EARLY DISTRESS IN OPEN-GRADED FRICTION COURSE

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16. Abstract

Field performance observations and tests were conducted on OGFC in four of six New England states. The data obtained included: distress surveys, friction measurements, surface texture values using two methods, air permeability and gradation of aggregate recovered from cores. These data were analyzed and the OGFC layer's performance evaluated.

Conclusions regarding performance are set forth based on the data obtained and the results of an extensive literature survey. Recommendations concerning the placement of OGFC and subsequent maintenance are presented.

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Early Distress in Open-Graded Friction Courses

Final Report

INTRODUCTION: In 1997 the New England Transportation Consortium (NETC) solicited problem statements from each of the six participating New England states. The performance of open-graded friction courses (OGFC) was selected for study and research, an action triggered by early failures in OGFC which required substantial financial resources to correct.

The staff of the CT Transportation Institute's Advanced Pavement Laboratory (CAP Lab) responded to the NETC request for proposals and was selected as the research agency for this project. CAP Lab staff proposed to carry out a series of field and laboratory activities designed to improve the performance of OGFC in New England. Technical guidance for NETC was provided by a panel of six state pavement and/or materials engineers and a representative of the Federal Highway Administration (FHWA) and chaired by Alan Schneck of Vermont. Work was begun on the project on 8/1/98.

BACKGROUND OF OGFC: In the late 1960's, through the mid 1970's a high percentage of wet-weather accidents was cited in several major studies. In turn, methods and systems to reduce these accidents were investigated. One concept which evolved was that of OGFC, whereby an asphaltic material was designed with a large void structure to reduce the water film thickness on the pavement surface.

Numerous trial sections were placed at the urging of FHWA and other safety conscious agencies. Reductions in wet-weather accidents were reported. On the negative side increased useage of winter deicing chemicals was reported by several snow belt states. The additional salt applications were required to prevent early and rapid ice buildup in the OGFC material. A second problem reported was the handling and placement of the OGFC material. The latter problem was subsequently addressed and improved by reducing the voids in the OGFC.

The safety benefits of OGFC were documented and provided the basis for accepting OGFC for use by state DOT's. Experience in Europe was similar to that in the United States.

After several years of use, early and very costly failures in OGFC materials were reported. Again, the Euopeans experienced similar problems as reported by an AASHTO sponsored scanning trip. Subsequently European research was focused on improving the performance of OGFC so that it could be used as a positive safety measure. Improvements were documented and attributed to increasing the binder's film thickness on the aggregate matrix. In general, this was acccomplished by employing fibers or other modifiers in the binder. The states of Georgia and Oregon have reached similar conclusions regarding OGFC recently.

In New England the primary means employed to improve OGFC peformance was to densify the mix, by adding fines. This modification improved handling and placement, but early failures were still reported as well as the good performance OGFC projects. Based on the costs to repair these failures, NETC initiated research addressing these performance issues. The Connecticut Transportation Institute was selected to carry out a study which addressed the following four Objectives:

1 - Determine the type and extent of failures in OGFC placed in New England;
2 - Compare failures in OGFC with sections that are performing well;
3 - Develop specifications for OGFC based on the state-of-the-art; and,
4 - Prepare recommended maintenance and rehabilitation practices and pertinent specifications for use on failed sections of OGFC.

METHODOLOGY EMPLOYED: The following methodology was developed to address the four objectives set forth above. As an initial step a detailed literature search was conducted. Selected references are shown as Appendix A. The results of the literature search were discussed at an initial advisory panel meeting held 8/19/98.

At the 8/19 meeting it was determined that 4 of 6 New England states could supply field projects for evaluation. The four states are Connecticut, Massachusetts, Rhode Island, and Vermont, with only Massachusetts and Vermont being able to provide "poor" and "good" performing OGFC sections. Connecticut has abandoned the use of OGFC while Rhode Island could provide recently placed (since 1995) OGFC. New Hampshire and Maine do not employ OGFC in their normal paving operations. Available data on materials and placement specifications were solicited as well as typical sections and other related construction information.

The researchers suggested and panel concurrence was received to secure in-situ field data on: pavement texture and permeability; cores of the OGFC layer; and a detailed mapping of distresses observed. In addition the panel recommended that friction values of the area surveyed be obtained. Subsequently, the ConnDOT was contacted and agreed to perform the needed friction surveys.

The field data were obtained for 1000-ft test sections, recommended by each of the four participating states. The 1000-ft area was, in turn, subdivided into 5-200 ft sublots for subsequent analysis purposes. Table 1 presents the locations of the areas tested; they are shown graphically in Figure 1. Table 2 summarizes the tests conducted. Photos of the equipment used in this project are shown in Appendix B. During field data gathering operations the state visited provided traffic control for the right-hand lane closure; obtained cores of the sections surveyed, and, provided needed traffic protection during friction testing of the pavements. All field data activities were performed during the months of September and October 1998. Friction surveys were conducted and completed during early October, 1998, separately from field performance data gathering activities.

The research team applauds the excellent cooperation and services provided by the participating states. Their efforts greatly facilitated our data acquisition activities.

Table 1

Summary of Field Test Site Locations

State		Location	State Condition Rating
CT	(1)	I-84 Union; between Exits 73 & 74	Poor
MA	(1)	I-495 NB at Exit 32 (MM 85.0)	Poor
	(2)	I-290 WB, Northboro after Solomon Road Exit	Good
RI	(1)	I-95 SB 0.7 Mi S of Rt. 3 Br., (Exit 6)	Good
	(2)	I-95 SB S of Exit 5 (MM 12.0)	Good
VT	(1)	I-89 SB; (MM70)	Good
	(2)	I-89 SB, (MM60)	Poor

Table 2

Summary of General Site Information

Location		ADT/Section*	% Trucks	Age (yr)
CT		20,600	19	12
MA	(1)	50,900	20	9
	(2)	36,500	20	7
RI	(1)	50,200	20	2
	(2)	36,500	20	3
VT	(1)	10,350	11-12	5
	(2)	10,350	11-12	3

*ADT-values for one direction only

FIGURE 1

FIELD TEST SITE LOCATIONS

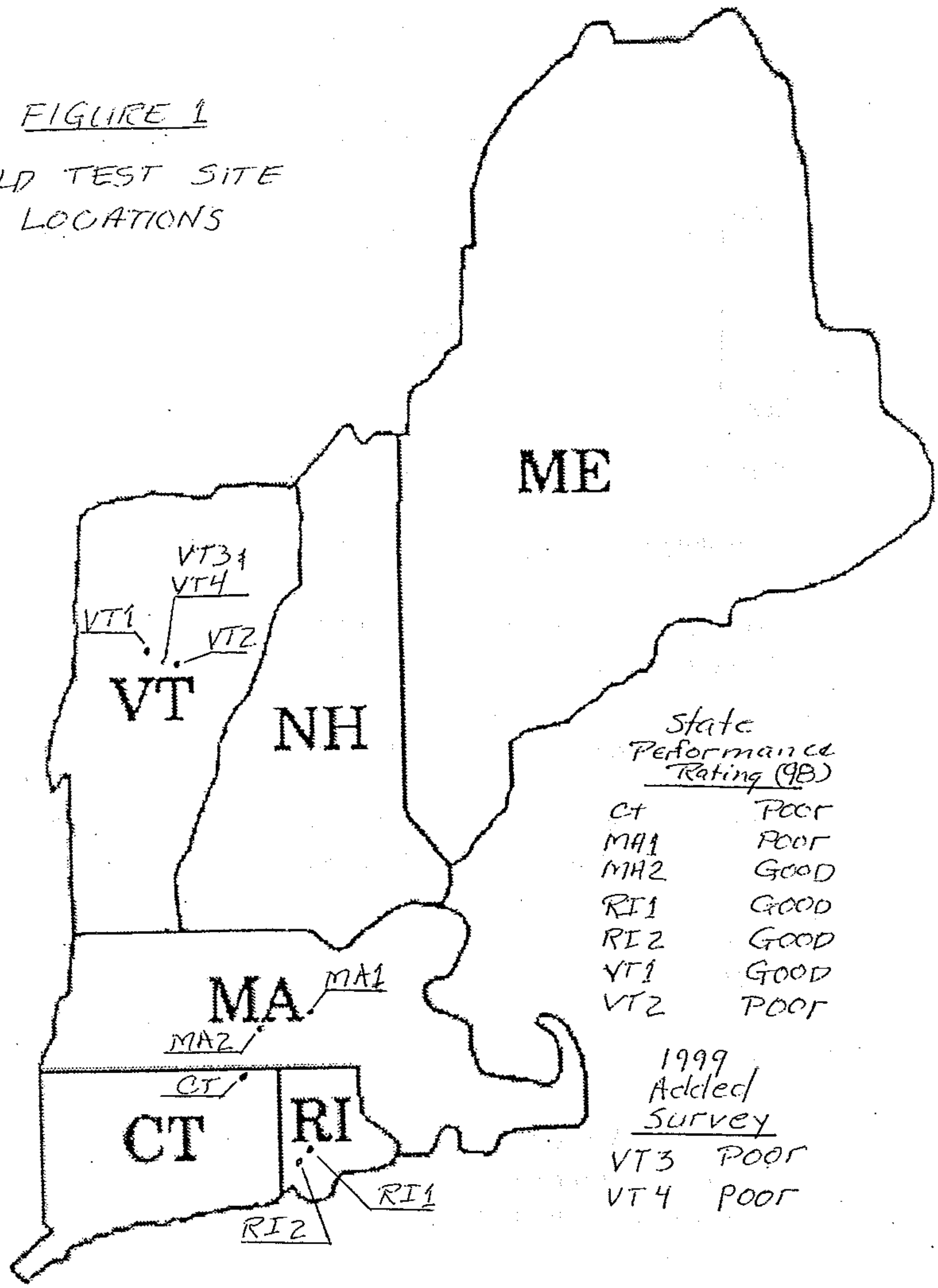
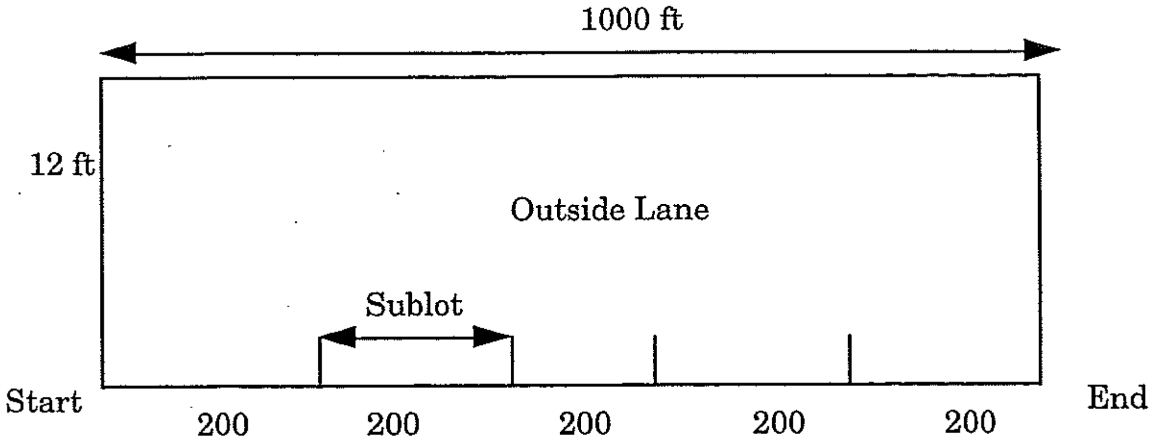


Table 3
Field Tests Performed

Typical Layout



Distresses - Map all Distresses.

Permeability Test - 2 tests per sublot (ASTM D3637-91) .

Surface Texture Test - 3 tests per sublot using both sand patch (ASTM E965-96) and silly putty methods of test (Total of 6 measurements).

Photos - Photographic record of each lot.

Cores - 2 4-in. cores per sublot with at least one core outside of the wheel path. 1 core/sublot if core is 6-in. in diameter.

Friction - Both ribbed and smooth-tire friction values for the test site (ASTM 274-90).

Rutting - Determined by drawing a string line across the pavement.

DATA ANALYSIS: The data set obtained for each state are shown in Appendices C-F inclusive. They represent the states of CT, MA, RI and VT, respectively. Typical photos of each site and typical views of cores removed appear therein as well.

Tables 4-7 were prepared to provide snapshots of those data elements considered most important in the field site reviews. They will be discussed individually in the following paragraphs.

Surface Texture measurements are shown in Table 4. Two methods of test were employed to assess this parameter; sand patch as defined in ASTM E965-96 and silly putty as presented in Reference 22. Three tests each were conducted in a 200-ft sub-lot. This procedure was employed consistently and provided reasonable data throughout the field surveys, with one unexplained exception in VT.

The "Silly Putty Test" was developed some thirty years ago as a means of correcting nuclear density readings to core densities. The nuclear gauge at that time included the volume of void space between the gauge and pavement at zero density as part of the density reading. For the test, a circular area in the middle of a 1/2 in. aluminum plate was machined 1/8 in. deep. A fifty gram ball of silly putty was placed on the pavement and covered by the plate and the plate placed on the putty and forced down until the unmilled area sat solidly on the pavement. The plate was removed and the diameter of the now flattened patty of putty measured. A volume, 1/8 in. times the area of the patty, was deducted from the known 50 gram putty ball volume. The remaining volume, divided by the area of the patty, provides a measure of the surface voids per unit of area attributable to the relief in the pavement surface. In this manner, simple comparisons of surface irregularities or relief are possible by merely comparing the putty diameters.

For each test the smaller values reflect a more open or coarse pavement surface. Comparison of the texture values measured to observations of the surface of cores obtained show there is agreement that the texture of MA and RI mixes is finer than those of CT and VT. Other parameters measured, which will be discussed shortly, apparently conflict with this observation.

Table 5 presents data on air permeability as measured by ASTM D3637-91 Method A. For this study a grease seal was employed to permit the test to be conducted under a head of 0.25 in. and a flow of 1000 ml of air. These values of head and flow were determined by initial test runs using the test equipment and provided a uniform data set for this work. Each sublot within the test area was tested twice. For this test the lower the value

Table 4
Summary of Surface Texture Measurements

State	Section	Sand Patch* Dia (in)	Silly Putty Dia (in)
CT		15.97	3.80
MA	1	18.77	3.98
	2	19.65	4.22
RI	1	19.23	4.11
	2	18.08	4.14
VT	1	16.55	4.03
	2	17.27	4.01

*Method used ASTM E965-96

recorded the more open or porous the surface being tested. In several tests, however, no flow was reported indicating that the surface tested was essentially impermeable.

Inspection of the data obtained reveals substantial scatter (see Range per 200 ft in Table 5). Other investigators /14&15/ have found similar results when using the falling-head air permeameter in the field. From these data it is surmised that there is still a degree of permeability remaining in those sites tested. The air permeameter tests on the more recently placed OGFC material are difficult to interpret. Low times indicating good permeability were found at most younger test sites but two of the zero permeability determinations were found in the newest material.

Rut measurements are shown in Table 6. For these data, a stringline was drawn taut over the surface of the lane being tested. The maximum rut was then obtained by measuring with a scale. Duplicate measurements were obtained in each sub-lot except in CT. In the CT section, limited, if any, rutting was noted initially. Subsequent measurements in the last two sublots revealed minor amounts of rutting. In the remaining field visits, rut measurements were routinely obtained.

Table 5
Summary of Air Permeability Measurements (1)

State	Section	Average Time (Sec) per Section	High Time (Sec.)	Low Time (Sec.)	Range of Time per Sublot
CT		140.5	304	16	14.5-255
MA	1	228.36*	456	118.8	12.7-302.5
	2	673.7	2456	270.7	71.7-1994.3
RI	1	363.94**	1084	70	5.2-1014
	2	347.03	677	81	44.3-285.8
VT	1	66.91**	176	7.0	.44-139.2
	2	23.61	107.6	3.12	0.68-22.86

*1 Test Zero Permeability Reported - not included in Average
**2 Tests Zero Permeability Reported - not included in Average
(1) Method of Test Used ASTM D3637-91

Table 6
Summary of Rutting Measurements (1)

State	Section	Range of Rut Measured (mm)
CT		8-10
MA	1	2-12
	2	0-12
RI	1	0-8
	2	0-5
VT	1	4.5-9
	2	3-5

(1) Method of Test Used - Stringline drawn taut across the outer lane

Distresses observed are summarized in Table 7. These data are the total distress recorded in the 1000-ft test section. It is the sum of all of the respective distresses in each 200-ft sublot. The total is the sum of each individual distress measured. It is noteworthy that only two of the seven test areas have distress. The remaining five contain no distress whatsoever.

Table 7
Summary of All Distresses Observed

State	Sec	Patching (sf)	Long (ft)	Trans (ft)	Map (sf)	Alligator (sf)	Raveling (sf)	Spalling (sf)	Gouges (sf)	Total all Distress Measures
CT		258	38	2629	2701	151	12.5	12.5	4	5793.5
MA	1	19	223	3	66	80	60	1.5	0	398.5
	2	NO DISTRESS OBSERVED								
RI	1	NO DISTRESS OBSERVED								
	2									
VT	1	NO DISTRESS OBSERVED								
	2									

Table 8
Summary of Friction Measurements

State		Average Friction Number*	High	Low	Range
CT		41.7	43.2	41.0	2.2
MA	1	51.2	52.2	50.2	2.0
	2	51.0	51.7	50.3	1.4
RI	1	49.6	51.2	48.3	2.9
	2	51.7	52.4	50.9	1.5
VT	1	58.1	60.5	56.5	4.0
	2	57.9	59.4	57.0	2.4

*Ribbed-Tire Friction Values (ASTM 274-90)

Table 8

Summary of Friction Measurements (Continued)

State	Average Friction Number**	High	Low	Range
CT	39.7	42.2	38.3	3.9
MA 1	48.0	49.5	47.2	2.3
2	47.2	48.4	48.8	2.6
RI 1	45.2	47.7	43.9	3.8
2	50.3	51.3	49.6	1.7
VT 1	56.2	59.9	54.6	5.3
2	57.5	60.5	55.5	5.0

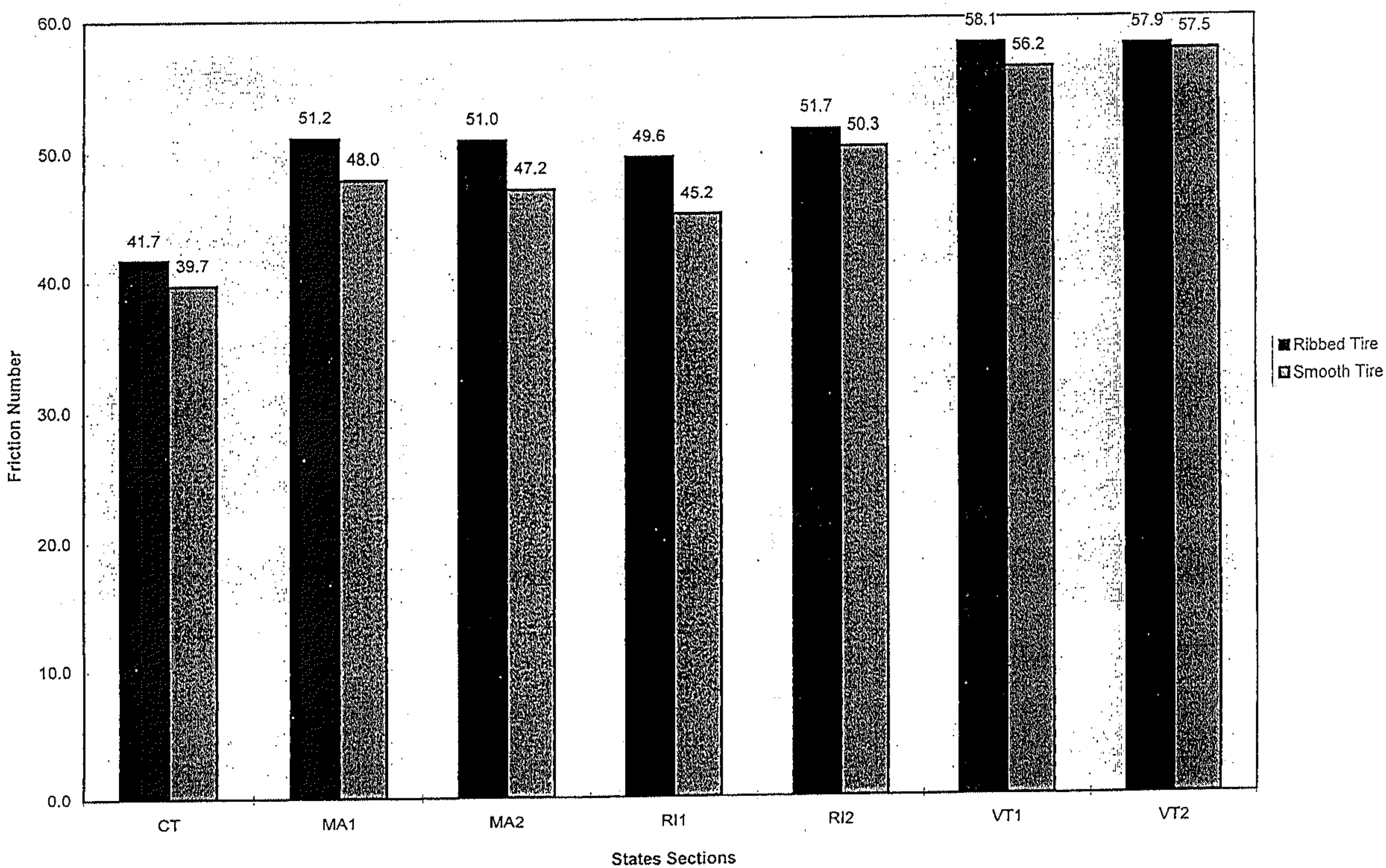
**Smooth Tire Friction Values (ASTM E274-90)

Friction data are presented in Table 8. The averages shown are for either 8 or 10 individual measurements. The values shown reflect the friction characteristics of the test site plus a short distance before and after the designated area. All tests were performed by ConnDOT staff in accordance with the requirements of ASTM E274-90. Separate runs were conducted with the ribbed and smooth ASTM test tires. All tests were performed using the left-hand wheel of the skid test trailer.

In all cases, the data shows good to excellent friction for the OGFC, both ribbed-tire and smooth-tire measurements. Figure 1 presents a graphical comparison of these data.

For VT the friction data shown for Section 2 was not obtained at the exact location the other data were obtained. The field site was moved approximately 3 miles south of the location of the friction tests to avoid a potential traffic conflict. Retest was considered and subsequently discarded when the friction data for Sections 1 and 2 were compared. Observations of the pavement surface and texture data support the decision not to retest Section 2.

Figure 2 Comparison of Friction Number by State



Technical analysis of the preceding data was started by first assigning a performance rating to each section evaluated. For this purpose, pavement rating manuals from Massachusetts and Connecticut were employed. Based on the criteria used by these two states, five of seven sites evaluated are rated excellent. There was no distress observed at these five sites. The remaining sites are classed good (MA) and fair to poor (CT). Table 9 presents a comparison of the research team's ratings to those of the individual state. The data were then plotted, to determine if trends existed, prior to conducting a more rigorous statistical analysis. In all cases, no trends could be detected.

Table 9

Comparison of Field Test Site Ratings

State	Location	State Rating	Rating By Researchers
CT	I-84/Union	Poor	Fair-Poor
MA	I-290 Northboro	Good	Excellent
	I-495	Poor	Good
RI	I-95 (Exit 6)	Good	Excellent
	I-95 (MM 12.0)	Good	Excellent
VT	I-89 (MM70)	Good	Excellent
	I-89 (MM 60)	Poor	Excellent

Two factors appear to have adversely impacted these results. First, the lack of data on poorly performing sections negates a focused statistical analysis of variance to determine the effect of various factors on OGFC performance. Further, delamination was considered to be a major failure in OGFC. No signs of delamination were recorded. Secondly, the broad variation on a range of data obtained (see Table 4) leads one to question the precision of the tests employed. Other researchers have encountered similar data variations and have associated these ranges with the wide range construction practices employed. Efforts to obtain as-built construction data have not been successful to date.

Based on the results of our preliminary analyses, or lack thereof, an advisory panel meeting was held 2/18/99. These data were discussed at length and the following direction provided.

1) Statistical analysis of the data and additional tests on OGFC mixes are not warranted;

(2) The researchers will seek additional projects in which OGFC is performing poorly. These projects will be field reviewed;

(3) The researchers will analyze cores removed from the initial seven OGFC test sites to see if performance trends are indicated; and,

(4) A final Report was to be initiated summarizing the results to date and focusing on implementation concepts to improve the performance of OGFC.

Analysis of the OGFC cores was initiated by measuring the thickness of OGFC on each core. Four measurements were made at cardinal points. The average values obtained by sublot and for the entire lot, are shown as Table 10.

Table 10

Summary of Thickness Measurements on OGFC Cores

Avg. Thickness (mm)/Sublot

Section	1	2	3	4	5	Avg. Depth per lot (mm)
CT (A)	30.4(C)	34.6(C)	25.6	33.2(C)	------	30.9
MA1(B)	29.4	28.2	29.6	25.2	26.5	27.7
MA2(B)	19.9	17.9	20.3	20.9	25.4	20.9
RI1(A)	34.1	32.8	30.2	32.2	38.6	33.6
RI2(A)	32.8	42.5	36.4	44.1	36.9	38.5
VT1(B)	26.5	15.7	21.6	29.0	28.7	24.3
VT2(B)	26.5	21.0	22.3	23.4	18.9	22.4

(A) 2 4-inch Cores/sublot

(B) 1 6-inch Core/sublot

(C) Average of 4 measurements

Where 6-inch cores were removed the sublot value shown represents the average of four measurements. For 4-inch cores the average is for eight measurements, except for the Connecticut cores. In the cores from Connecticut, five of the ten cores obtained, two in sublot 5, crumbled during the coring process and thicknesses were not obtained. This is the reason that for sublot 5 there are no data.

Inspection of Table 10 shows the substantial variation in core depths measured. Subsequent analysis of these data did not show any trends which could be attributed to performance or affect performance of the OGFC.

Following the measurements, the OGFC layer was separated from the core. For this purpose a 3/16-inch steel dowel was used to focus or concentrate stress at the layer interface. This process placed the bonded interface in direct tension. For the four-inch cores, the OGFC separated at the interface when the dowel had penetrated the core approximately 3/16-inch For the six-inch cores a single load did not separate the OGFC from the base material. Separation took as many as five separate loads on the circumference of the 6-inch core sample. This tenaceous bond explains why no delamination was found at the various field test sites.

Once removed, the OGFC was heated 10 minutes in a 150C oven. The perimeter, which contained sawn aggregate, was then removed. During the removal process, pockets of uncoated fines were found. These, it is assumed, are the remains of winter sanding operations. The presence of these fines can affect the gradation and asphalt contents determined. Figure 3 presents the gradation analyses. Table 11 is a tabulation of all binder gradations obtained from the cores.

In general, all mixes fell within applicable OGFC ranges. The Rhode Island and Mass sections have more fines and were less permeable than the CT and VT sections. It is recognized that the presence of uncoated fines have biased these results such that they may not truly reflect mix properties, measured at the time of construction. Limited attempts were made to quantify these errors. For example, the difference in the values for the fine sieves was tested and found to be about five percent on the minus 50 sieve. However, the nominal maximum size aggregate is reduced by only a few tenths of a percent. It is judged that all OGFC materials tested reflect the as-built OGFC pavement surface.

Figure 3 - Results of Gradation Analysis of OGFC Cores

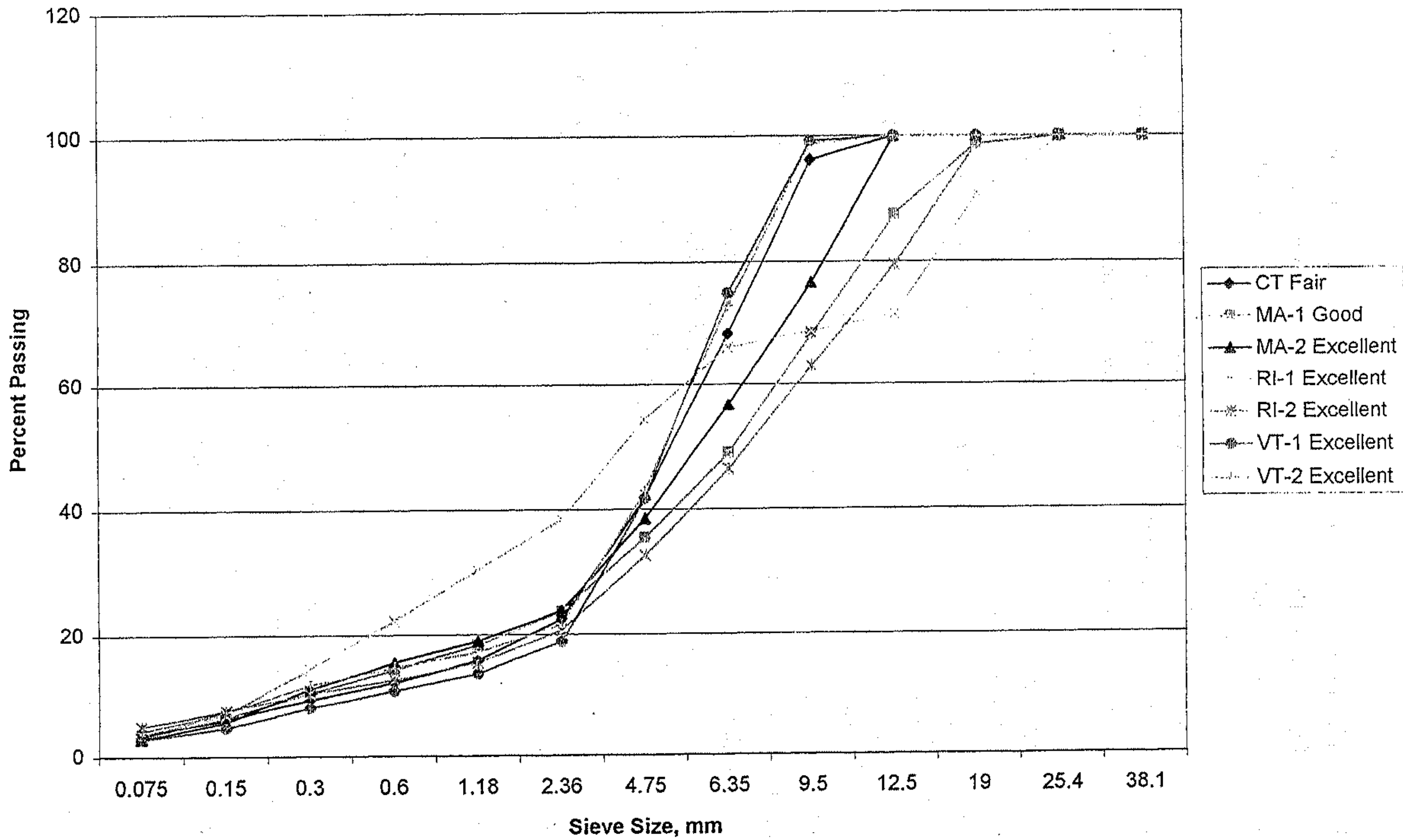


Table 11

Gradation and Binder Content of OGFC Mixes from Cores

Sieve		Percent Passing						
mm	British	CT	MA-1	MA-2	RI-1	RI-2	VT-1	VT-2
38.1	1.5"	100	100	100	100	100	100	100
25.4	1"	100	100	100	99.5	100	100	100
19	3/4"	100	98.6	100	90.7	98.6	100	100
12.5	1/2"	100	87.4	100	71.3	79.5	100	100
9.5	3/8"	96.2	68.2	76.6	68.7	62.9	99.2	98.7
6.35	1/4"	68.3	48.8	56.6	66	46.3	75	72.9
4.75	#4	41.8	35.5	3.5	54.2	32.6	41.7	42.9
2.36	#8	22.5	23.7	23.8	38.4	20.6	18.8	21.6
1.18	#16	15.7	18.2	18.9	30.4	15.3	13.6	17.1
0.6	#30	12.1	14.3	15.4	22.3	12.6	10.8	14.6
0.3	#50	9.4	10.5	11.1	14.4	10.4	8.1	11.8
0.15	#100	6.2	6.5	5.8	7	7.6	4.9	7.3
0.075	#200	3.7	3.3	3	3.8	5.1	2.9	4.3
AC, %		5,96	5.7	6.89	6.92	6.89	6.98	7.1

Follow-up performance observations were made on two sections of I-89 in Vermont at approximately Mile-post 63. These were the only two additional sections (one in each roadway approximately 0.2 mile long) recommended by the participating state representatives who, by the way, made exhaustive searches of records for poor performing OGFC pavements. The limited number of poor performers is attributed to prompt pavement treatments applied by maintenance forces.

The results of field inspections revealed transverse cracking in fill areas. Few transverse cracks were detected in cut section and there were no longitudinal cracks found. The pavement's surface texture is the same as that in the test sections at Milepost 70.0 and 57.1, indicating good friction characteristics. Based on the fact that no delamination or patching was found and the limited amount of transverse cracking found the section is judged to be rated as a "good" performing pavement. The transverse cracking documented is in all likelihood the reflection of temperature cracks in the overlain pavement. Several marks which at first view appeared to be cracks were actually depressed grooves as yet uncracked. The OGFC appears to be settling into an underlying crack.

CONCLUSIONS:

The following conclusions are set forth based on the results of field surveys conducted and literature searches.

(1) OGFC surfaces can be designed and constructed and perform very well under the conditions encountered in New England. Field surveys showed that seven sections are performing exceptionally well. Their ages range from two to seven years. In all these cases the OGFC had a nominal maximum aggregate size of 3/8 inches which should have improved the handling and placement compared to earlier mixes. The higher percentage of fines in the RI and MA mixes accounts for the lower permeability of these sections compared to the CT and VT sections. These OGFC pavements can be expected to provide reasonable performance until they reach the age of 12-15 years. This is supported in the literaure and by the performance of the CT section studied. The CT section, placed in 1986, is 7-10 years older than those inspected in other states, yet it is performing reasonably well.

(2) Friction values obtained, using both ribbed and smooth test tires are good to excellent. If the poorest performing section is eliminated the friction values range in the high 40's and 50's.

(3) Surface texture measurements follow the general trend that the more surface relief measured (smaller measurement value), the higher the friction value measured. This is true when the reader compares data from VT to that from MA and RI. This is not true when CT values are compared to those of the other states.

(4) In general, the new sections placed appear to be less permeable than the older sections. Although the data obtained showed wide variability, this conclusion is supported by the "zero" values obtained and statements by state personnel noting that the OGFC section employed a "modified" or denser OGFC mix.

(5) Adherence of OGFC layers to the pavement layer immediately below the OGFC is excellent. Researchers had a difficult time separating the OGFC from the base layer in order to determine the gradation of the OGFC sections.

(6) The results of gradation analyses performed on core samples show that all materials complied with applicable state gradation requirements. In general, the gradations reflect a fine OGFC. There were marked variations where the samples approached the extreme limits of the individual master range values. For example one state was high on the number 4 sieve, another on the plus 3/8-in. sieve, but in all cases the minus 200 material was well within the gradation limits even though the winter sand residue was included.

DESIGN RECOMMENDATIONS: The following recommendations represent the current state-of-practice in the application of OGFC technology. They were gleaned from available literature, contacts with OGFC practitioners and experience of those on the research team.

(1) OGFC should be placed on a firm dense-graded base layer.

(2) Patching of potholes, sealing of cracks, correcting ruts or other surface distortions should be completed prior to placing OGFC to avoid internal drainage blockage. If bleeding is present in the old surface, the effect on the new OGFC should be evaluated before placement.

(3) OGFC layers should be placed full width (including shoulder and paved borders) over the pavement being overlaid to preclude entrapment of surface runoff.

(4) The thickness of OGFC placed varies from project to project. In general, the old thickness rule of thumb that the layer should be placed at least twice as thick as the largest nominal size aggregate has been proven worthwhile.

Additional recommendations concerning construction and maintenance of OGFC pavements follow.

CONSTRUCTION RECOMMENDATIONS: As stated above, an extensive literature search was conducted using the Transportation Research Information Service (TRIS) as well as other data sources known to the Research team. Early performance observations and studies in Europe confirmed U.S. findings of premature failures in OGFC applications. These failures were attributed to rapid oxidation or hardening of the binder in the OGFC. Due to the substantial benefits associated with OGFC surfaces, studies to improve the performance of OGFC in Europe were undertaken. Similar initiatives were persued in the U.S. with the Georgia DOT becoming a leader in this area.

Research results in Europe which employ modified asphalt cements and the use of fiber additives to increase binder film thicknesses have improved OGFC performance substantially. These changes to the OGFC provided longer life to the layer and provided a larger internal void structure to facilitate drainage of surface waters from the pavement's surface. In 1991 Georgia modified their open-graded mix in accordance with European recommendations. To date results from trial sections placed by the Georgia DOT project a 50% increase in life (8-yr for conventional OGFC vs. 12-yr. for modified OGFC). Improved drainage capability and significantly smoother surfaces when compared to dense-graded are reported also.

The down side of modified OGFC is that placement is more difficult than dense graded mixes. The mix is stiff and has a tendency to "set-up" quickly. Cold lumps can form during transportation, which can blemish the final surface by being dragged under the screed. These problems predominate when OGFC is placed in cooler weather. To minimize these cold weather related problems, the mix is run at higher temperatures and proper truck heating and tarping are emphasized. A material transfer device virtually eliminates lumping problems and improves smoothness. A nominal maximum aggregate size of 3/8 is recommended with a slightly increased amount of fines. A trial specification, which employes SUPERPAVE design technology, has been developed. It is included as Appendix G.

OGFC material should be placed during warm periods. An air temperature of 60°F and rising is recommended for this purpose. To assure proper adhesion of the OGFC surface to the receiving or base layer a tack coat is recommended. The application rate should comply with individual state practice and experience.

MAINTENANCE RECOMMENDATIONS: Little was uncovered during the literature search and subsequent activities concerning the maintenance of OGFC. In general failures in OGFC which resulted in loss of material were patched with available materials. In some cases the patch material was thought to hasten the OGFC deterioration by trapping surface water at the top of the underlying HMA.

In general, OGFC is usually badly oxidized and beginning to ravel when rehabilitation is scheduled. This is true for the test site in CT. Photos of the cores removed show progressive signs of raveling when compared to cores from more newly placed OGFC (i.e. the RI sections).

Based on the foregoing: (1) removal of a raveled OGFC surface is recommended. Milling has proven to be an excellent tool for this purpose (2) Routine patching of OGFC should be accomplished with an open-graded patch. This is designed to preclude damming and trapping surface water at the OGFC/dense-graded interface.

APPENDIX A
SELECTED REFERENCES

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2. Hibbs, B.O. and Larson, R.M., "Tire Pavement Noise and Safety Performance," FHWA-SA-96-068, 1996.

3. Page, G.C., "Open-Graded Friction Courses: Florida's Experience," TRB Record 1427, 1993.

4. Page, G.C., et. al., "Florida's Approach Using Ground Tire Rubber in Asphalt Concrete Mixtures, " TRB Record 1339, 1992.

5. Besselievre, W.C., "Deicing Chemical Rates on Open-Graded Pavements, " TRB Special Report 185, 1979.

6. "Open-Graded Friction Courses for Highways," NCHRP Report 49, 1978.

7. Pelletier, R.F., "Demonstration Project No. 10, Improved Skid Resistant Pavements," FHWA-DP-10, 1976.

8. Adam, V. & Shah, S.C., "Evaluation of Open-Graded Plant-Mix Seal Surfaces for Correction of Slippery Pavement," TRB Record 523, 1974.

9. Oppenlander, J.C. & Goetz, W.H., "Triaxial Testing of Bituminous Mixtures at High Confining Pressures, " HRB Proceedings of the 37th Annual Meeting, 1958.

10. "Distress Identification Manual for the Long-Term Pavement Performance Project," SHRP-P-338, 1993.

11. "Pavement Distress & Rehabilitation Manual," Mass. Highway Dept., Dec. 1993.

12. Larsen, D.A., "Pavement Management in Connecticut - Phase II, Development: Distress Evaluation Manual for Field Performance of Pavements," ConnDOT Report Number 887-5-84-11, Dec. 1984, Revised Sept. 1987.

13. Larsen, D.A. "Connecticut Long-Term Pavement Performance. Study - Final Report," ConnDOT Report Number 1342-F-95-7, June 1996.

14. Bowers, D.G., Performance of an Open-Graded Bituminous Concrete Overlay," ConnDOT Report Number 343-4-78-11, Oct. 1978.

15. Dougan, C.E., "Performance Observations on Open-Graded Bituminous Concrete Overlays in Connecticut," ConnDOT Report Number 343-17-81-7, May 1981.

16. Kandhal, P.S. & Mallick, R.B., "Open-Graded Asphalt Friction Course: State-of-the-Practice," National Center for Asphalt Technology.

17. Landa, S., "A Comparison of Modified Open-Graded Friction Courses to Standard Open-Graded Friction Course," Georgia DOT Report Number FHWA-GA-97-9110, April 1997.

18. Georgia DOT - Various Special Provisions & Test Methods

19. "Report on the AASHTO Survey of Current State Use of Open-Graded Friction Courses (OGFC)," May 1989.

20. "Open-Graded Friction Courses" FHWA Technical Advisory T5040.31, December 26, 1990.

21. "Georgia's Modified Open-Graded Friction Course."

22. Stephens, J.E., "Connecticut Procedure for Pavement Density Measurements," JHRAC Project Number 63-6, 1964.

APPENDIX B
TEST EQUIPMENT USED

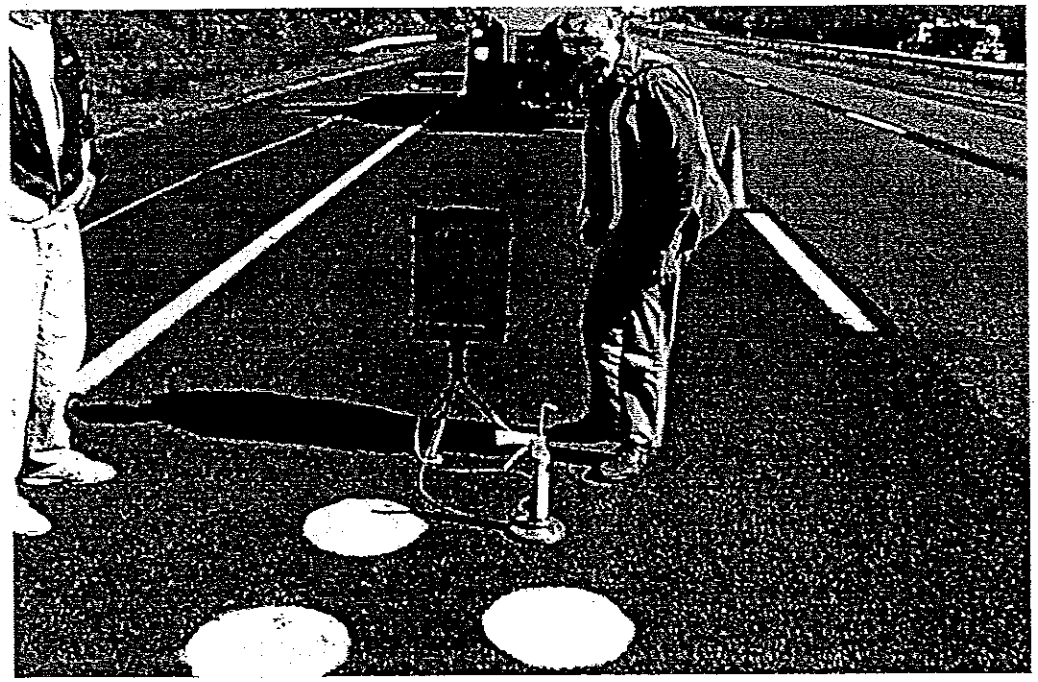

Photo B1 – Air Permeability Set-up

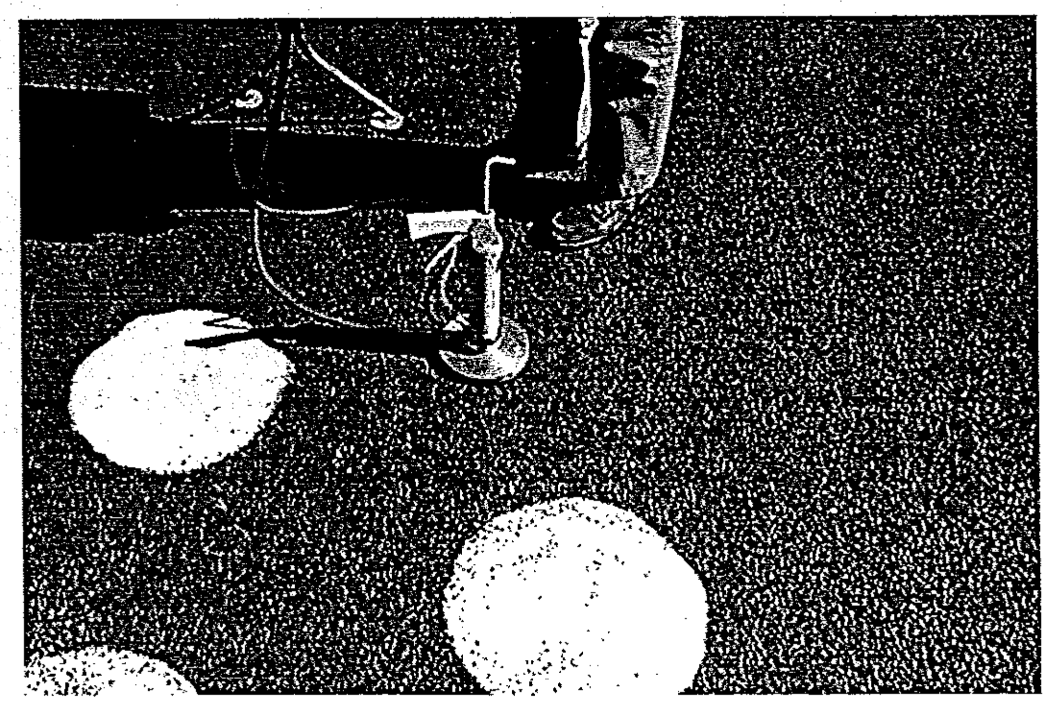

Photo B2 – Close-up of Permeablity Test

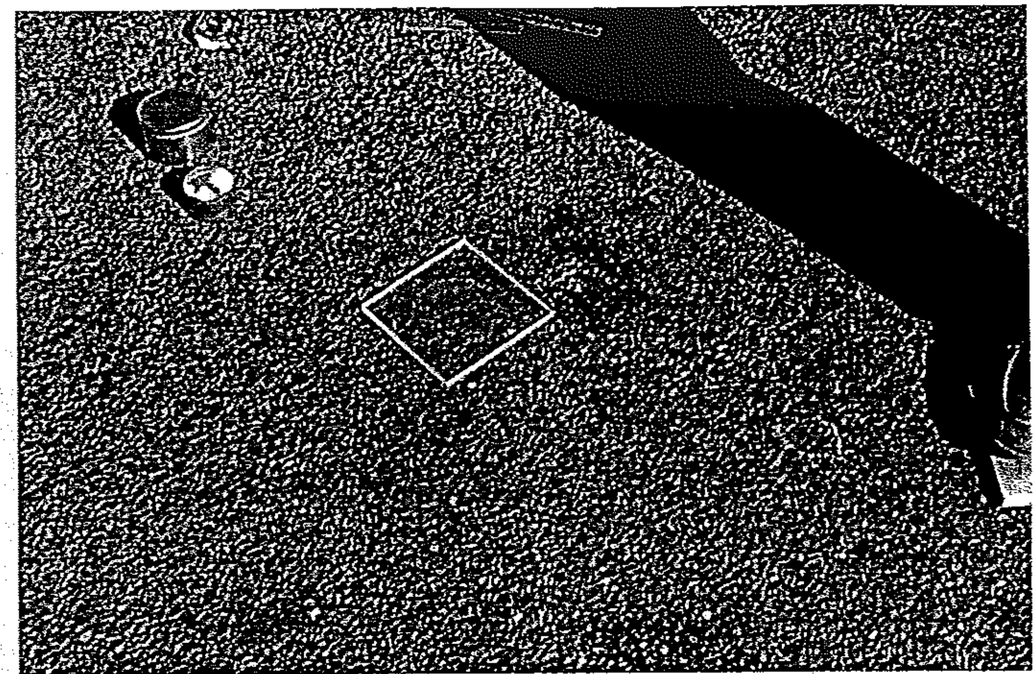

Photo B3 – Apparatus for determining Surface Texture – Silly Putty Method

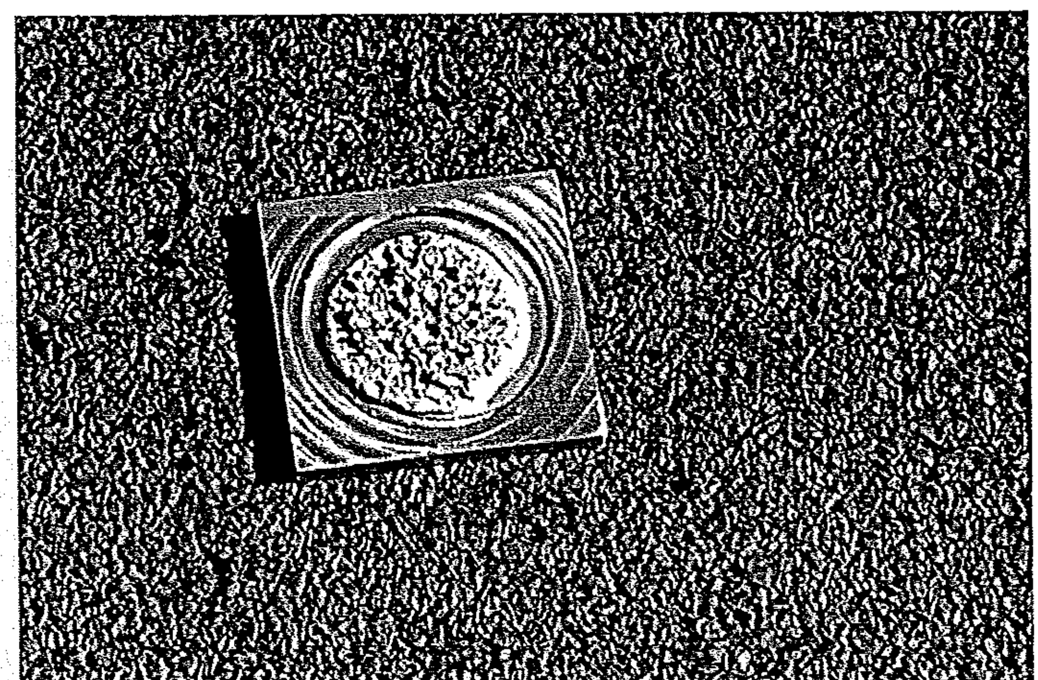

Photo B4 – Texture Determined by Silly Putty Method

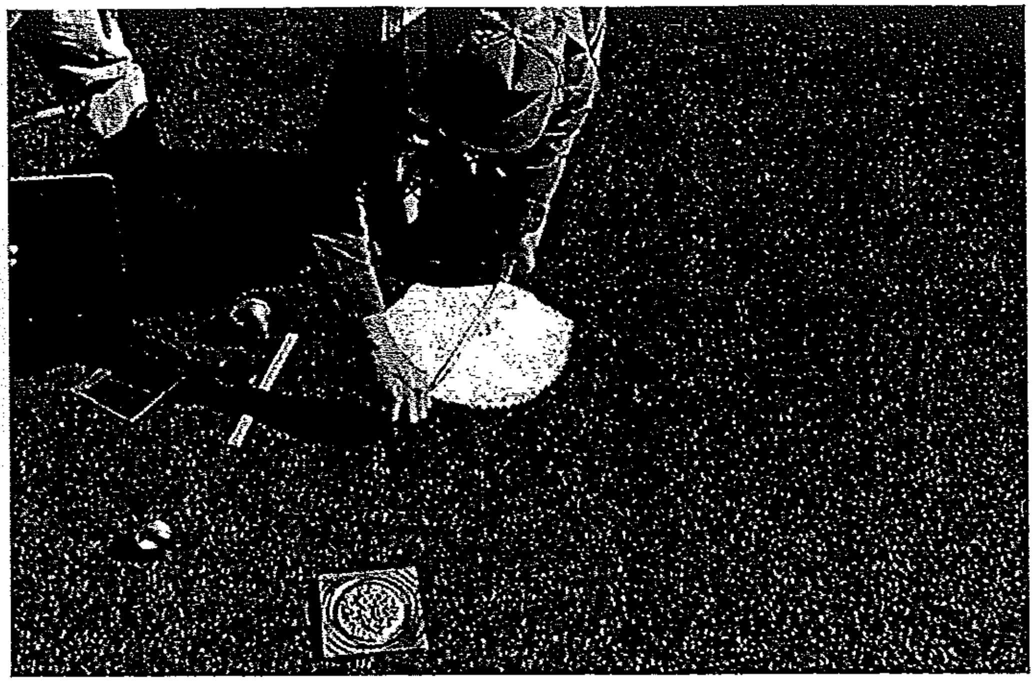

Photo B5 – Determining Surface Texture Using Sand Patch Method

Photo B6 – ConnDOT Friction Measuring Equipment

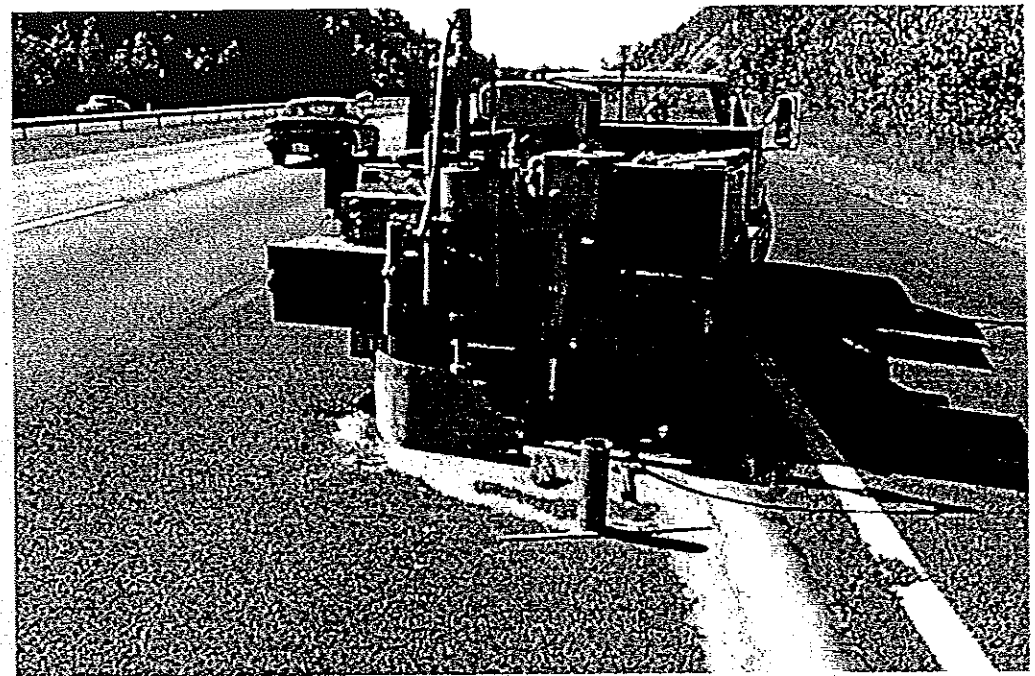

Photo B7 – Coring Equipment

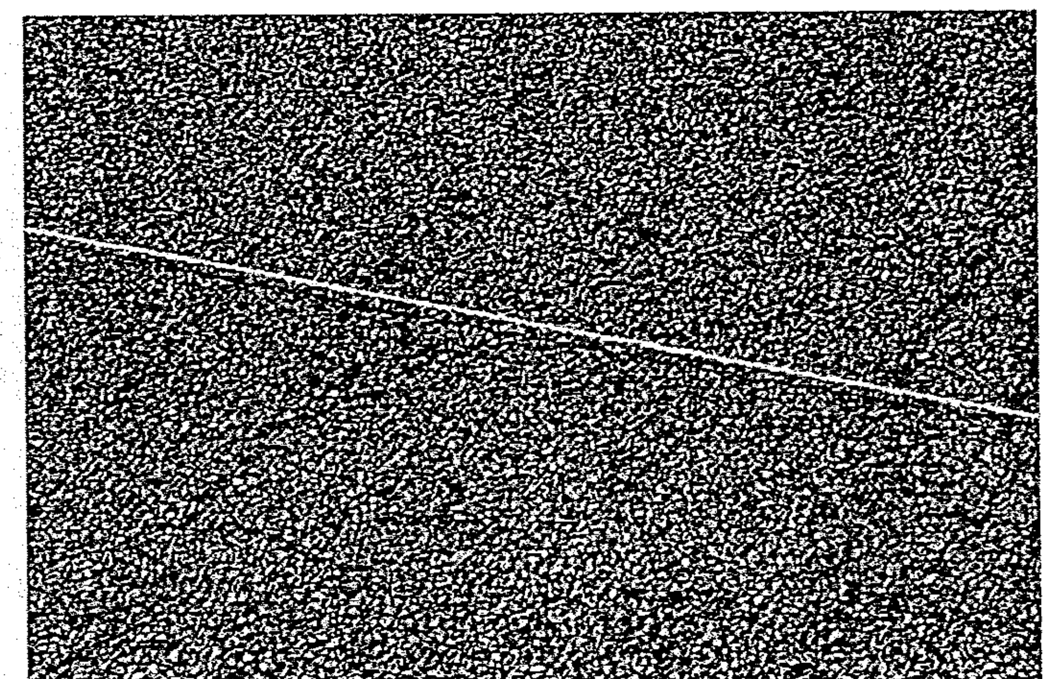

Photo B8 – Rut Measured By Stringline, Sublot 4 (6-800ft)

APPENDIX C

CONNECTICUT TEST SITE

I-84 WB; Union, CT Between Exits 74 & 73 (911/98)

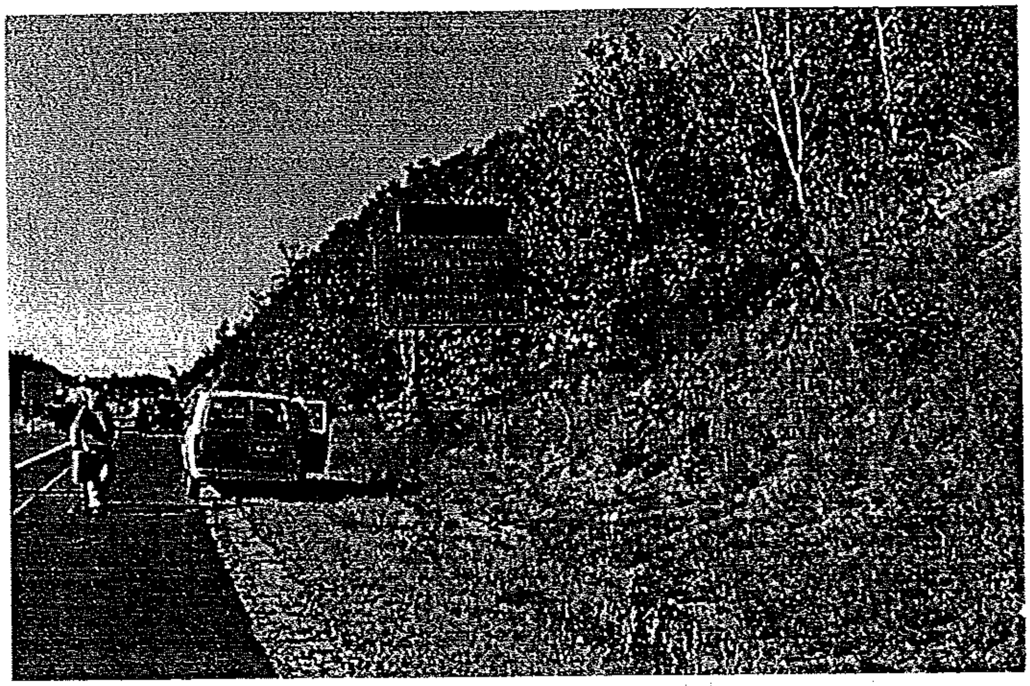

Photo C1 – Start of Test Site

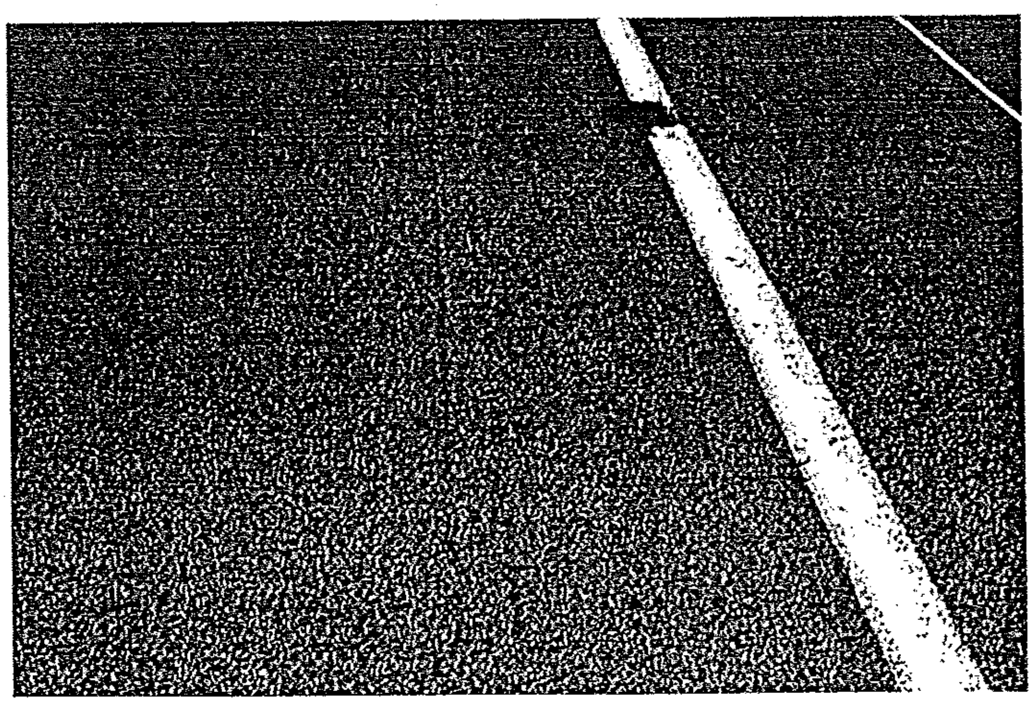

Photo C2 – Sub-lot 1 (0-200 ft) longitudinal cracking and surface "gouges"

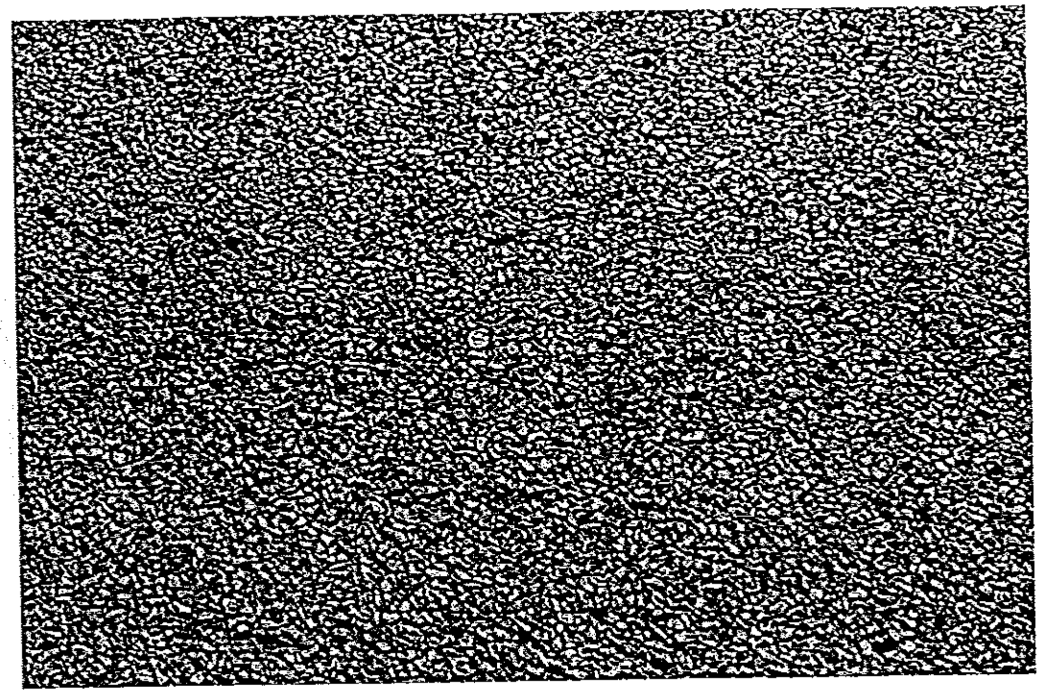

Photo C3 – Sub-lot 1 (0-200 ft) Typical Surface. Note loss of fines.
Coin is a dime.

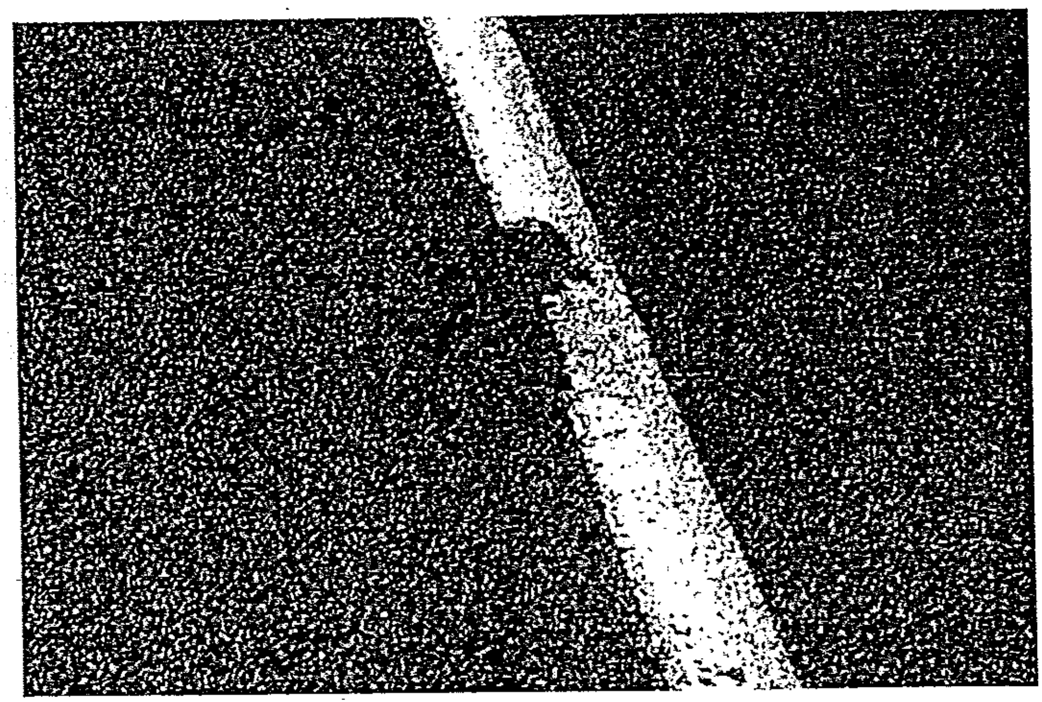

Photo C4 – Sub-lot 4 (6-800 ft) Loss of Material @ Right-hand edge of Pavement

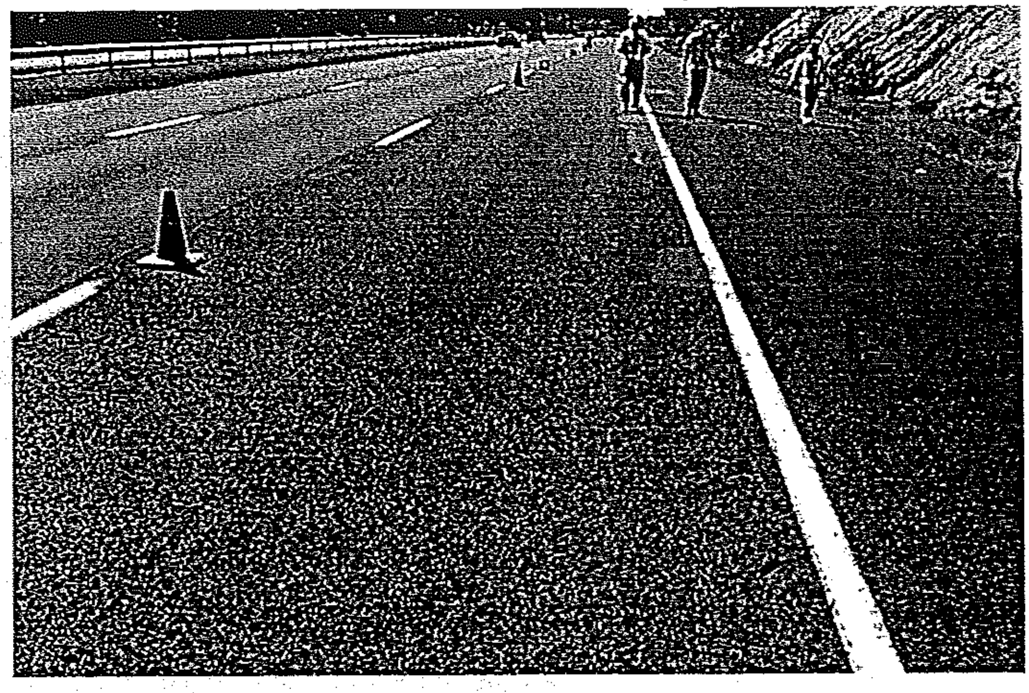

Photo C5 – Sub-lot 5 (8-1000 ft) General View of Sub-lot

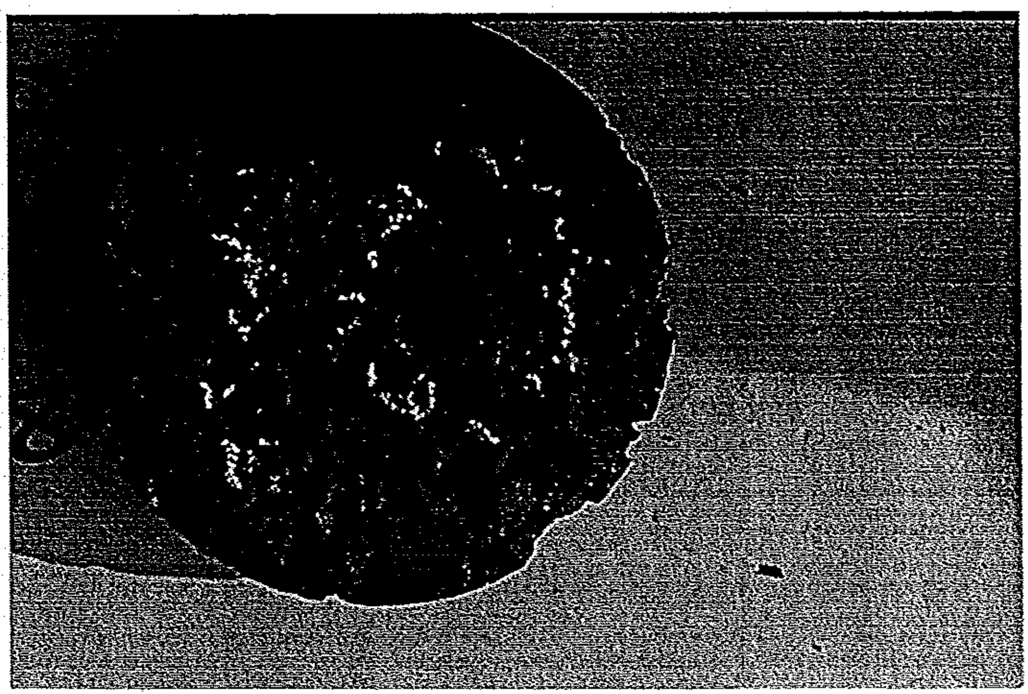

Photo C6 – Close-up of Cored Surface, Core 10 –thickness 2.8 cm

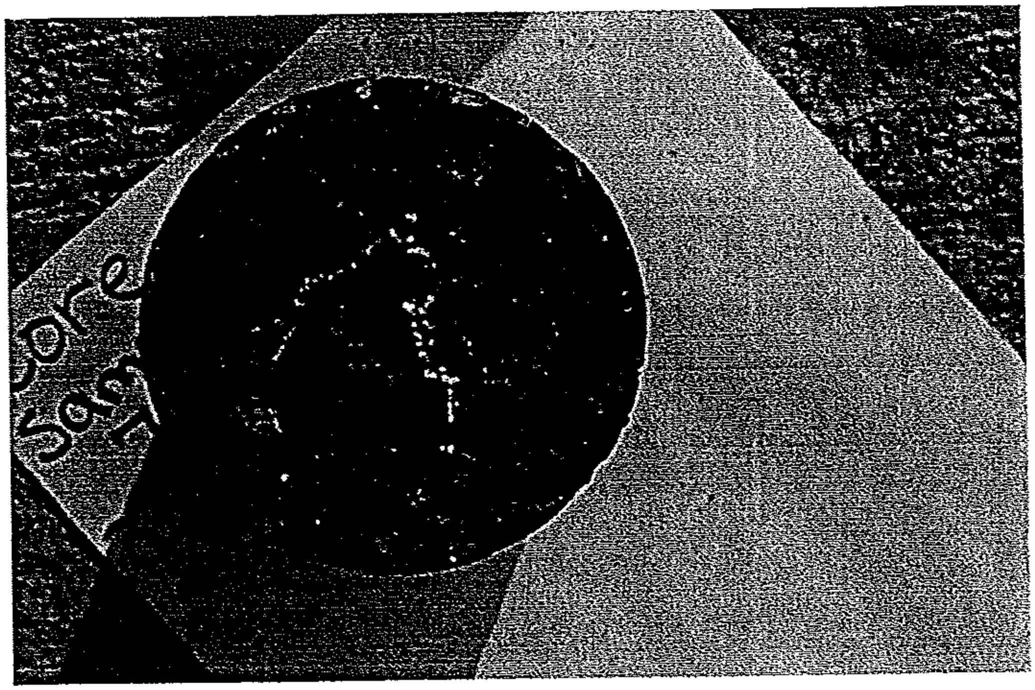

Photo C7 – Core 7; OGFC 3.0 cm thick

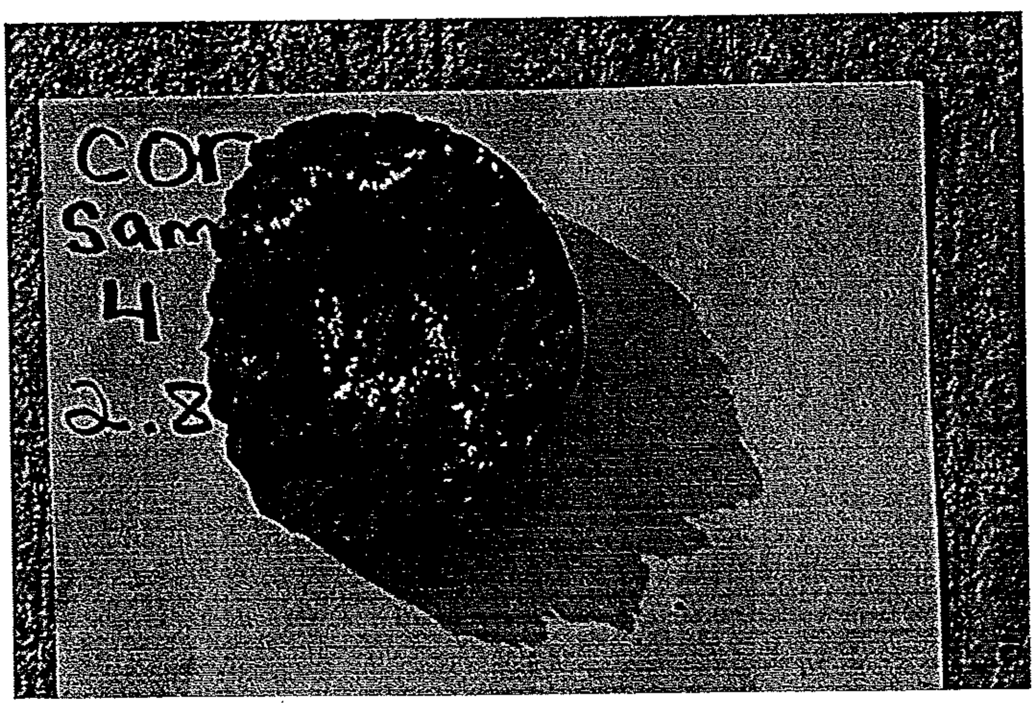

Photo C8 – Core 4 - OGFC 2.8 cm thick

Table C1 - Data obtained from CT, I-84 WB

OPEN GRADED FRICTION COURSE SURVEY

State - CT

Date 9/11/98

Route I-84WB

Start Point- Sign for Weigh Station

	Sand patch Test (350 gm)			Silly Putty Test (50 gm)			Air permeability					Rutting
	Station *(ft)*	Offset*(ft)*	Diameter*(in)*	Station*(ft)*	Offset*(ft)*	Diameter*(in)*	Station*(ft)*	Offset*(ft)*	Head*(in)*	Quantity*(ml)*	Time*(sec)*	*(mm)*
0 - 200	170	6	16			3.625		6	0.25	1000	63	Not Meas.
	170	6	15.75			3.75						
	170	6	15			3.937						
Average			15.58			3.77			0.25	1000	63	
200 - 400	270	2	16.5	270	2	3.75	266	2	0.25	1000	22.5	Not Meas.
	270	3	15	270	2	3.5	267	2.5	0.25	1000	37	
	270	1	14.75	270	2	3.7						
Average			15.42			3.65			0.25	1000	29.75	
400 - 600	495	4.4	15.75	695	7	3.75	497	6	0.25	1000	244	Not Meas.
	495	6.5	18.25	695	9	3.75	496	6	0.25	1000	198	
	495	4.5	16.08	695	4.5	3.5						
Average			16.69			3.67			0.25	1000	221	
600 - 800	690	3	18.75	690	3	3.89	694	5	0.25	1000	160	9.5
	690	4.5	17.5	690	6.5	4.05	693	5.5	0.25	1000	224	
	690	2.5	17.5	690	2.5	3.75	694	5	0.25	1000	42	
Average			17.92			3.90			0.25	1000	142	
800 - 1000	904	0.5	14.25	904	1.5	3.75			0.25	1000	49	10.0
	905	2.5	14.62	905	1.5	4.25			0.25	1000	304	8.0
	905.5	2.5	15	905.5	3.5	3.94			0.25	1000	304	
Average			14.62			3.98			0.25	1000	219	
Average			16.05			3.79			0.25	1000	134.95	

Table C2 - Summary of Distresses Observed

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location CT I-84 WB	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	3	None	None	525	520	None	None	None
2 (200-400 ft)	7	None	None	760	785	None	5	None
3 (400-600 ft)	180	38	None	610	475	150	Not Meas.	4
4 (600-800) ft)	12	None	None	410	460	None	4 1/2	None
5 (800-1000 ft)	56	None	None	324	461	1	3	None

TABLE C3
Pavement Friction Testing Results
October 1998

Results for Connecticut Site No. 1:
I-84 Westbound, Right Lane, Milepost 95.39 - 95.17, Town of Union.
Test Date: October 9, 1998

Milepost	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
95.39	41.4	38.7
95.36	41.4	39.4
95.34	41.0	42.2
95.32	41.1	39.5
95.29	41.6	39.4
95.27	41.5	40.4
95.24	42.0	39.6
95.22	41.5	38.3
95.20	41.8	39.5
95.17	43.2	39.9
Average	**41.7**	**39.7**

APPENDIX D

MASSACHUSETTS TEST SITES

I-290 WB NORTHBORO (10/5/98)
I-495 NB @ EXIT 31 (10/6/98)

Photo D1 – I-290 WB Test Area Looking Easterly (8-1000ft)

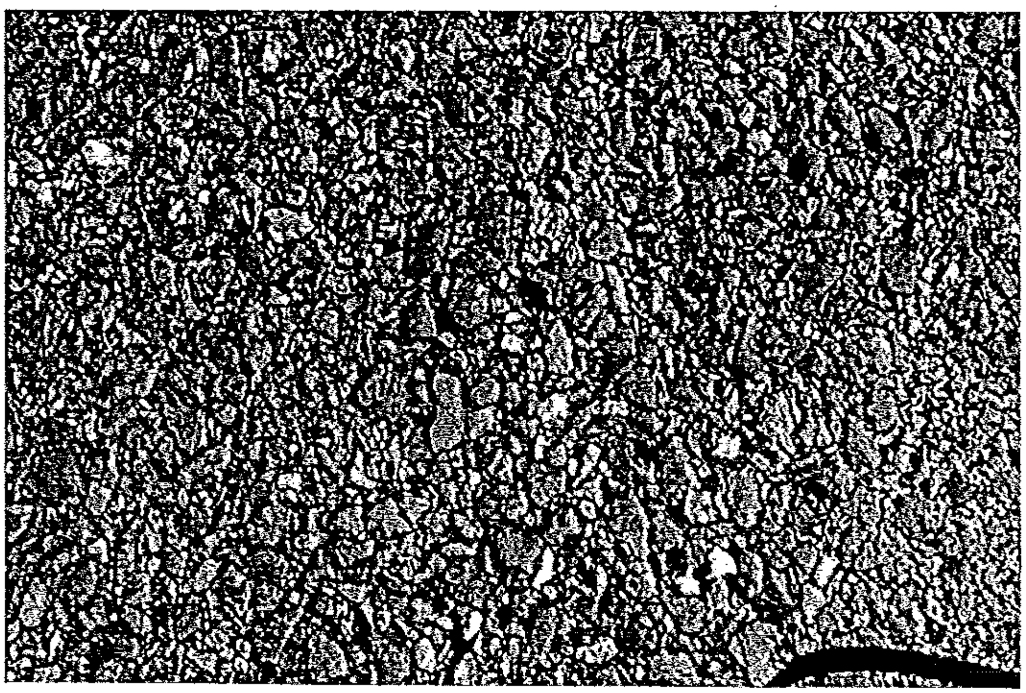

Photo D2 – I-290 WB Typical Surface Texture, Inner Wheel Path
(8-1000 ft)

Photo D3 – WB Gouge in Pavement Surface (4-600 ft)

Photo D4 – I-495 Test Area looking Southerly (8-1000 ft)

Photo D5 – I-290 WB – Close-up of Typical Core (0-200 ft)

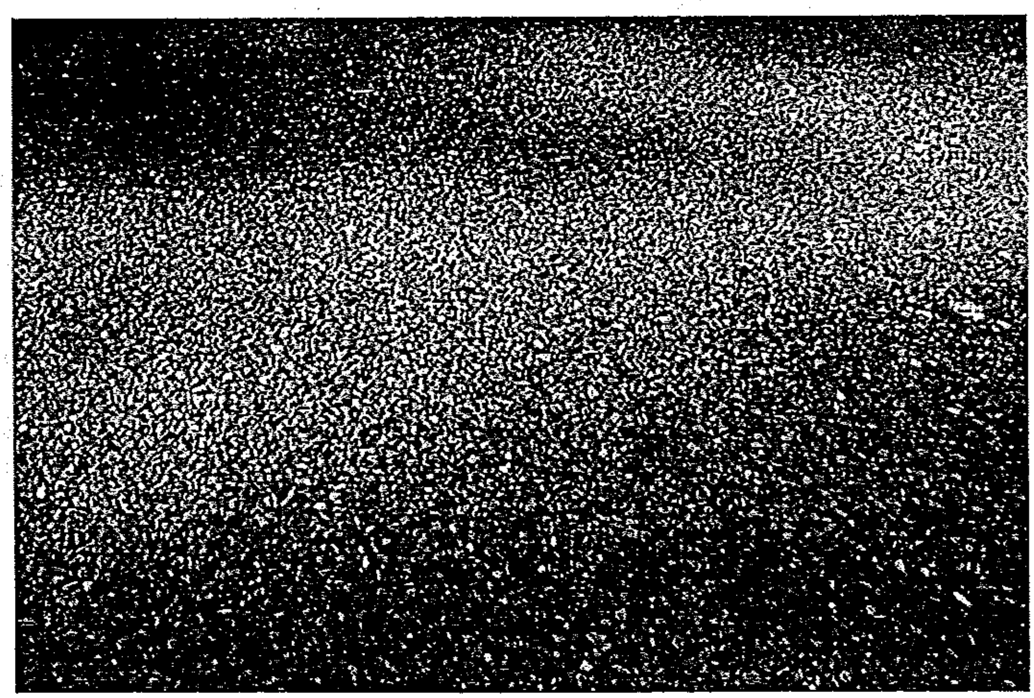

Photo D6 – I-495 NB Typical Surface Texture (6-800 ft)

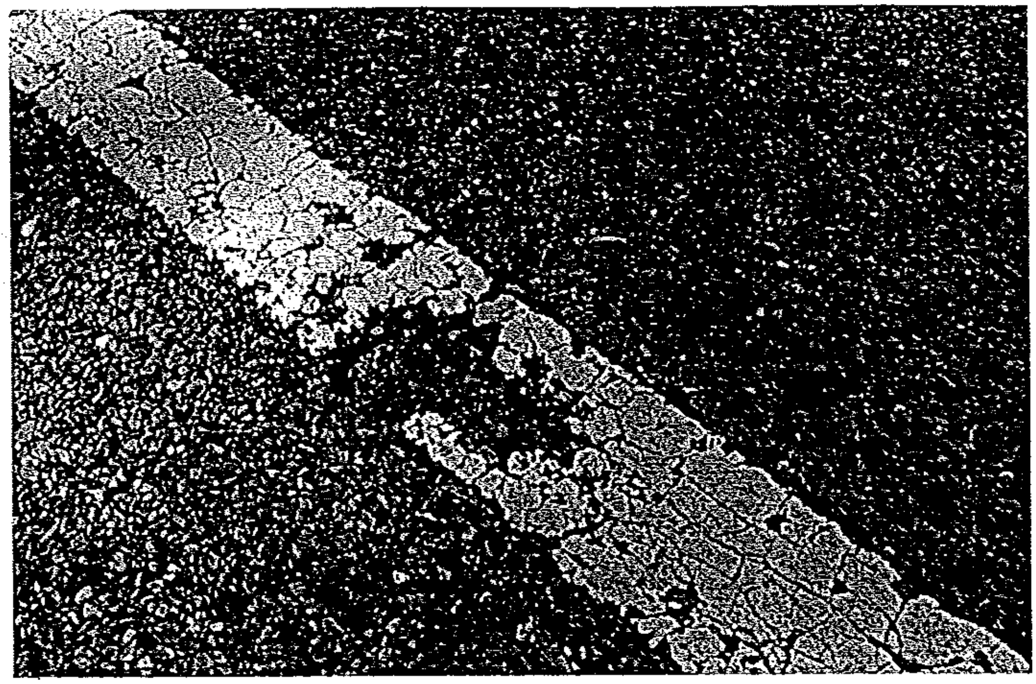

Photo D7 – I-495 NB – Distress @ Outer Edge of Pavement (6-800 ft)

Photo D8 – I-495 NB Surface Texture and Distress @ Outer edge of Pavement (8-1000 ft)

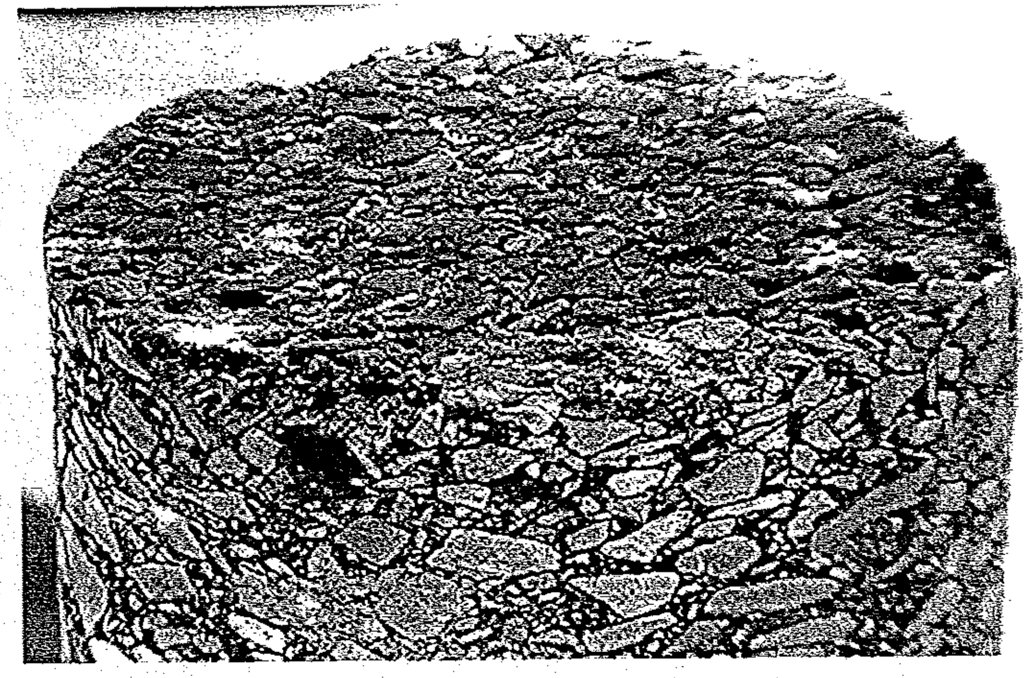

Photo D9 – I-495 Close-up of Typical Core (6-800 ft)

Table D1 - Data obtained from MA Section 2, I-290WB

OPEN GRADED FRICTION COURSE SURVEY

State - Mass

Date 10/5/98

Route I-290WB Starting Point-

	Sand Patch Test (350 gm)			Silly Putty Test (50 gm)			Air Permeability					Rutting
	Station *(ft)*	Offset*(ft)*	Diameter*(in)*	Station*(ft)*	Offset*(ft)*	Diameter*(in)*	Station*(ft)*	Offset*(ft)*	Head*(in)*	Quantity*(ml)*	Time*(sec)*	*(mm)*
0 - 200	101	3.5	19.5	100	3.5	4.13	99	4	0.25	1000	340	6
	106	4	18	103	3	4.18	110.5	3			No Flow	5
	47	4	18.5	105	3.5	4.13						
Average			18.67			4.15			0.25			
200 - 400	295	6	21	301.5	3.5	4.5	298.5	5.5	0.25	1000	461.8	12
	292	6	21	298	5.5	4.25	304	6	0.25	1000	2456	0
	300	5.5	20.5	276.5	5.75	4.25						
Average	295.67	5.83	20.83	292	4.92	4.33			0.25	1000	1458.9	
400 - 600	501	3	18.75	499.5	3	4.13	499	3	0.25	1000	337	10
	497.5	2.5	19.5	502.5	3	4.25	508	3	0.25	1000	435.3	5
	513	3	19.75	510.5	3	4.13						
Average			19.33			4.17			0.25	1000	386.15	
600 - 800	702	6.5	19.25	700.5	6.5	4.44	701	6.5	0.25	1000	823.5	12
	699	6.5	20.5	697	6.5	4.15	706	6.5	0.25	1000	1794	9
	709	6.5	20.75	705	6.5	4.44						
Average			20.17			4.34			0.25	1000	1308.75	
800 - 1000	893	9	19.5	895	9	4.13	899	9	0.25	1000	270.6	10
	889	9	18.75	891.5	9	4.1	905	9	0.25	1000	342.3	6
	896	9	19.5	897	9	4.19						
Average			19.25			4.14			0.25	1000	306.45	
Average			19.65			4.23			0.25	800	692.05	

Table D2 - Summary of Distresses Observed; I-290 WB

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location MA I-290 WB	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	No Distress Observed							
2 (200-400 ft)	No Distress Observed							
3 (400-600 ft)	No Distress Observed						1/2	Immeasurable
4 (600-800) ft)	No Distress Observed							1/2
5 (800-1000 ft)	No Distress Observed							

Table D3 - Data obtained from MA Section 1, I-495 NB Exit 31

OPEN GRADED FRICTION COURSE SURVEY

State - Mass

Date 10/6/98

Route I-495NB

Start Point - Exit 31

	Sand Patch Test (350 gm)			Silly Putty Test (50 gm)			Air Permeability						Rutting
	Station *(ft)*	Offset*(ft)*	Diameter*(in)*	Station*(ft)*	Offset*(ft)*	Diameter*(in)*	Station*(ft)*	Offset*(ft)*	Head*(in)*	Quantity*(ml)*	Time*(sec)*	*(mm)*
0 - 200	98	3	17.75	105	3	4.13						
	102	3	18	100	3	3.88	102	3	0.25	1000	128.4	7
	100	3	18.5	100	3	4	100	3	0.25	1000	144	2
Average			18.08			4.00			0.25	1000	136.2	
200 - 400	296.5	6	19	295	6	3.88	302	6	0.25	1000	376.4	12
	294	6	17.5	298.5	6	4	304	6	0.25	1000	352	12
	301	5	19.25	300	5	4.06						
Average			18.58			3.98			0.25	1000	364.2	
400 - 600	491	3	20	493	3	4	500	3	0.25	1000	118.7	3
	494.5	3	19.5	498.5	3	4.06	497	3	0.25	1000	153.4	2
	502	3	19.5	499	3	4.13						
Average			19.67			4.06			0.25	1000	136.05	
600 - 800	698	5.5	19.25	697	5.5	4.12	703	5.5	0.25	1000	194	6
	702	5.5	19.5	704	5.5	4	700	5.5	0.25	1000	206.7	2
	707	5.5	19.75	706	5.5	4						
Average			19.5			4.04			0.25	1000	200.35	
800 - 1000	902	9	18	901	9	3.4	900	9	0.25	1000	153.7	11
	897	9	17.5	903.5	9	3.94	904.5	9	0.25	1000	456	5
	909.5	9	18.5	906.5	9	4.06						
Average			18			3.8			0.25	1000	304.85	
Average			18.77			3.98			0.25	1000	228.33	

Table D4 - Summary of Distresses Observed, I-495 NB

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location MA I-495 MM 85	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	17	20	None	15	80	None	None	None
2 (200-400 ft)	None	173	None	23	None	None	None	None
3 (400-600 ft)	None	30	3	20	None	None	None	None
4 (600-800) ft)	None	None	None	2	None	None	None	None
5 (800-1000 ft)	2	None	None	6	None	60	1.5	None

TABLE D3
Pavement Friction Testing Results
October 1998

Results for Massachusetts Site No. 2:
I-290 Westbound, Right Lane, 0.04-0.21 miles west of BM 67.45 on bridge, Northborough.
Test Date: October 1, 1998

Miles West BM 67.45	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
0.04	50.2	47.2
0.07	50.8	47.2
0.10	50.7	47.4
0.12	51.4	48.3
0.14	51.3	47.9
0.17	52.2	49.5
0.19	52.1	48.2
0.21	51.1	48.0
Average	**51.2**	**48.0**

Results for Massachusetts Site No. 1:
I-495 Northbound, Right Lane, Milepost 85.00-85.24, Town of Westford.
Test Date: October 1, 1998

Milepost	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
85.01	50.4	46.8
85.04	50.6	46.7
85.06	50.3	45.8
85.09	51.3	46.9
85.11	50.8	47.6
85.14	51.8	48.4
85.17	50.8	46.9
85.19	51.2	48.0
85.22	51.7	48.3
85.24	51.2	47.0
Average	**51.0**	**47.2**

APPENDIX E

RHODE ISLAND TEST SITES
I-95 SB @ RT 3, BRIDGE (10/7/98
I-95 SB @ MM 12.0 (10/7/98)

Photo E1 – I-95 SB @ Rt 3, Texture @ Centerline of Lane (6-800 ft)

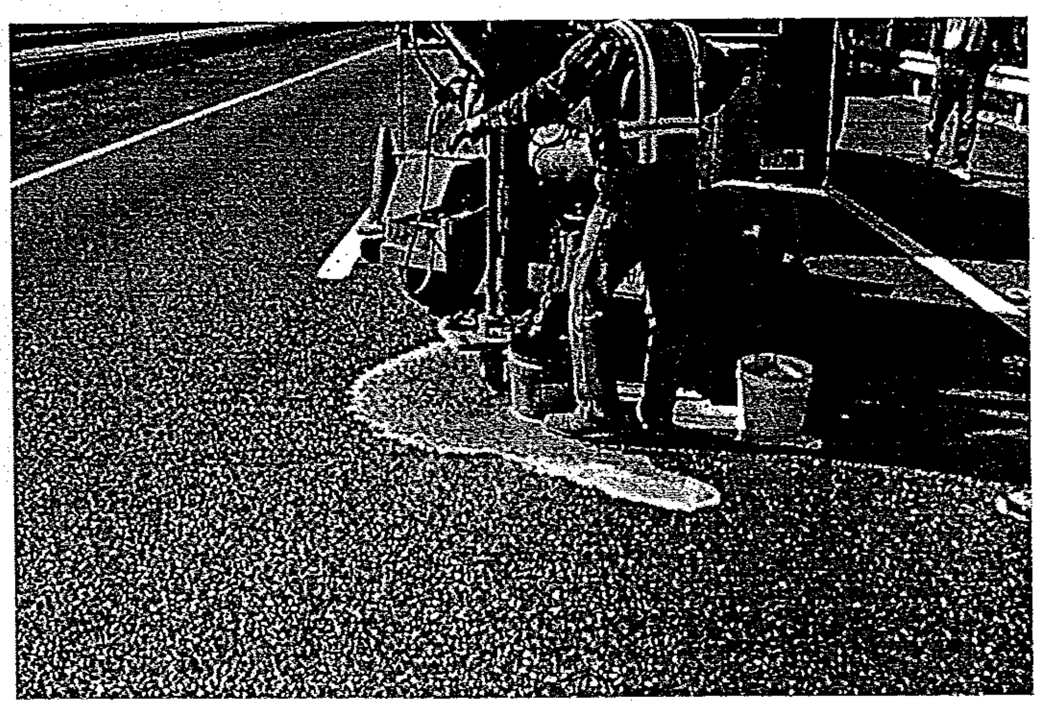

Photo E2 – I-95 SB @ Rt 3, Typical Surface Texture in Left Wheel Path (8-1000 ft)

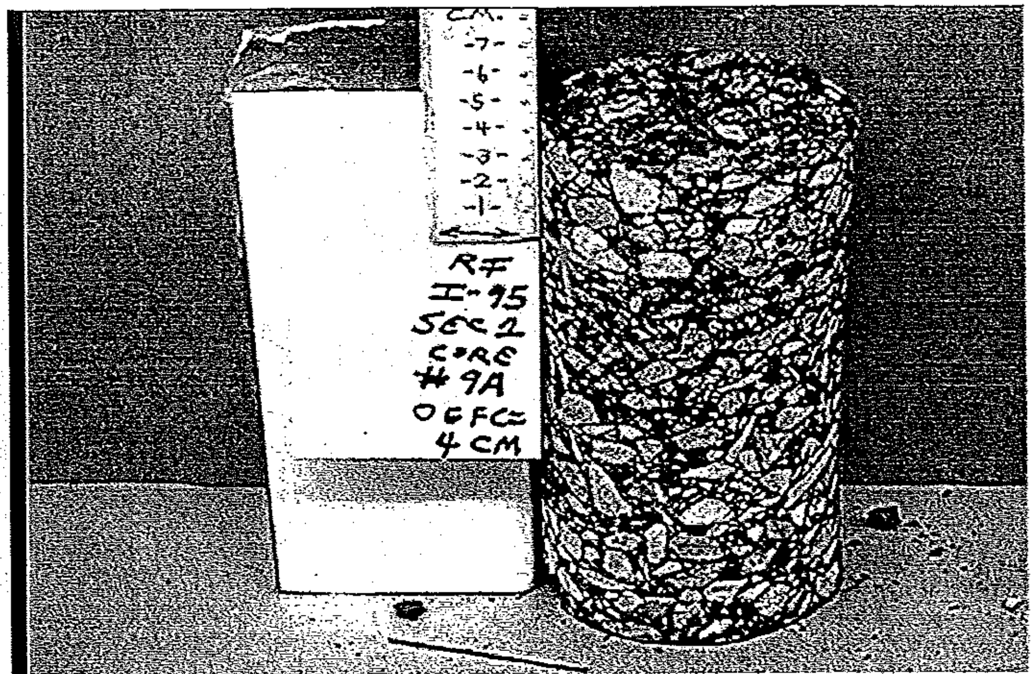

Photo E3 – I-95 SB @ Rt 3. Typical Core (8-1000 ft)

Photo E4 – I-95 SB MM 12.0 – Typical Surface Texture (0-200 ft)

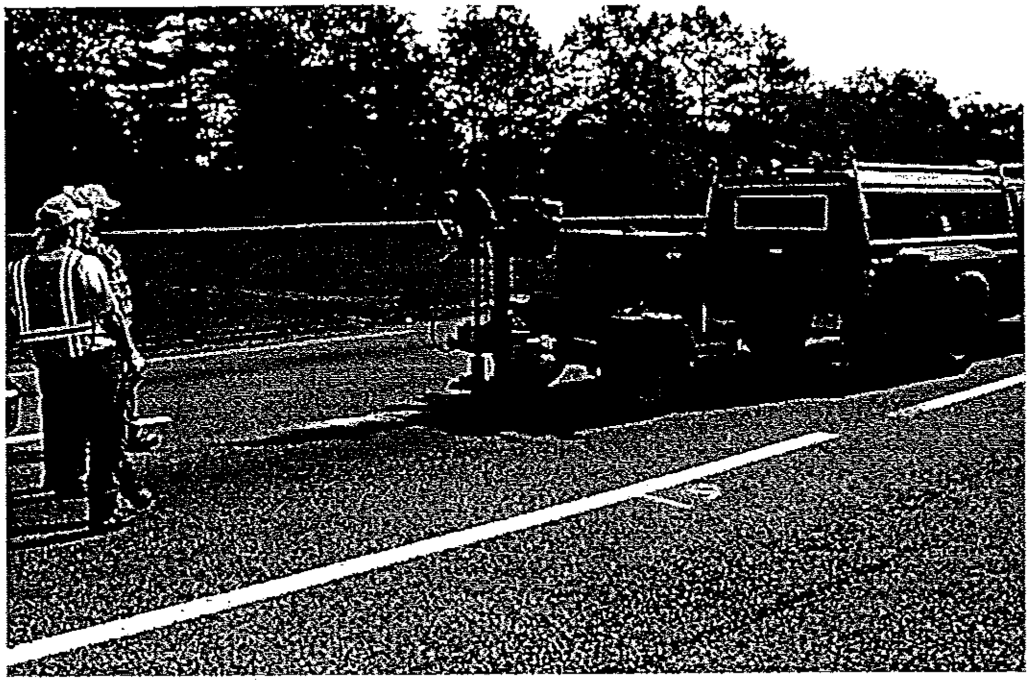

Photo E5 – I-95 SB MM 12.0 Typical Surface
@ Edge of Pavement (8-1000 ft)

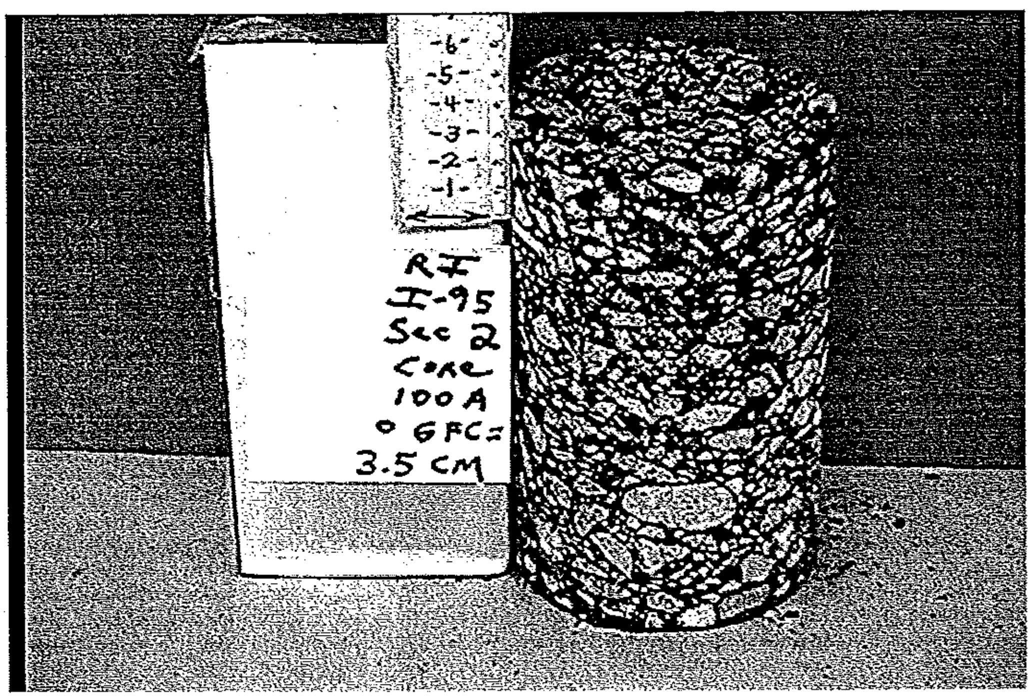

Photo E6 – I-95 SB – MM12.0 Close-up of Typical Core (0-200 ft)

Table E1 - Data obtained from RI Section 1, I-95 SB Exit 6

OPEN GRADED FRICTION COURSE SURVEY

State - RI

Date 10/7/98

Route I-95SB

Start Point: Exit 6

	Sand Patch Test (350 gm)			Silly Putty Test (50 gm)			Air Permeability					Rutting
	Station (ft)	Offset(ft)	Diameter(in)	Station(ft)	Offset(ft)	Diameter(in)	Station(ft)	Offset(ft)	Head(in)	Quantity(ml)	Time(sec)	(mm)
0 - 200	102	3	20	97.5	3	4.38	100	3	0.25	1000	112	3
	98	3	18	103	3	4.25	102	3	0.25	1000	106.8	0
	97	3	19.5	101	3	4.13						
Average			19.17			4.25			0.25	1000	109.4	
200 - 400	296	6	16.75	294.5	6	4.09	298	6	0.25	1000	303.4	0
	293	6	17	300	6	3.88	297	6	0.25		No Flow	0
	302	6	18.5	303	6	4.07						
Average			17.42			4.01			0.25			
400 - 600	495	3	20.75	502	3	4.13	496	3	0.25	1000	608	2
	492	3	20.5	500	3	4.22	495.5	3	0.25	1000	295.3	8
	504	3	20	501	3	4.13						
Average			20.42			4.16			0.25	1000	451.65	
600 - 800	695	6	19.5	699	6	4.13	697	6	0.25		No Flow	0
	692	6	20.5	700	6	4.06	699	6	0.25	1000	330	2
	702	6	18.5	699.5	6	4						
Average			19.5			4.06			0.25			
800 - 1000	902	9	19	900	9	4.06						0
	899	9	19.5	898	9	4	896	9	0.25	1000	1084	3
	897	9	20.5	894	9	4.06	897	9	0.25	1000	70	
Average			19.67			4.04			0.25	1000	577	
Average			19.23			4.11			0.25			

Table E2 - Summary of Distresses Observed, I-95 SB

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location I-95 SB Exit 6	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	No Distress Observed							
2 (200-400 ft)	No Distress Observed							
3 (400-600 ft)	No Distress Observed							
4 (600-800) ft)	No Distress Observed							
5 (800-1000 ft)	No Distress Observed							

Table E3 - Data obtained from RI Section 2, I-95 SB MM 12.0

OPEN GRADED FRICTION COURSE SURVEY

State - RI | Date 10/7/98

Route I-95SB | Start Point - MM 12.0

	Sand Patch Test (350 gm)			Silly Putty Test (50 gm)			Air Permeability					Rutting
	Station (ft)	Offset(ft)	Diameter(in)	Station(ft)	Offset(ft)	Diameter(in)	Station(ft)	Offset(ft)	Head(in)	Quantity(ml)	Time(sec)	(mm)
0 - 200	93	3	16.5	100	3	4.06	99	3	0.25	1000	222.67	2
	95	3	16	98	3	4	97	3	0.25	1000	81	5
	101	3	16	96	3	3.88						
Average			16.17			3.98			0.25	1000	151.84	
200 - 400	295	6	17.25	301	6	4.22	300	6	0.25	1000	606.7	0
	293	6	18.5	299	6	4.25	298	6	0.25	1000	562.3	3
	302	6	18	297	6	4.18						
Average			17.92			4.22			0.25	1000	584.5	
400 - 600	497	3	19.25	500	3	4.13	499	3	0.25	1000	170.7	0
	494	3	19.5	495.5	3	4	501	3	0.25	1000	104	3
	504	3	19.25	501	3	4.19						
Average			19.33			4.11			0.25	1000	137.35	
600 - 800	704	6	18.5	700	6	4.25	699	6	0.25	1000	158.3	2
	697	6	18	695.5	6	4.18	701	6	0.25	1000	444	0
	697	6	17.75	704	6	4.22						
Average			18.08			4.22			0.25	1000	301.15	
800 - 1000	904	9	19.25	901	9	4.31	902	9	0.25	1000	440	0
	894	9	18.5	889	9	4.06	900	9	0.25	1000	677	0
	896	9	19	904.5	9	4.16						
Average			18.92			4.18			0.25	1000	558.5	
Average			18.08			4.14			0.25	1000	346.67	

Table E4 - Summary of Distresses Observed, I-95 SB, MM 12.0

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location RI-I-95 SB MM 12	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	No Distress Observed							
2 (200-400 ft)	No Distress Observed							
3 (400-600 ft)	No Distress Observed							
4 (600-800) ft)	No Distress Observed							
5 (800-1000 ft)	No Distress Observed							

TABLE E3
Pavement Friction Testing Results
October 1998

Results for Rhode Island Site No. 1:
I-95 Southbound, Right Lane, 0-.70-0.95 miles south of Route 3 Overpass, West Greenwich.
Test Date: October 2, 1998

Miles South Of Rt. 3 Overpass	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
0.72	49.0	44.9
0.75	49.6	46.1
0.78	48.3	43.9
0.80	49.0	44.3
0.83	50.4	45.3
0.85	51.2	45.6
0.88	50.9	47.7
0.90	48.9	43.9
0.93	49.2	44.5
0.95	49.1	46.1
Average	**49.6**	**45.2**

Results for Rhode Island Site No. 2:
I-95 Southbound, Right Lane, Milepost 12.00-11.77, Town of Exeter.
Test Date: October 2, 1998

Milepost	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
12.00	51.3	50.5
11.97	50.9	50.2
11.94	51.7	49.9
11.91	51.3	49.9
11.89	52.1	50.0
11.86	52.4	51.3
11.84	51.7	50.3
11.82	51.5	49.7
11.79	51.9	49.6
11.77	51.8	51.1
Average	**51.7**	**50.3**

APPENDIX F

VERMONT TEST SITES
I-89 SB, MM 70.0 (10/1/98)
I-89 SB, MM 57.1 (10/2/98)

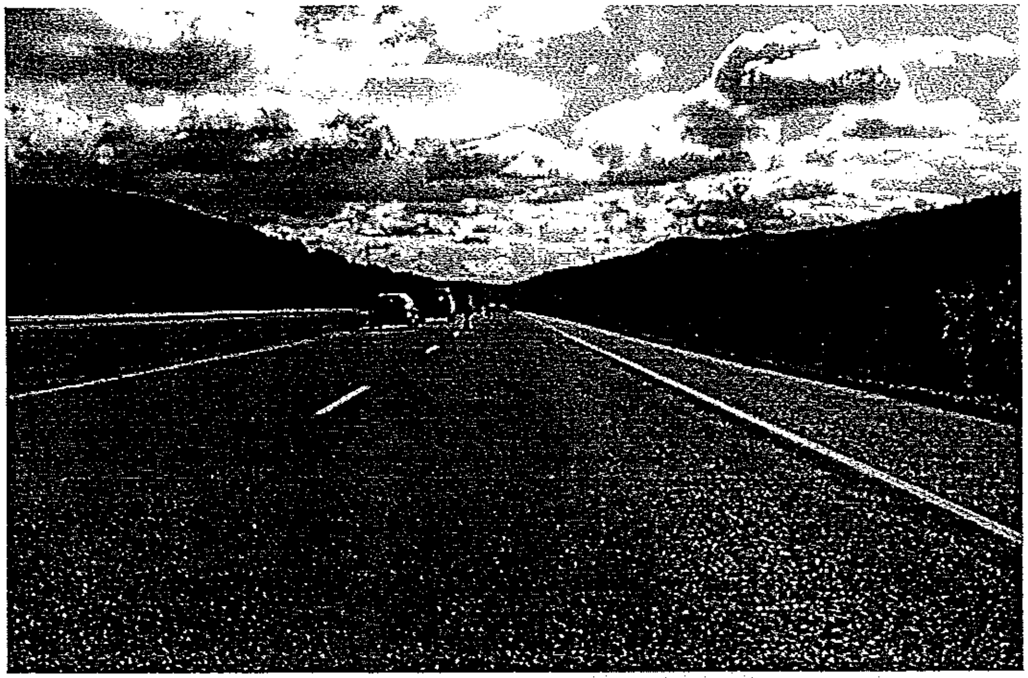

Photo F1 – I-87 SB MM 70.0 Southerly View of Test Area

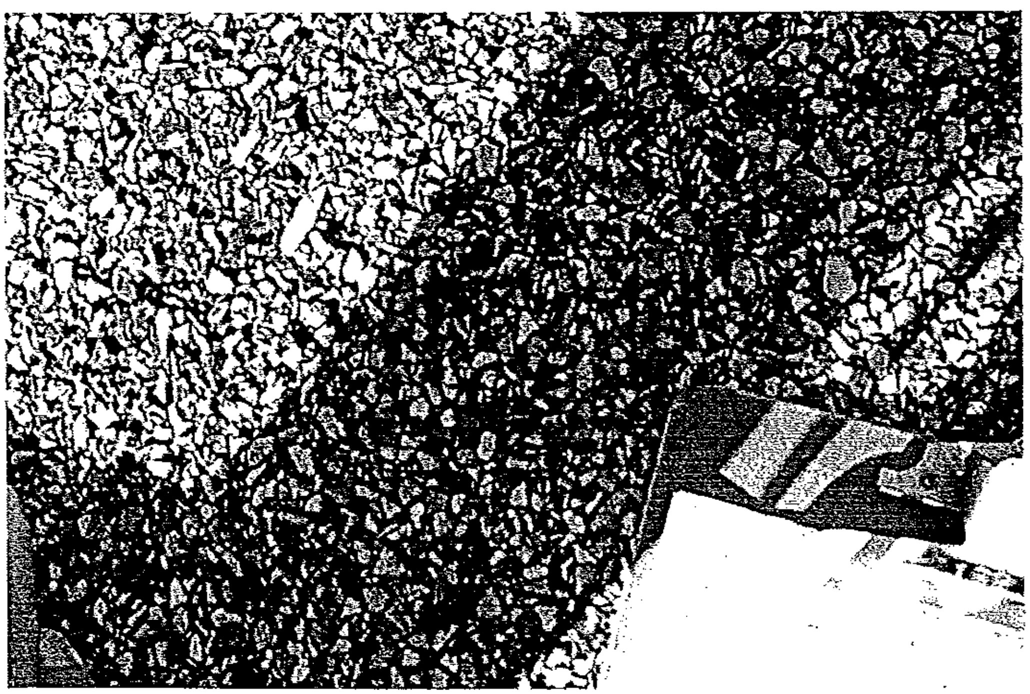

Photo F2 – I-87 SB – MM 70.0 Typical Surface Texture @ Center of Lane (6-800 ft)

Photo F3 – Close-up of Texture of Cores

Photo F4 – I-87 SB MM 57.1 General View of Test Area looking Northerly

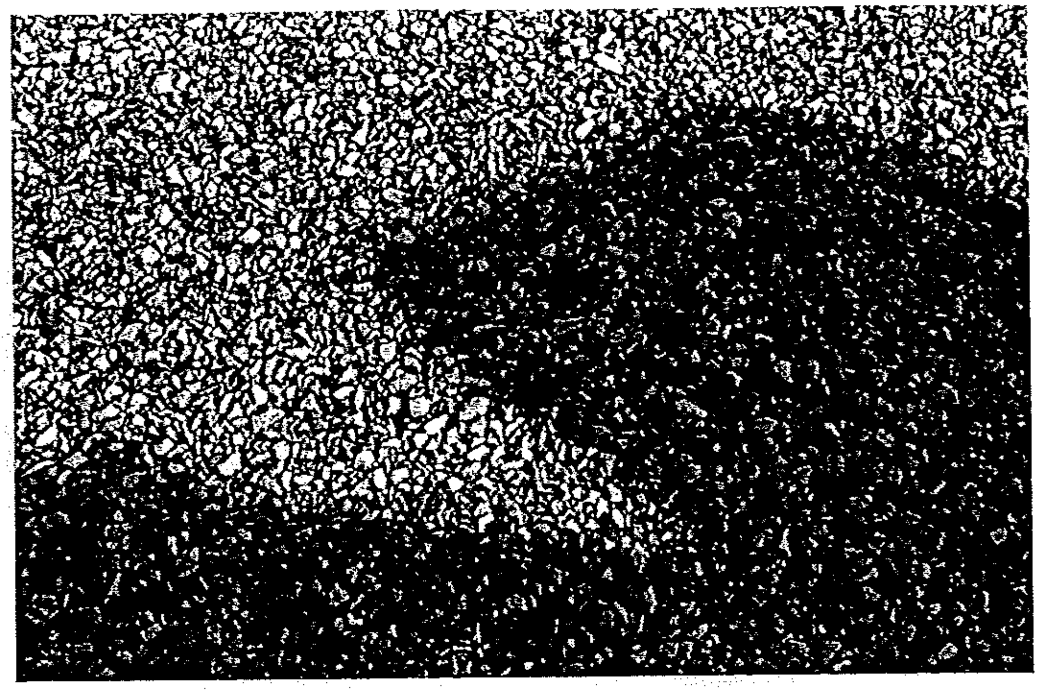

Photo F5 – I-87 SB – MM 57.1 Typical Surface Texture in Right Wheel Path (4-600 ft)

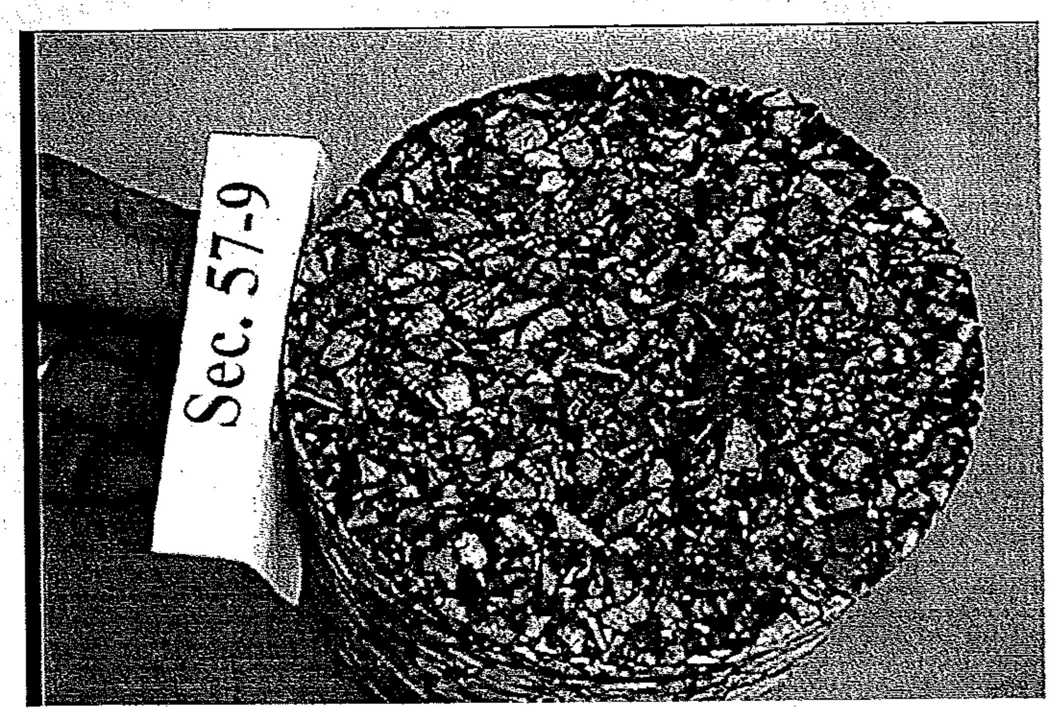

Photo F6 – Close-up of Texture of Cores

Table F1 - Data obtained from VT Section 1, I-89 SB MM 70.0

OPEN GRADED FRICTION COURSE SURVEY

State - VT

Date 10/1/98

Route I-89SB

Start Point - MM 70.0

	Sand Patch Test (350 gm)			Silly Putty Test (50 gm)			Air Permeability					Rutting
	Station (ft)	Offset (ft)	Diameter (in)	Station (ft)	Offset (ft)	Diameter (in)	Station (ft)	Offset (ft)	Head (in)	Quantity(ml)	Time (sec)	(mm)
0 - 200	96.7	2.5	15	98	4	4	97.2	3	0.1	1000	17.5	6
	96.7	5.2	16	98.3	2.75	4	95.7	3	0.1	1000	18.6	7
	98.7	3.8	16.75									
Average			15.92			4			0.1	1000	18.05	
200 - 400	283	1.2	15.5	284.7	6	4.05	283.5	6	0.25	1000	56	6
	281	6	19.15	283.5	7.25	4.15	282	6	0.25	1000	38.6	7.5
	284.7	6	16.25	284.1	6	4						
Average			16.97			4.07			0.25	1000	47.3	
400 - 600	500	3	17.25	503.5	3.75	4	502	3.5	0.25	1000	21.4	7.5
	503	2.5	16.5	501	4.25	4.05	499	3.5	0.25	1000	7.6	5.5
	495	3.2	17	498.5	3	3.95						
Average			16.92			4			0.25	1000	14.5	
600 - 800	706	6.4	16	707	6	4	705	6	0.25		No Flow	5.5
	700	6	16.5	705	7	3.9	698	5.5	0.25		No Flow	6
	703	1.5	16.5	705	5	4						
Average			16.33			3.97			0.25		0	
800 - 1000	899	9	16	897	9	4.25	898	9	0.25	1000	86.4	9
	897.5	9	16.25	901.5	9	4.2	900	9	0.25	1000	74.7	4.5
	902	9	17.62	904	9	3.93						
Average			16.62			4.13			0.25	1000	80.55	
Average			16.55			4.03			0.22	800	32.08	

Table F2 - Summary of Distresses Observed, I-89 SB, mm 70.0

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location I-89 SB MM 70.0	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	No Distress Observed							
2 (200-400 ft)	No Distress Observed							
3 (400-600 ft)	No Distress Observed							
4 (600-800) ft)	No Distress Observed							
5 (800-1000 ft)	No Distress Observed							

Table F3 - Data obtained from VT Section 2, I-89 SB MM 57.1

OPEN GRADED FRICTION COURSE SURVEY

State - VT | Date 10/2/98

Route I-89SB | Start Point - MM 57.1

	Sand Patch Test (350 gm)			Silly Putty Test (50 gm)			Air Permeability					Rutting
	Station (ft)	Offset (ft)	Diameter (in)	Station (ft)	Offset (ft)	Diameter (in)	Station (ft)	Offset (ft)	Head (in)	Quantity (ml)	Time (sec)	(mm)
0 - 200	98.5	3.5	17	101.5	3	4.37	100	3	0.1	1000	15.45	4
	94.5	3.5	17.5	97.5	2.5	4.13	97	3	0.1	1000	19.2	5
	91.5	3.5	18	96.5	3	4.25						
Average			17.5			4.25			0.1	1000	17.33	
200 - 400	303	5.6	16	302	5	3.9	301.5	6	0.09	1000	17.5	4
	303.5	5.6	16.62	301	4.5	3.87	299	6	0.05	1000	15.8	5
	296	5.5	15.87	299	6	4.13						
Average			16.16			3.97			0.07	1000	16.65	
400 - 600	504.5	3	16.75	503	3	4.1	501	3	0.1	1000	18	4
	494	3	17.5	500	3	3.82	499	3	0.08	1000	19	3
	497.5	3	17.25	498.5	3	3.94						
Average			17.17			3.95			0.09	1000	18.5	
600 - 800	705	6.5	17.25	702	6.25	4.03	701	6.5	0.05	1000	19	4.5
	694	6.5	17.25	700	6.5	4	699	6.5	0.05	1000	15.6	5
	691	6.5	17.25	698	6.5	4						
Average			17.25			4.01			0.05	1000	17.3	
800 - 1000	905	8.5	18	902	9	3.81	901.5	9	0.25	1000	24.8	4
	908	8	19	907	8.5	3.81	900	9	0.25	1000	107.6	4
	909.5	8	17.88	900.5	9	3.94						
Average			18.29			3.85			0.25	1000	66.2	
Average			17.27			4.01			0.11	1000	27.20	

Table F4 - Summary of Distresses Observed, I-89 SB, MM 57.1

Sublot	Patching	Cracking		Map	Alligator	Ravelling	Spalling	Gouges
		long.(ft)	trans.(ft)					
Location I-89 SB MM 57.1	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	(sf)	Sf)
1 (0- 200 ft)	No Distress Observed----------							
2 (200-400 ft)	No Distress Observed----------							
3 (400-600 ft)	No Distress Observed----------							
4 (600-800) ft)	No Distress Observed----------							
5 (800-1000 ft)	No Distress Observed----------							

TABLE F5
Pavement Friction Testing Results
October 1998

Results for Vermont Site No. 1:
I-89 Southbound, Right Lane, Milepost 70.00-69.75, Town of Bolton.
Test Date: October 13, 1998

Milepost	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
69.99	59.2	55.6
69.96	57.5	54.8
69.93	56.5	54.6
69.91	57.5	54.9
69.88	57.1	55.7
69.86	58.5	56.9
69.83	57.6	57.8
69.81	58.6	55.9
69.78	60.5	59.9
69.76	57.8	56.3
Average	**58.1**	**56.2**

Results for Vermont Site No. 2:
I-89 Southbound, Right Lane, Milepost 60.00-59.75, Town of Waterbury.
Test Date: October 13, 1998

Milepost	Ribbed Tire (SN40R)	Smooth Tire (SN40S)
59.99	59.4	58.0
59.96	59.0	57.6
59.93	58.3	58.3
59.90	58.4	56.9
59.88	58.1	57.9
59.85	57.4	60.5
59.82	57.0	57.5
59.80	57.5	55.5
59.77	57.6	56.2
59.75	56.5	56.4
Average	**57.9**	**57.5**

APPENDIX G
SAMPLE SPECIFICATION

OPEN-GRADED FRICTION COURSE (OGFC) HOT MIX ASPHALT CONCRETE MIXTURES

BACKGROUND:
Most states will have converted to Superpave for the mix design process by the year 2000. Several Superpave principles such as aggregate angularity and percentage flat and elongated can be applied to OGFC mixes but the gradation design process can not. The Superpave protocol requires that, using the gyratory compactor, the mix is compacted to 4% air voids at a designated number of compaction cycles. As an OGFC mix requires, and is designed for a minimum of 15% air voids, it is apparent that a mix meeting Superpave requirements could not be classed open graded. The Superpave equipment and design approach might possibly work if new limiting values for air were developed. All OGFC mixes inspected in the field were or had performed well at young ages. The two classed poor and fair were the oldest and carry the heaviest traffic volumes. It is then doubtful that there would be any gain from changing the gradation limits.

A weak correlation was observed between pavement age and condition. As the aggregate does not age appreciably, this trend must be due to the aging of the binder. Given that a major portion of binder aging is due to binder oxidation, the air accessibility of the OGFC accelerates aging. This same permeability is wanted for water escapement under tires which in turn, acts as a means of safely reducing vehicle hydroplaning. Thicker binder films would slow the aging process of the OGFC mix. A simple increase in the percentage of PG 64 - 28 binder would reduce the mix stability without appreciable slowing of aging as the additional binder would drain down in the large voids and not increase the film thickness coating aggregate particles in the bulk of the mix.

An increase in film thickness has been accomplished in Europe and some states, Georgia for example, by a slight increase in the binder quantity and the addition of fibers or cellulose to stiffen the films against drain-down.

Not to be disregarded are the effects of construction on performance. Typically an OGFC can be expected to cool faster than a conventional hot-mix layer. This is not a property of the material but is a function of the mass being placed. As an OGFC surface layer is typically thinner than a surface hot-mix layer, rolling must be accomplished more quickly. The thinness also makes surface preparation very important. Irregularities can cause sharp differences in degree of compaction in thin layers. When using a smooth steel roller, with or without vibration, the top surface is brought to a plane. For a two-inch overlay a half-inch deep gouge in the old surface can result in a one or two percent reduction in voids when compacted. However for a .75 inch layer, that half-inch increase in depth can increase the voids after compaction by 8 to 10 percent.

The Georgia OGFC specification provides for the addition of hydrated lime and/or an anti-strip to reduce the detrimental effect of moisture. As aggregates in New England are less susceptible to stripping, the cost and inconvenience of this procedure may not be justified for all New England sites.

SUGGESTIONS FOR AN OGFC SPECIFICATION IN NEW ENGLAND

Purpose: Provide a thin overlay to improve the frictional characteristics of a pavement.

Binder: Binder shall be a PG graded asphalt cement either 64 - 22 or 64 - 28 depending on the annual temperatures at the site.

Aggregate: The Aggregate to comply with Superpave criteria except for gradation.

Estimated Traffic Million 80kN ESALs	Coarse Agg Angularity Minimum % 1 Face/% 2 (PennDOT 621)	Maximum % Flat Elongated 1/5 ratio ASTM (D 4791)
<0.3	55/-	-
<1	65/-	-
<3	75/-	10
<10	85/80	10
<30	95/90	10
<100	100/100	10
≥100	100/100	10

Toughness, L.A.Abrasion (AASHTO T 96): Maximum allowable loss 40%

Sulfate Soundness (AASHTO T 104): Maximum allowable Loss 15%

Deleterious Materials (AASHTO T 112): Maximum allowable Loss 2%

Fine Aggregate: The Superpave requirements for fine aggregate, Sand Equivalent and Angularity, are of little or no value for OGFC as the percentage of fines is so low that these properties have very little effect on performance of the mix.

Aggregation Gradation:

Standard Sieve	Nominal Size 9.5 mm	OGFC 2.5mm
25.5 mm	100	
19.0 mm	100	100
12.5 mm	100	90-100
9.5 mm	90-100	60-80
4.75 mm	25-45	20-40
2.35 mm	5-15	10-25
0.075 mm	2-4	2-4
AC	5.5-7.5	7.75-7.25

Modifiers: Mixes using modified binders or fibers may have less binder drain-down thus permitting the use of thicker films. A specification could give the engineers the option of using such a modified mix but at the present time this would be on a test or research basis as there is little information on using modified binders or fibers in OGFC in a cool or cold environment.

The use of fibers would require determination of a fiber testing procedure and a specification for fibers. Those used by Georgia DOT (GDT-124) and included as Appendix Ga provide a starting point.

Determination of binder content for OGFC is somewhat different from that for a Superpave or Marshall processes. The controlling factor is drain-down of the binder. The goal is maximum film thickness without serious drain-down. Procedure at the present time is to prepare a number of identical graded mixes with different AC levels and observe the drain-down. There is no precise factor to measure and so the experience of the observer is a factor in the decision. The Georgia Procedure (GDT - 114) is part of Appendix Ga.

APPENDIX GA

GEORGIA TEST METHODS

GDT - 114 Method of Test for Determining Optimum Asphalt Content for Open-Graded Bituminous Paving Mixtures

GDT - 124 Method of Test for the Resistance of Fibers to Degradation by Abrasion in the Micro-Deval Apparatus

GDT-114
METHOD OF TEST FOR DETERMINING OPTIMUM ASPHALT CONTENT FOR OPEN-GRADED BITUMINOUS PAVING MIXTURES

The purpose of this test method is to determine the optimum asphalt content for an open-graded bituminous mix.

TEST METHOD A (USING UNMODIFIED ASPHALT CEMENT)

A. SCOPE:

This method of design for standard open-graded bituminous mixtures consists of five steps. The first is to conduct a measurement of the surface capacity (KC) of the predominant aggregate size fraction (material retained on No. 4 sieve). Surface capacity includes absorption, superficial area, and surface roughness, all of which affect asphalt cement requirements. The second step is to mold nine samples by using a modified ASTM-D-1559. The third step is to prepare samples for visual evaluation in Pyrex pie pans. Determine optimum asphalt content is the fourth step and then GDT-56 performed as the final step.

B. APPARATUS:

The apparatus required shall consist of the following:

1. 13 metal pie pans
2. oven capable of maintaining 250°± 3.5°F temperature
3. oven capable of maintaining 140°± 3.5°F temperature
4. beakers, glass, 500 ml
5. balance, 5000 gr. Capacity, .1 gr. accuracy
6. glass funnels, top diameter = 3 1/2 in.; height = 4 1/2 in.; orifice = 1/2 in with a piece of No. 10 sieve positioned at the top of the funnel neck. Cork stopper to fit outlet of funnel neck.
7. oil, S.A.E. No. 10 lubricating
8. timer
9. Marshall design equipment as specified in AASHTO: T-245
10. 4 twelve inch diameter Pyrex pie pans

C. STEP 1 - SURFACE CAPACITY (KC)

1. Determine the surface capacity of the aggregate fraction that is retained on a No. 4 sieve in accordance with the following procedure.

   1.1 Quarter out 105 gr. of aggregate representative of the material passing the three-eighth inch sieve and retained on the No. 4 sieve.

   1.2 Dry aggregate in 250°± 3.5°F oven to a constant weight and allow to cool.

   1.3 Weigh out 100.0 gr. and place in glass funnel.

   1.4 Completely immerse the aggregate in S.A.E. No. 10 oil for five minutes by plugging funnel outlet with cork stopper.

   1.5 Remove cork stopper from funnel outlet.

   1.6 Drain for two minutes.

   1.7 Place funnel containing sample in the 140°F oven for 15 minutes for additional draining.

   1.8 Pour sample from funnel into a tared pan; cool and reweigh sample to nearest 0.1 gram. Subtract original weight and record difference as percent oil retained (based on 100 gr. of dry aggregate).

   1.9 Use the attached chart for determination of "KC".

      a. If the apparent specific gravity for the fraction is greater than 2.70 or less than 2.60 apply correction to oil retained, using the following formula:

      $$\text{Oil Retained Corrected (\%)} = \frac{\text{Oil Retained (\%) X Apparent Sp. Gr. of Coarse Agg.}}{2.65}$$

      b. Start at the bottom of chart with the corrected percent of oil retained; follow a straightedge vertically upward to intersection with diagonal line; hold point, and follow the straightedge horizontally to the left. The value obtained will be the surface content for the retained fraction and is known as KC.

   1.10 Determine the required asphalt content from the following formula.

   Percent Asphalt = 2.0 (KC) + 3.5
   (no correction need be applied for viscosity)

D. STEP 2 - MODIFIED MARSHALL DESIGN

2. The following procedure is suggested for the Modified Marshall design:

2.1 Heat aggregate to 275°F±3.5°F; heat molds to 300°F±3.5°F and heat A.C. to proper mixing temperature specified in Mixture Control Temperature Chart.

2.2 Mix aggregate with asphalt at three asphalt contents in 0.5% intervals nearest the optimum asphalt content established in step 1. Three specimens should be compacted at the nearest 0.5% interval to optimum and three specimens each at both 0.5% above and below the mid- interval.

2.3 After mixing, return to oven if necessary, and when at 250°F±3.5°F compact using 25 blows on each side. (Use oil on base plate to prevent sticking.)

2.4 When compacted, cool to room temperature before removing from mold.

2.5 Bulk Specific Gravity

a. Determine the density of a regular shaped specimen of compacted mixture from its dry mass (in grams) and its volume in cubic centimeters obtained from its dimensions for height and radius. Convert the density to bulk specific gravity by dividing by 0.99707 gr/cm^3, the density of water at 25°C (77°F).

Formula: $$\text{Bulk Sp. Gr.} = \frac{W}{\frac{\pi r^2 h}{0.99707}} = \frac{\text{Weight (gms.)} \times 0.0048417}{\text{Height (in.)}}$$

W = Weight of specimen in grams

$\pi = 3.1416$

r = Radius in centimeters (5.08 cm for 4" diameter molds)

h = Height in centimeters

0.99707 = Density of water at 25°C (77°)F

2.6 Determine stability and flow after 1 hour in 77°F water bath.

2.7 Calculate percent voids, VMA, and voids filled with asphalt based on aggregate bulk specific gravity.

2.8 Plot VMA curve versus A.C. content.

2.9 Select the optimum asphalt content at the lowest point on the VMA curve.

E. STEP 3 - PYREX BOWL METHOD

3. The following procedure is to be used for visual evaluation:

3.1 Batch up 990 gms. of aggregate in each of four pans and heat aggregate to 250±9°F; heat A.C to temperature specified in Step 2.1 above.

3.2 Add 10 grams hydrated lime into mixing bowl of heated aggregate; mix thoroughly to coat aggregate.

3.3 Add A.C. at 5.5% for total weight and thoroughly mix. Pour mixture evenly into clean, clear glass (Pyrex) pans without disturbing the mixture after it comes in contact with the pan. Repeat the process for the remaining pans except that the amount of A.C. in the total mix is increased in 0.5% increments (such as 5.5%, 6.0%, 6.5%, 7.0%).

3.4 Place samples back in 250°F±3.5°F oven for one hour; remove and let cool to room temperature.

3.5 Visually observe the amount of liquid asphalt on the bottom of each pan.

3.6 Select the optimum asphalt content at a level where ample bonding is evident between film coating and glass pan without having excessive drainage. Estimate optimum between the 0.5% intervals.

F. STEP 4 - SELECT OPTIMUM A.C.

Determine the optimum A.C. content for the mix by averaging the selected asphalt contents from the three methods: surface capacity, Modified Marshall and Pyrex Bowl. Any previous field experience should also be considered in establishing the optimum A.C.

G. STEP 5 - BOIL TEST

Perform Boil Test according to GDT - 56 with a complete batch of open-graded mix at the optimum asphalt content determined in Section F above. If the sample treated with hydrated lime fails to maintain 95% coating, a sample shall be tested in which 0.5% liquid anti-strip additive has been used to treat the asphalt cement in addition to treatment of aggregate with hydrated lime. In some cases a specific brand of A.C. and/or liquid additive may be needed to prevent stripping.

TEST METHOD B (USING MODIFIED ASPHALT CEMENT)

A. SCOPE

This method of design for a modified open-graded bituminous mixture consists of four steps. The first step is to conduct a modified AASHTO T-245 to determine asphalt cement content; secondly, determine optimum asphalt content. The third step is to perform GDT-127. The final step is to perform GDT-56.

B. APPARATUS

The apparatus required shall consist of the following:

1. Drain-Down equipment as specified in GDT-127

2. Marshall design equipment as specified in AASHTO T-245

3. Equipment as specified in GDT-56

4. Balance, 5000 gr. Capacity. 0.1 gr. accuracy

C. STEP 1 - MODIFIED MARSHALL DESIGN

Perform test in accordance with Section D, Step 2 of Test Method A with the following exceptions:

Section 2.1: Aggregate should be heated to 350°F±3.5°F; heat molds to 300°F±3.5°F and heat A.C. to 330°F±3.5°F.

Section 2.3: After mixing, return to oven if necessary, and when at 325°F±3.5°F compact using 25 blows on each side.

D. STEP 2 - SELECT OPTIMUM A.C.

Determine the Optimum A.C. content for the mix by using Modified Marshall Process as outlined in Step 2 of Test Method "A".

E. STEP 3 - DRAIN-DOWN TEST

Perform drain test in accordance with GDT-127 (Method of Test for Determining Drain-Down Characteristics in Uncompacted Bituminous Mixtures). If the sample fails to meet the requirements increase the fiber content by 0.1% and repeat the test.

F. STEP 4 - BOIL TEST

Perform boil test in accordance with GDT-56 as referenced in Step 5 of Method "A".

GDT-124
METHOD OF TEST
FOR
THE RESISTANCE OF FIBERS TO DEGRADATION BY ABRASION IN THE MICRO-DEVAL APPARATUS

1. SCOPE

1.1 This method covers the testing of fibers to determine their abrasion loss in the presence of water and an abrasive charge.

2. APPARATUS

2.1 MICRO-DEVAL ABRASION MACHINE: A jar rolling mill capable of running at 100 ± 5 rpm.

2.2 CONTAINERS: Stainless steel, micro-Deval abrasion jars having a 5 liter capacity with a rubbber ring in the rotary locking cover. Internal diameter = 194 mm, Internal height = 170 mm.

2.3 ABRASION CHARGE: Stainless steel balls with a diameter of 9.5 ± 0.5 mm. Each jar requires a charge of 1250 ± 5 grams of balls.

2.4 SIEVES: Sieves of 200 mm diameter with square openings, and of the following sizes conforming to AASHTO: M 92 specifications:

2.36 mm
1.18 mm
600 µm
300 µm
150 µm
75 µm
45 µm
38 µm

2.5 OVEN: An oven capable of maintaining a temperature of 110 ± 5°C.

2.6 BALANCE: A balance or scale accurate to 0.1 grams.

3. SAMPLE PREPARATION

3.1 Dry two representative 10 gram samples of the fibers.

3.2 Subject one of the samples to AASHTO: T 11 (Total minus 75 µm alternate except that the sample is washed over a 38 µm sieve instead of a 75 µm seive). This will be the reference sample.

4. TEST PROCEDURE

4.1 Place the remaining sample in the micro-Deval abrasion container with 1250 ± 5 grams of steel balls and 750 ml of tap water. Place the micro-Deval container on the machine.

4.2 Run the machine at 100 ± 5 rpm for ten minutes.

4.3 Remove the balls from the sample by pouring the sample and water onto a nest of 200 mm diameter sieves with 4.75 µm and 38 µm openings, being careful not to lose any material that is retained on the 38 µm sieve.

4.4 Subject the sample to AASHTO: T 11 (Total minus 75 µm alternate except that the sample is washed over a 38 µm sieve instead of a 75 µm sieve) using the 10 gram original weight for calculations. Record the cumulative percent retained on each sieve for the 2.36 mm through the 38 µm sieves.

5. CALCULATION AND REPORT

5.1 A percent loss per sieve, 2.36 mm through the 38 µm, is calculated by dividing the original cumulative percent retained (from the reference sample) on each sieve into the loss for the same sieve on the abrasion test sample and multiplying by 100. The loss is simply expressed as the arithmetic average loss per sieve (2.36 mm thru the 38 µm seive).

EXAMPLE:

Sieve	Acc. % Ret. Reference Sample	-	Acc. % Ret. Test Sample	=	Loss	Loss	:	Acc. % Ret. Reference Sample	x	100	=	% Loss/Sieve
2.36 mm	89.0	-	43.5	=	45.5	45.5	:	89.0	x	100	=	51.1
1.18 mm	90.1	-	44.2	=	45.9	45.9	:	90.1	x	100	=	50.9
600 µm	92.4	-	45.0	=	47.4	47.4	:	92.4	x	100	=	51.3
300 µm	93.3	-	49.6	=	43.7	43.7	:	93.3	x	100	=	46.8
150 µm	96.6	-	53.1	=	43.5	43.5	:	96.6	x	100	=	45.0
75 µm	98.7	-	57.7	=	41.0	41.0	:	98.7	x	100	=	41.5
45 µm	99.0	-	62.1	=	36.9	36.9	:	99.0	x	100	=	37.3
38 µm	99.3	-	65.0	=	34.3	34.3	:	99.3	x	100	=	34.5
								Average % Loss			=	44.8