3	5.31	20	1.2270	3681	0.40490
	5	35.5	5.28	20	1.2409	3723	0.40951
Polyfelt **TS 800** Washed	1	32.6	4.88	20	1.2330	3699	0.40688
	2	33.8	5.05	20	1.2353	3706	0.40766
	3	34.4	5.13	20	1.2376	3713	0.40842
	4	33.3	4.92	20	1.2492	3748	0.41224
	5	35.5	5.30	20	1.2363	3709	0.40796
				Average	1.2383	3715	0.40863
Mirafi 600X Unwashed	1	30.5	35.27	20	0.1596	479	0.01021
	2	31.6	36.65	20	0.1591	477	0.01018
	3	32.1	37.05	20	0.1599	480	0.01023
	4	31.8	36.80	20	0.1595	478	0.01021
	5	31.9	36.92	20	0.1595	478	0.01021
Mirafi 600X Washed	1	32.4	37.92	20	0.1577	473	0.01009
	2	30.8	35.84	20	0.1586	476	0.01015
	3	31.3	36.66	20	0.1576	473	0.01009
	4	32.2	38.04	20	0.1562	469	0.01000
	5	31.7	37.14	20	0.1575	473	0.01008
				Average	0.1575	473	0.01008

Table C.14 (cont.) - Permittivity Test Results for the Trial Wash (Control) Samples.

Specimen No.	Run No.	Water Level Drop (cm)	Time For Drop (sec)	Temp. (C)	Permittivity (1/sec)	Flow Rate (l/min/m2)	Permeability (cm/sec)
Synthetic	1	30.2	59.91	20	0.0930	279	0.00520
Industries	2	30.1	60.03	20	0.0925	278	0.00517
956	3	30.7	60.59	20	0.0935	281	0.00523
Unwashed	4	29.9	60.06	20	0.0919	276	0.00514
	5	29.7	59.99	20	0.0914	274	0.00511
Synthetic	1	30.6	60.02	20	0.0941	282	0.00526
Industries	2	30.4	60.00	20	0.0935	281	0.00523
956	3	30.4	59.98	20	0.0935	281	0.00523
Washed	4	30.3	60.06	20	0.0931	279	0.00521
	5	30.3	60.14	20	0.0930	279	0.00520
				Average	0.0935	280	0.00522

Thicknesses used to calculate the permeability values

Fabric Type	Thickness, cm (mils)
Typar 3401	0.0432 (17)
Polyfelt TS 600	0.20 (79)
Polyfelt TS 800	0.33 (130)
Mirafi 600X	0.064 (25)
Synthetic Industries 956	0.056 (22)

Table C.15 - Thicknesses Used for Determining the Permeability Values.

Site Name	Geotextile Type & Weight g/m^2 (oz/yd^2)	Thickness cm (mils)	Source
Columbia Hts Road	Trevira 1114 143 (4.2)	0.1651 (65)	Manufacturer's Typical Value
Coal Creek Road	Typar 3401 136 (4.0)	0.0432 (17)	Manufacturer's Typical Value
Pacific Way	Trevira 1115 153 (4.5)	0.2159 (85)	Manufacturer's Typical Value
SR-14	Exxon GTF 300 231 (6.8)	0.0769 (30)	WSDOT Conformance Test Results
SR-9 (Marsh Rd.)	Permeatex 2350 163 (4.8)	0.065 (26)	WSDOT Conformance Test Results
SR-546	Propex 2002 149 (4.4)	0.0558 (22)	WSDOT Conformance Test Results
Carroll Road	Typar 3401 136 (4.0)	0.0432 (17)	Manufacturer's Typical Value
SR-504	Trevira 1125 251 (7.4)	0.2794 (110)	Manufacturer's Typical Value
49th Ave NE	Permeatex 2300 153 (4.5)	0.061 (24)	WSDOT Conformance Test Results
SR-16	Propex 2002 149 (4.4)	0.015 (6)	WSDOT Conformance Test Results
SR-502	Trevira 1115 153 (4.5)	0.2159 (85)	Manufacturer's Typical Value
Olson Road	Trevira 1120 204 (6.0)	0.2413 (95)	Manufacturer's Test Results for Lot Number
SR-9 (Sumas)	Permeatex 2200 122 (3.6)	0.0381 (15)	Manufacturer's Typical Value

APPENDIX D

Grab Tensile and Wide Width Strength Test Procedures and Results

Grab Tensile and Wide Width Strength Test Procedures and Results

A discussion of the grab tensile and wide width strength tests are presented in Chapter 7, Sections 7.3.3 and 7.3.4, respectively. The results are summarized in Sections 7.4.4 and 7.4.5. The grab tensile (ASTM D 4632) and wide width strength (ASTM D 4595) tests were performed at the Geosynthetics Laboratory at the University of Washington. The test results are presented in Table D.1.

In general, the following procedures were followed:

1. Lay the recovered geotextile sample out on a cutting surface. Randomly select six areas for wide width and grab tensile test specimens to be cut from.

2. Mark all the specimens so that they will be cut out and tested in the assumed machine direction for each site. The assumed machine direction is the direction which is parallel to the traffic lane.

3. Grab and wide width specimens should be marked so that they will be adjacent to each other for each specimen number (i.e. grab specimen 1 should be adjacent to wide width specimen 1).

4. Cut the test specimens out with scissors or an X-acto knife and straight edge. The nonwoven specimens are cut to the specified testing dimensions and the woven specimens are cut 1 cm or larger in the cross machine direction. The wovens are cut larger so that individual tapes can be pulled away to obtain the appropriate test specimen width. This also ensures that the tapes in the machine direction will be parallel to the axial direction of the applied test load.

5. After the grab and wide width specimens are cut, place each specimen over a light table and record the approximate number of holes, and average sizes, which will lie in the area between the testing grips (i.e. middle 102 mm for the wide width test, and middle 76 mm for the grab tests).

6. Mark the test dimension on each specimen according to the ASTM procedures. This is most important for the grab tests, so that the middle 25 mm of fabric is tested and that the tapes (wovens) stay parallel to the test direction. The wide width specimens do not necessarily have to be marked so long as the upper and lower grips remain parallel and exactly 102 mm apart when the specimen is clamped. A bubble level should be placed on the upper grip frame, which is able to swivel, so that it can be rotated to be parallel with the lower grips.

7. Soak all the specimens in water for 24 hr prior to testing.

8. Set up the MTS equipment so that the output will be recorded on a plotter, as well as, recorded on a voltmeter. The voltage change should be used to obtain the load from a calibration curve because this is the most accurate indicator of the peak strength of the test.

9. For the different material types, adjust the duration of the test so that the stroke of the piston will move at the desired strain rate (10 %/min for wide width tests and 30 cm/min for grab tests).

10. Calibrate the X and Y axes on the plotter for each set of specimens so that the expected curves will be a reasonable size.

11. The plotter output should be used to obtain the percent elongation at the peak load.

12. When the outputs are similar for a site, record only three curves (specimen) per page of the plotting paper. Therefore, only two sheets of plotting paper is needed for each set of six tests.

Table D.1 - Geotextile Strength Test Data.

		Wide Width Test Data				Grab Test Data			
				Approximate Geotextile Damage				Approximate Geotextile Damage	
Site	Specimen Number	Wide Width Strength kN/m (lb/in)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)	Grab Tensile Strength kN (lb)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)
Columbia Hts. Road	1	22.9 (131.0)	23.5	4	2 to 3	0.868 (195.1)	29.7	0	-
	2	3.7 (21.2)	26.8	120	2 to 3	0.431 (96.9)	57.0	8	2 to 3
	3	5.0 (28.6)	38.8	30	1 to 2	0.449 (100.9)	56.0	13	1 to 2
	4	5.9 (33.5)	40.5	30	1 to 3	0.386 (86.8)	52.0	8	1 to 2
	5	3.9 (22.0)	36.8	8	5 to 7	0.315 (70.8)	41.7	3	3 to 4
	6	4.9 (28.2)	43.3	11	1 to 3	0.288 (64.8)	53.3	7	2 to 4
	Average	4.7 (26.7)	37.2			0.374 (84.0)	52.0		
Coal Creek Road	1	4.4 (24.9)	24.5	2	6 to 7	0.208 (46.7)	43.0	0	-
	2	4.8 (27.2)	27.0	2	10 to 15	0.431 (96.9)	49.0	0	-
	3	6.1 (34.9)	30.8	0	-	0.493 (110.9)	66.3	0	-
	4	4.4 (25.4)	22.8	3	4 to 6	0.395 (88.8)	45.3	2	5
	5	5.6 (31.9)	34.5	2	2 to 3	0.377 (84.8)	57.0	1	10
	6	3.4 (19.4)	19.8	6	30	0.226 (50.7)	48.3	1	3
	Average	4.8 (27.3)	26.6			0.384 (86.4)	53.2		
Pacific Way	1	5.9 (33.7)	101.8	3	1 to 2	0.600 (135.0)	100+	3	1 to 2
	2	3.6 (20.4)	51.8	14	1 to 3	0.386 (86.8)	95.3	2	1 to 2
	3	3.1 (17.6)	38.5	9	1 to 3	0.458 (102.9)	86.0	2	1 to 2
	4	5.8 (33.2)	81.0	4	2 to 3	0.529 (118.9)	95.7	2	2
	5	5.9 (33.9)	79.8	4	1 to 3	0.520 (116.9)	94.3	0	-
	6	6.2 (35.2)	93.5	5	2 to 3	0.493 (110.9)	127.0	5	2 to 3
	Average	5.1 (29.0)	74.4			0.477 (107.3)	99.7		

Table D.1 (continued) - Geotextile Strength Test Data.

		Wide Width Test Data				Grab Test Data			
				Approximate Geotextile Damage				Approximate Geotextile Damage	
Site	Specimen Number	Wide Width Strength kN/m (lb/in)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)	Grab Tensile Strength kN (lb)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)
SR-14	1	26.7 (152.4)	13.1	0	-	1.252 (281.4)	12.3	0	-
	2	25.0 (142.9)	12.5	1	2	1.029 (231.2)	12.0	0	-
	3	26.2 (149.5)	12.8	0	-	1.350 (303.5)	14.0	0	-
	4	26.5 (151.1)	12.8	0	-	1.064 (239.3)	11.7	0	-
	5	22.2 (126.9)	11.3	2	3, 10	1.100 (247.3)	12.3	0	-
	6	26.3 (149.9)	13.1	0	-	0.993 (223.2)	12.0	0	-
	Average	25.5 (145.5)	12.6			1.131 (254.3)	12.4		
SR-9 (Marsh Rd.)	1	26.6 (152.0)	17.3	0	-	1.127 (253.3)	15.7	0	-
	2	26.0 (148.3)	18.0	0	-	1.055 (237.3)	16.3	0	-
	3	26.2 (149.5)	17.5	0	-	1.109 (249.3)	16.0	0	-
	4	25.3 (144.1)	17.5	0	-	1.046 (235.3)	16.3	0	-
	5	26.6 (151.6)	17.3	0	-	1.100 (247.3)	16.7	0	-
	6	26.5 (151.1)	17.5	0	-	1.073 (241.3)	17.0	0	-
	7	28.1 (160.2)	23.1	0	-				
	8	28.8 (164.3)	23.1	0	-				
	9	28.0 (159.8)	21.9	0	-				
	Average	28.3 (161.4)	22.7			1.085 (244.0)	16.3		
SR-546	1	25.1 (143.3)	24.5	0	-	1.064 (239.3)	18.7	0	-
	2	25.8 (147.4)	26.0	0	-	1.011 (227.2)	17.3	0	-
	3	24.2 (138.0)	20.8	0	-	1.046 (235.3)	18.3	0	-
	4	23.8 (135.9)	22.0	0	-	0.939 (211.2)	16.7	0	-
	5	25.2 (143.7)	25.0	0	-	1.038 (233.3)	17.3	0	-
	6	24.0 (137.2)	23.3	1	1	0.993 (223.2)	19.0	0	-
	Average	24.7 (140.9)	23.6			1.015 (228.2)	17.9		

Table D.1 (continued) - Geotextile Strength Test Data.

		Wide Width Test Data				Grab Test Data			
				Approximate Geotextile Damage				Approximate Geotextile Damage	
Site	Specimen Number	Wide Width Strength kN/m (lb/in)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)	Grab Tensile Strength kN (lb)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)
Carroll Road	1	3.1 (17.9)	8.5	60	3 to 6	0.235 (52.7)	32.7	23	3 to 6
	2	2.7 (15.4)	7.3	40	5 to 15	0.145 (32.7)	11.7	25	4 to 10
	3	2.1 (11.9)	6.8	50	4 to 15	0.092 (20.6)	33.0	18	4 to 15
	4	1.8 (10.4)	6.8	35	5 to 20	0.074 (16.6)	6.0	20	5 to 15
	5	2.3 (12.9)	8.3	45	3 to 15	0.083 (18.6)	27.0	40	3 to 10
	6	2.4 (13.6)	7.0	40	3 to 15	0.136 (30.7)	29.3	25	5 to 15
	Average	2.4 (13.7)	7.5			0.127 (28.7)	23.3		
SR-504	1	13.8 (78.5)	43.5	0	-	0.895 (201.2)	50.3	0	-
	2	15.7 (89.3)	49.5	0	-	0.966 (217.2)	55.7	0	-
	3	16.9 (96.6)	53.0	0	-	0.895 (201.2)	51.3	0	-
	4	14.1 (80.6)	42.3	0	-	1.082 (243.3)	58.0	0	-
	5	16.9 (96.4)	58.0	0	-	0.850 (191.1)	57.0	0	-
	6	14.6 (83.3)	49.3	0	-	1.127 (253.3)	52.0	0	-
	Average	15.3 (87.5)	49.3			0.969 (217.9)	54.1		
49th Ave N.E.	1	17.7 (101.0)	11.3	2	1 to 2	0.663 (149.0)	12.0	1	1
	2	9.1 (52.0)	7.3	10	2 (15-25), 8 (2-4)	0.368 (82.8)	8.0	9	3 to 5
	3	15.3 (87.4)	10.8	6	1 (7), 5 (1 to 3)	0.681 (153.0)	11.3	2	1 to 2
	4	17.6 (100.6)	10.5	1	1	0.645 (145.0)	9.7	0	-
	5	9.8 (56.2)	7.5	6	1 (8), 5 (3 to 4)	0.484 (108.9)	9.3*	1	2
	6	12.1 (69.3)	7.5	1	7	0.458 (102.9)	11.3*	4	2 to 3
	Average	13.6 (77.7)	9.2			0.550 (123.6)	10.3		

Table D.1 (continued) - Geotextile Strength Test Data.

		Wide Width Test Data				Grab Test Data			
				Approximate Geotextile Damage				Approximate Geotextile Damage	
Site	Specimen Number	Wide Width Strength kN/m (lb/in)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)	Grab Tensile Strength kN (lb)	Elongation (%)	Number of Holes in Test Area	Average Size (mm)
SR-16	1	19.3 (110.4)	15.5	0	-	0.806 (181.1)	14.3	0	-
	2	20.2 (115.4)	16.3	0	-	0.788 (177.1)	13.7	0	-
	3	21.1 (120.7)	17.4	0	-	0.859 (193.1)	14.0	0	-
	4	20.1 (115.0)	16.5	0	-	0.823 (185.1)	16.7	0	-
	5	20.2 (115.4)	17.4	0	-	0.797 (179.1)	14.0	0	-
	6	19.4 (110.8)	15.3	0	-	0.806 (181.1)	15.0	0	-
	Average	20.1 (114.6)	16.4			0.813 (182.8)	14.6		
SR-502	1	6.8 (38.7)	36.8	0	-	0.422 (94.9)	43.3	0	-
	2	7.4 (42.4)	34.8	0	-	0.511 (114.9)	48.3	0	-
	3	7.0 (39.9)	34.3	0	-	0.395 (88.8)	39.0	0	-
	4	7.3 (41.4)	42.0	0	-	0.547 (122.9)	61.7	0	-
	5	6.8 (38.7)	39.8	0	-	0.368 (82.8)	37.0	0	-
	6	6.5 (37.2)	37.3	3	1 to 2	0.413 (92.8)	52.7	0	-
	Average	7.0 (39.7)	37.5			0.443 (99.5)	47.0		
Olson Road	1	6.9 (39.4)	51.3	2	2 to 3	0.627 (141.0)	46.3	1	2
	2	7.9 (45.0)	37.0	0	-	0.707 (159.0)	54.3	2	1 to 2
	3	10.4 (59.5)	40.5	3	1 to 3	0.734 (165.1)	48.3	0	-
	4	10.0 (57.0)	41.5	4	1 to 4	0.707 (159.0)	50.3	1	2
	5	14.3 (81.6)	43.5	9	1 to 3	0.672 (151.0)	52.0	2	2 to 3
	6	11.6 (66.3)	38.0	15	2 to 10	0.743 (167.0)	46.3	1	3
	Average	10.2 (58.1)	42.0			0.698 (157.0)	49.6		

Table D.1 (continued) - Geotextile Strength Test Data.

		Wide Width Test Data				Grab Test Data			
		Wide Width Strength	Elongation	Approximate Geotextile Damage		Grab Tensile Strength	Elongation	Approximate Geotextile Damage	
Site	Specimen Number	kN/m (lb/in)	(%)	Number of Holes in Test Area	Average Size (mm)	kN (lb)	(%)	Number of Holes in Test Area	Average Size (mm)
SR-9	1	11.6 (66.4)	13.4	2	1 to 2	0.422 (94.9)	11.7	3	3 to 5
(Sumas)	2	10.1 (57.8)	11.9	3	3 to 5	0.413 (92.8)	10.7	1	6
	3	12.5 (71.4)	12.5	0	-	0.520 (116.9)	13.7	0	-
	4	11.9 (67.7)	12.6	4	2 to 4	0.591 (133.0)	15.3	0	-
	5	12.8 (73.0)	14.0	1	6	0.520 (116.9)	13.7	1	2
	6	15.0 (85.3)	16.1	0	-	0.538 (120.9)	13.3	1	1
	Average	12.3 (70.3)	13.4			0.501 (112.6)	13.1		

▨ - Indicates tests which were not included in the averages due to the following:

Columbia Heights Road - Specimen 1 was a heavier weight material (from under the overlap).
Coal Creek Road - Strain rate was set at the wrong speed.
Pacific Way - Elongation went beyond the initial test range.

APPENDIX E

Illustration of Blinding, Clogging, and Caking

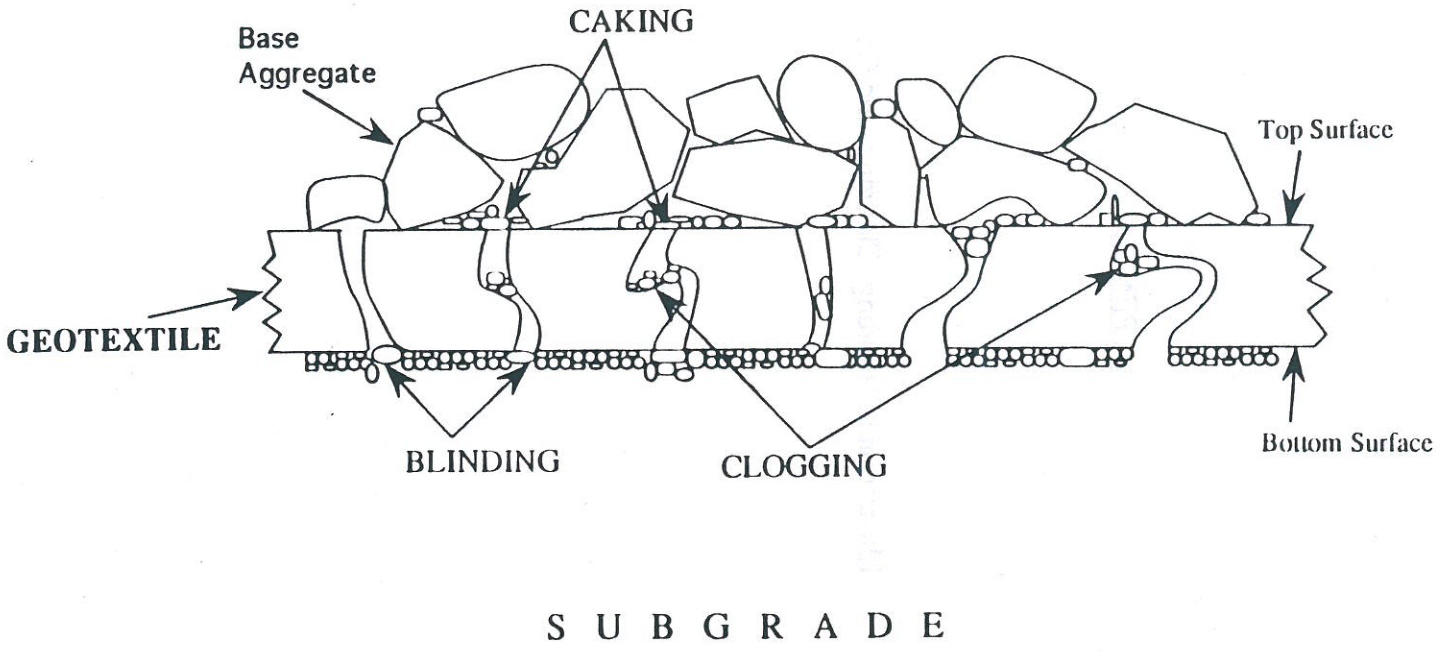


Figure E.1 - Illustration of Blinding, Clogging, and Caking.

APPENDIX F

General Special Provisions Division 8

Washington State Department of Transportation (WSDOT)

Specifications for Construction Geotextile

October 23, 1989

CONSTRUCTION GEOTEXTILE

October 23, 1989

Description

The Contractor shall furnish and place construction geotextile in accordance with the details shown in the Plans.

Materials

Geotextile and Thread for Sewing

The material shall be a woven or non-woven geotextile consisting only of long chain polymeric filaments or yarns formed into a stable network such that the filaments or yarns retain their position relative to each other during handling, placement, and design service life. At least 95 percent by weight of the long chain polymers shall be polyolephins, polyesters, or polyamides. The material shall be free from defects or tears. The geotextile shall conform to the properties as indicated in Tables 1, 2, and 3 for each specified use. The geotextile shall be free of any treatment or coating which might adversely alter its physical properties after installation.

Thread used shall be high strength polypropylene, polyester, or Kevlar thread. Nylon threads will not be allowed. The thread used to sew permanent erosion control geotextiles must also be resistant to ultraviolet radiation.

Geotextile Properties

Table 1: Geotextile for underground drainage.

Geotextile Property	Test Method	Geotextile Property Requirements	
		Low Survivability	High Survivability
AOS	WSDOT Test Method 922	.21 mm max. (#70 sieve)	.21 mm max. (#70 sieve)
Water Permeability	WSDOT Test Method 924	.08 cm/sec min.	.08 cm/sec min.
Tensile Strength, min. in machine and x-machine direction	WSDOT Test Method 916	90 lbs min.	180 lbs min.
Seam Breaking Strength	WSDOT Test Method 918 and WSDOT Test Method 916 (Grab Test)	80 lbs min.	160 lbs min.
Burst Strength	WSDOT Test Method 920	140 psi min.	290 psi min.

Puncture Resistance	WSDOT Test Method 921	40 lbs min.	80 lbs min.
Tear Strength, min. in machine and x-machine direction	WSDOT Test Method 919	30 lbs min.	60 lbs min.

Table 2: Geotextile for soil stabilization.

Geotextile Property	Test Method	Geotextile Property Requirements
AOS	WSDOT Test Method 922	.42 mm max. (#40 sieve)
Water Permeability	WSDOT Test Method 924	.005 cm/sec min.
Tensile Strength, min. in machine and x-machine direction	WSDOT Test Method 916	180 lbs min.
Seam Breaking Strength	WSDOT Test Method 918 and WSDOT Test Method 916 (Grab Test)	160 lbs min.
Burst Strength	WSDOT Test Method 920	290 psi min.
Puncture Resistance	WSDOT Test Method 921	75 lbs min.
Tear Strength, min. in machine and x-machine direction	WSDOT Test Method 919	50 lbs min.

Table 3: Geotextile for permanent erosion control.

Geotextile Property	Test Method[2]	Geotextile[1] Property Requirements Low Survivability[3]	High Survivability
AOS	WSDOT Test Method 922	.30 mm max. (#50 sieve)	.30 mm max. (#50 sieve)
Water Permeability	WSDOT Test Method 924	.04 cm/sec min.	.04 cm/sec min.
Tensile Strength, min. in machine and x-machine direction	WSDOT Test Method 916	130 lbs min.	270 lbs min.
Strain at Failure	WSDOT Test Method 916	15% min.	15% min.
Seam Breaking Strength	WSDOT Test Method 918 and WSDOT Test Method 916 (Grab Test)	110 lbs min.	240 lbs min.
Burst Strength	WSDOT Test Method 920	200 psi min.	430 psi min.
Puncture Resistance	WSDOT Test Method 921	60 lbs min.	110 lbs min.
Tear Strength, min. in machine and x-machine direction	WSDOT Test Method 919	40 lbs min.	80 lbs min.
Ultraviolet (UV) Radiation Stability	ASTM D 4355-84	70% Strength Retained min.	70% Strength Retained min.

[1] All geotextile properties in Tables 1, 2, and 3 are minimum average roll values (i.e., the test result for any sampled roll in a lot shall meet or exceed the values shown in the table).

[2] WSDOT test methods 916, 919, and 924 are in conformance with ASTM geotextile test procedures, except for geotextile sampling and

Full product name. and
Proposed geotextile use(s).

If the manufacturer of the proposed geotextile(s) has not previously submitted a geotextile for initial source approval for the proposed use and obtained approval. a sample of each proposed geotextile shall be submitted to and approved by the Headquarters Materials Laboratory in Tumwater. After the sample and required information for each geotextile type have arrived at the Headquarters Materials Laboratory in Tumwater. a maximum of 14 calendar days will be required for this testing. Source approval will be based on conformance to the applicable values from Tables 1. 2. and 3. Each sample shall have minimum dimensions of 1.5 yards by the full roll width of the geotextile. A minimum of 6 square yards of geotextile shall be submitted to the Engineer for testing. The geotextile machine direction shall be marked clearly on each sample submitted for testing. The machine direction is defined as the direction perpendicular to the axis of the geotextile roll.

The geotextile samples shall be cut from the geotextile roll with scissors. sharp knife. or other suitable method which produces a smooth geotextile edge and does not cause geotextile ripping or tearing. The samples shall not be taken from the outer wrap of the geotextile roll nor the inner wrap of the core.

Acceptance Samples

Samples will be randomly taken by the Engineer at the jobsite to confirm that the geotextile meets the property values specified.

Approval will be based on testing of samples from each lot. A "lot" shall be defined for the purposes of this specification as all geotextile rolls within the consignment (i.e.. all rolls sent to the project site) which were produced by the same manufacturer. and have the same product name. After the samples and manufacturer's certificate of compliance have arrived at the Headquarters Materials Laboratory in Tumwater. a maximum of 14 calendar days will be required for this testing. If the results of the testing show that a geotextile lot. as defined. does not meet the properties required for the specified use as indicated in Tables 1. 2. and 3. the roll or rolls which were sampled will be rejected. Two additional rolls from the lot previously tested will then be selected at random by the Engineer for sampling and retesting. If the retesting shows that either or both rolls do not meet the required properties. the entire lot will be rejected. All geotextile which has defects. deterioration. or damage. as determined by the Engineer. will also be rejected. All rejected geotextile shall be replaced at no cost to the State.

Acceptance will be by manufacturer's certificate of compliance without sampling if one or both of the following two conditions are met:

(1) The quantities of geotextile proposed for use in each geotextile application are less than or equal to the following amounts:

specimen conditioning. Copies of all WSDOT geotextile test methods are available at the Headquarters Materials Laboratory in Tumwater.

[3] Low and high survivability for geotextiles used for underground drainage and permanent erosion control are defined in this Special Provision under the respective subsections.

Aggregate Cushion for Permanent Erosion Control Geotextile

The gradation requirements for aggregate cushion are as follows:

% Passing 2 1/2 inch square opening	80-100
% Passing 1/4 inch square opening	25-100
% Passing U.S. No. 100 sieve	0-5

All percentages are by weight.

Geotextile Approval And Acceptance

Geotextile properties and Test Methods

Properties of geotextiles shall be determined by the following test methods:

Geotextile Property	Test Method and Title
AOS	WSDOT Test Method 922: Apparent Maximum Opening Size of Geotextiles
Water Permeability	WSDOT Test Method 924: Water Permeability of Geotextiles by Permittivity
Tensile Strength and Strain at Failure	WSDOT Test Method 916: Breaking Load and Elongation of Geotextiles (Grab Method)
Seam Breaking Strength	WSDOT Test Method 918: Failure in Sewn Seams of Geotextiles; and WSDOT Test Method 916: Breaking Load and Elongation of Geotextiles (Grab Method)
Burst Strength	WSDOT Test Method 920: Diaphragm Bursting Strength of Geotextiles
Puncture Strength	WSDOT Test Method 921: Puncture Strength of Geotextiles
Tear Strength	WSDOT Test Method 919: Trapezoid Tearing Strength of Geotextiles
Ultraviolet (UV) Radiation Stability	ASTM D 4355-84, after 500 hours in weatherometer

Source Approval

The Contractor shall submit to the Engineer the following information regarding each geotextile proposed for use:

Manufacturer's name and current address, shall the geotextile be dragged through mud or over sharp objects which could damage the geotextile. The cover material shall be placed on the geotextile in such a manner that a minimum of 12 to 18 inches of material, depending on the survivability of the geotextile, will be between the equipment tires or tracks and the geotextile at all times. Construction vehicles shall be limited in size and weight such that rutting in the initial lift above the geotextile is not greater than 3 inches deep, to prevent overstressing the geotextile. Turning of vehicles on the first lift above the geotextile will not be permitted. End-dumping the cover material directly on the geotextile will not be permitted. Compaction of the first lift above the geotextile shall be limited to routing of placement and spreading equipment only. No vibratory compaction will be allowed on the first lift.

Pegs, pins, or the manufacturer's recommended method shall be used as needed to hold the geotextile in place until the specified cover material is placed.

Should the geotextile be torn or punctured or the overlaps or sewn joints disturbed, as evidenced by visible geotextile damage, subgrade pumping, intrusion, or roadbed distortion, the backfill around the damaged or displaced area shall be removed and the damaged area repaired or replaced by the Contractor at no cost to the State. The repair shall consist of a patch of the same type of geotextile placed over the damaged area. The patch shall overlap the existing geotextile a minimum of 2 feet from the edge of any part of the damaged area.

If geotextile seams are to be sewn in the field or at the factory, the seams shall consist of two parallel rows of stitching. The two rows of stitching shall be 0.5 inch apart with a tolerance of ± 0.25 inch and shall not cross, except for restitching. The stitching shall be a lock-type stitch. The minimum seam allowance, i.e., the minimum distance from the geotextile edge to the stitch line nearest to that edge, shall be 1.5 inches if a flat or prayer seam, Type SSa-2, is used. The minimum seam allowance for all other seam types shall be 1.0 inch. The seam, stitch type, and the equipment used to perform the stitching shall be as recommended by the manufacturer of the geotextile and as approved by the Engineer.

The seams shall be sewn in such a manner that the seam can be inspected readily by the Engineer or his representative. The seam strength will be tested and shall meet the requirements stated in this Special Provision.

Specific Construction Requirements

The construction requirements which follow shall apply in addition to the general construction requirements previously stated.

Underground Drainage

The geotextile shall either be overlapped a minimum of 1 foot at all longitudinal and transverse joints, or the geotextile joints shall be sewn. In those cases where the trench width is less than 1 foot, the minimum overlap shall be the trench width. Either low survivability or high survivability geotextile shall be used, meeting the property requirements specified in Table 1. Low survivability geotextile may be used in trench drains if the trench walls are smooth, stable, and less than 10 feet in depth. High survivability geotextile shall be used if the trench depth is greater than equal to 10 feet.

Application	Geotextile Quantity
Underground Drainage	500 sq. yd.
Soil Stabilization	1500 sq. yd.
Permanent Erosion Control	1000 sq. yd.

(2) The geotextile samples previously tested for the purpose of source approval came from the same geotextile lot as defined which is proposed for use at the project site, provided that the number of samples submitted and tested meet the requirements of WSDOT Test Method 914 "Practice for Sampling of Geotextiles for Testing".

The manufacturer's certificate of compliance shall include the following information about each geotextile roll to be used:

Manufacturer's name and current address,
Full product name,
Geotextile roll number,
Proposed geotextile use(s), and
Certified test results.

Approval of Seams

If the geotextile seams are to be sewn in the field, the Contractor shall provide a section of sewn seam before the geotextile is installed which can be sampled by the Engineer.

The seam sewn for sampling shall be sewn using the same equipment and procedures as will be used to sew the production seams. If production seams will be sewn in both the machine and cross-machine directions, the Contractor must provide sewn seams for sampling which are oriented in both the machine and cross-machine directions. The seams sewn for sampling must be at least 2 yards in length in each geotextile direction. If the seams are sewn in the factory, the Engineer will obtain samples of the factory seam at random from any of the rolls to be used. The seam assembly description shall be submitted by the Contractor to the Engineer and will be included with the seam sample obtained for testing. This description shall include the seam type, seam allowance, stitch type, sewing thread tex ticket number(s) and type(s), stitch density, and stitch gage.

Construction Requirements

Shipment and Storage

During periods of shipment and storage, the geotextile shall be kept dry at all times and shall be stored off the ground. Under no circumstances, either during shipment or storage, shall the material be exposed to sunlight, or other form of light which contains ultraviolet rays, for more than five calendar days.

General Construction Requirements

The area to be covered by the geotextile shall be graded to a smooth, uniform condition free from ruts, potholes, and protruding objects such as rocks or sticks. The geotextile shall be spread immediately ahead of the covering operation. The geotextile shall not be left exposed to sunlight during installation for a total of more than five calendar days. The geotextile shall be laid smooth without excessive wrinkles. Under no circumstances by the Engineer. If the geotextile is placed on slopes steeper than 2:1, the stones shall be placed on the slope without free-fall for both low survivability and high survivability geotextiles.

Temporary Silt Fences

The Contractor shall be fully responsible to install and maintain temporary silt fences at the locations shown in the Plans. A silt fence shall not be considered temporary if the silt fence must function beyond the life of the contract. The silt fence shall prevent soil carried by runoff water from going beneath, through, or over the top of the silt fence, but shall allow the water without soil to pass through the fence. The minimum height of the top of the silt fence shall be 30 inches above the original ground surface. Damaged and otherwise improperly functioning portions of silt fences shall be repaired or replaced by the Contractor at no cost to the State, as determined by the Engineer.

Sediment deposits shall either be removed when the deposit reaches approximately 1/2 the height of the silt fence, or a second silt fence shall be installed, as determined by the Engineer.

Measurement

Construction geotextile, with the exception of silt fence geotextile and underground drainage geotextile used in trench drains, will be measured by the square yard for the ground surface area actually covered. Silt fence geotextile will be measured by the linear foot of silt fence installed. Underground drainage geotextile used in trench drains will be measured by the square yard for the perimeter of drain actually covered.

Payment

The unit contract prices per square yard for "Construction Geotextile For Underground Drainage", "Construction Geotextile For Soil Stabilization", and "Construction Geotextile For Permanent Erosion Control", and per linear foot for "Construction Geotextile For Silt Fence" as are included in the proposal shall be full pay to complete the work as specified.

Sediment removal behind silt fences will be paid by force account. If a new silt fence is installed in lieu of sediment removal, as determined by the Engineer, the silt fence will be paid for at the unit contract price per linear foot for "Construction Geotextile For Silt Fence".

An area drain is defined as a geotextile layer placed over or under a horizontal or near-horizontal layer of drainage aggregate. The geotextile shall be overlapped a minimum of 2 feet at all longitudinal and transverse joints in an area drain, or the geotextile joints shall be sewn together. The minimum initial lift thickness over the geotextile shall be 18 inches if low survivability geotextile is used and shall be 12 inches if high survivability geotextile is used.

Soil Stabilization

The geotextile shall either be overlapped a minimum of 2 feet at all longitudinal and transverse joints, or the geotextile joints shall be sewn together. The initial lift thickness shall be 12 inches or more.

Permanent Erosion Control

Unless otherwise specified in the Plans, the geotextile shall either be overlapped a minimum of 2 feet at all longitudinal and transverse joints, or the geotextile joints shall be sewn together. If overlapped, the geotextile shall be placed so that the upstream strip of geotextile will overlap the next downstream strip. Where placed on slopes, each strip shall overlap the next downhill strip.

Placement of aggregate, riprap or both on the geotextile shall start at the toe of the slope and proceed upwards. The geotextile shall be keyed at the top and the toe of the slope as shown in the Plans. The geotextile shall be secured to the slope, but shall be secured loosely enough so that the geotextile will not tear when the riprap is placed on the geotextile. The geotextile shall not be keyed at the top of the slope until the riprap is in place to the top of the slope.

All voids in the riprap face that allow the geotextile to be visible shall be backfilled with quarry spalls or other small stones, as designated by the Engineer, so that the geotextile is completely covered. When an aggregate cushion between the geotextile and the riprap is required, it shall have a minimum thickness of 12 inches.

An aggregate cushion will be required to facilitate drainage when hand placed riprap, sack riprap, or concrete slab riprap, as specified in Sections 9-13.2, 9-13.3, or 9-13.4, respectively, is used with the geotextile.

Either low survivability or high survivability geotextile shall be used, meeting the property requirements specified in Table 3. Low survivability geotextile shall be used if a 12 inch thick aggregate cushion is placed between the geotextile and the riprap and the geotextile is placed on a slope of 2:1 or flatter. High survivability geotextile shall be used if an aggregate cushion is not used or if the geotextile is placed on a slope steeper than 2:1.

Grading of slopes after placement of the riprap will not be allowed if grading results in stone movement directly on the geotextile. Under no circumstances shall stones weighing more than 100 pounds be allowed to roll downslope. Stones shall not be dropped from a height greater than 3 feet above the geotextile surface. Lower drop heights may be required if geotextile damage from the stones is evident, as determined