FINAL REPORT

Effect of Asphalt Cement Deficiency on Open-Graded Friction Courses

Contract No. BB891, FM Number 403703

by

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ERRATA

1. Page 20: Line 7

   - The stabilized subgrade (compacted native or borrow soil with stabilizing material added as necessary).

2. Page 21: Line 9

   Please remove the statement "It should be dense to better sustain the imposed stresses and safe for road user's safety and comfort.

3. Page 29: Line 7

   Please remove the statement "During mixing of HMA, some air is usually absorbed".

ABSTRACT

Raveling is a very common and visible form of asphalt concrete degradation that decreases the effective life of open-graded friction courses. This, in turn, reduces their effectiveness for skid resistance and traffic safety. One of the major causes of raveling is an initial asphalt cement content below design value (asphalt cement deficiency or lean mix).

This research project studies the effect of asphalt cement deficiency on open-graded friction courses in the state of Florida. Two types of OGFC friction course (FC-2 and FC-5) currently in use in Florida are investigated. This is accomplished by searching FDOT road construction databases for original AC content information for selected Florida highways and then conducting laboratory testing on pavement cores obtained from these roads.

Several graphs are generated using the data obtained and conclusions are drawn.

ACKNOWLEDGMENTS

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CHAPTER 1. INTRODUCTION

1.1 Importance of subject

Transportation is the backbone of every economy. Roads constitute the means through which vital activities take place: goods are transported, people get to and from work and tourists travel to their vacation destination.

The United States' transportation network is no exception. As of 1990, there were about 2.2 million miles of paved roads in the US, of which 94% were asphalt-surfaced (Huang, 1993). This percentage is still increasing.

The National Center for Asphalt Technology (NCAT) reports that $20 billion is used yearly by US agencies on maintenance activities for US roads (NCAT, 1996). In its Special Report 178, the National Asphalt Pavement Association (NAPA, 1999) related that in the US, $90 billion is spent yearly on the planning, design, construction, rehabilitation and maintenance of highways, a figure which represents 1.5% of our GNP.

The Hot-Mix Asphalt industry directly employs some 300,000 people and another 600,000 indirectly. As we can see, the transportation industry has a significant impact on the economic vitality of the nation, not only as an employer, but also as the sector responsible for a vital organ of our economy.

The objective of adequate pavement design and maintenance is to provide better serviceability and subsequent lower cost to users by stretching pavement life and reducing problems associated with pavement rehabilitation such as congestion, lost wages, loss of productivity.

Paved roads typically carry more than 90% of all traffic in a network and vehicle operating costs are greatly influenced by road condition, maintenance and deterioration. This means that user costs such as delay, fuel and wear and tear on vehicles increase as pavement life is reduced due to low road quality and conditions.

1.2 Identification of the problem

Asphalt concrete is the main paving material used today. It is also the most costly material used in the construction of flexible pavements. Long-term performance of HMA pavements is contingent upon good mix and thickness design and quality construction.

Raveling is a very common and visible form of asphaltic concrete degradation that decreases the effective life of open-graded friction courses (OGFC). This, in turn, reduces their effectiveness for skid resistance and safety. One potential cause of premature raveling is when the asphalt cement content of an asphalt pavement is below design target (an asphalt deficit).

Presently, there is a lack of empirical information dealing with the prediction of the reduced pavement life due to asphalt cement (AC) deficit. This lack of information makes it difficult to make accurate and uniform decisions with regard to acceptance or rejection of asphalt deficient pavement.

Currently, the Florida Department of Transportation (FDOT) uses a system where a pay factor is deducted from the contractor's fee to account for low AC contents. However, the actual impact such as increased maintenance and user costs and accelerated deterioration, is never really assessed and the reduction in the life of the pavement is not quantified.

1.3 Objectives of research

Since low AC content is a cause of raveling, we should be able to predict the occurrence of raveling by correlating it to asphalt cement deficiency and also to the reduction of the useful life of the pavement.

The goal of this research is to correlate the reduction of HMA pavement life to asphalt cement (AC%) deficit. The project addresses the following open-graded friction course issues for FC-2 and FC-5, two types of friction course currently in use in the state of Florida:

(a) How much (if any) AC content loss takes place as the friction course ages?

(b) How the following values correlate: AC content determined from the asphalt plant hot mix samples vs. in-place core samples?

(c) Can the results of this study apply to FC-5 as well as FC-2 open-graded mixes?

(d) How do in-place AC contents compare to design mix target values?

(e) How does AC content deficiency relate to the expected life for FC-2 and FC-5 open-graded pavements?

(f) A study of current raveling related to the present acceptance practices.

The information generated as a result of this study can be used to reduce open-graded friction course raveling in the state of Florida. The study also aims to produce guidelines for decision-making on projects with deficient AC content.

CHAPTER 2. LITERATURE REVIEW

Pavement distresses are expected to occur over the useful life of the structure due to repeated traffic loads and unusual stresses such as those resulting from accidents and environmental factors. It would therefore take long-term and large-scale research projects to accurately monitor and study pavement disintegration. Invariably, this would translate into very high costs and elaborate data collection procedures. For these reasons, pavement distresses and raveling in particular have not been topics of choice for research projects and the published literature lacks quantitative data relating pavement life and such distresses.

As a result, there is a lack of empirical information dealing with the prediction of the reduced pavement life due to asphalt cement (AC) deficit.

A literature search related to the problem of raveling was conducted but uncovered only a few journal articles and

short paragraphs in textbooks where raveling was defined and its causes were offered.

This chapter will define raveling and condense findings of the literature search into issues related to the problem of raveling such as causes, prediction and prevention.

2.1 Definition of raveling

Raveling is an environmental distress of flexible pavements. This implies that its initial occurrence is not associated with traffic (it is not load-related) although increased tensile stresses associated with traffic contribute to its progression.

Raveling is a very common and visible form of asphaltic concrete degradation. It is the mechanical deterioration of the asphalt-aggregates mixture: the asphalt hardens and therefore no longer serves as a binder for the aggregates; stone particles separate from the structure of the friction course, leaving gaps which continue to grow as more and more aggregates erode away under traffic loading stress.

The reviewed literature offered the following definitions of raveling:

- Loss of stone particles from the exposed surface of the friction course, due to mechanical breakdown. When raveling occurs in the presence of water, it is referred to as "stripping" (Paterson, 1987).
- "wearing away of the pavement surface caused by the dislodging of aggregate particles due to stripping and the loss of asphalt binder due to hardening" (Huang, 1993)
- "progressive disintegration of HMA layer from the surface downward by the dislodgment of the aggregate particles" (NCAT, 1996).

Following are close-up pictures of a road section showing signs of raveling. They were taken during site visits related to this research project.

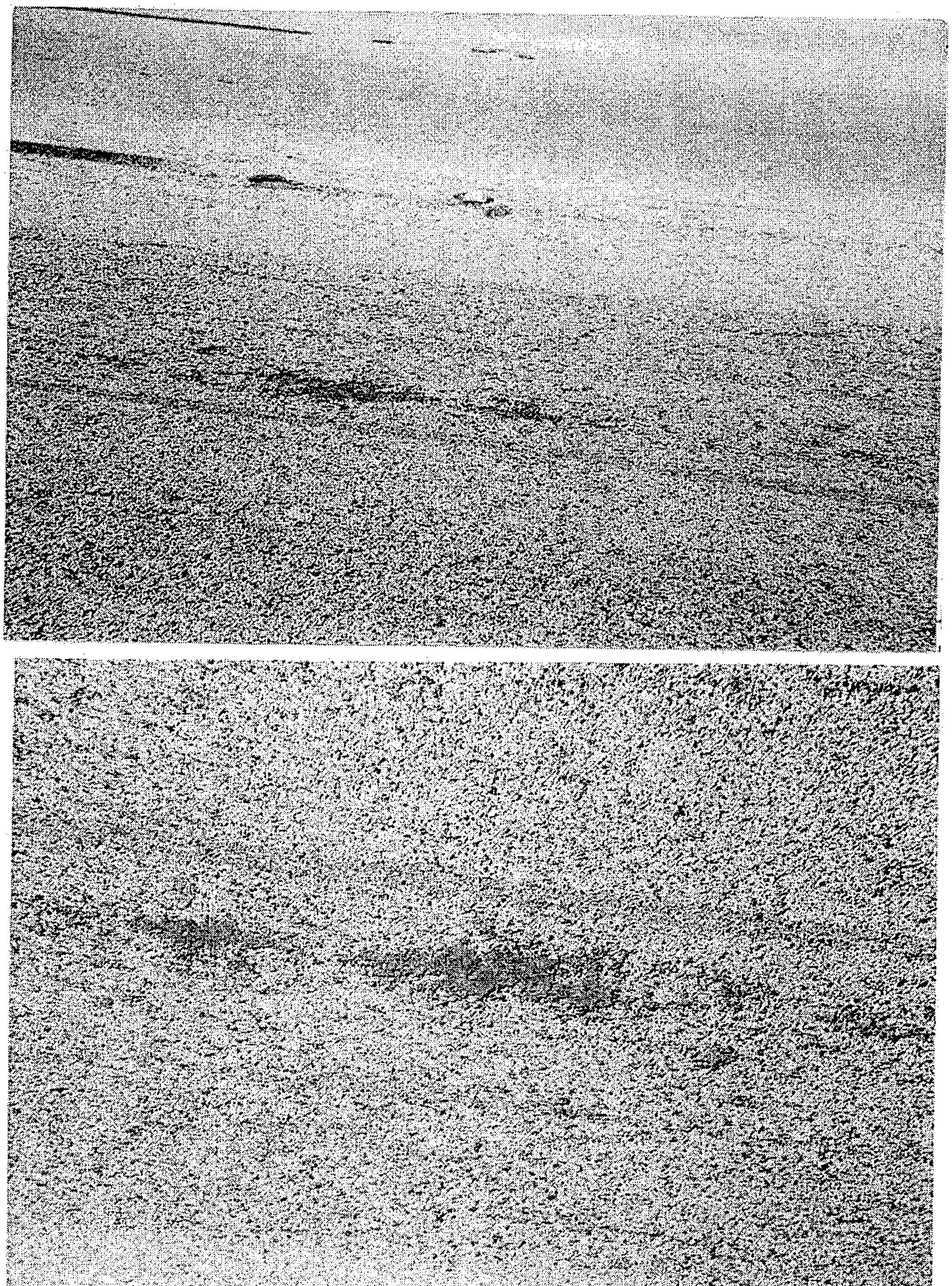

Figure 1. Raveling road section

2.2 Causes of raveling

Raveling has been attributed to several factors, ranging from inadequate mix design to poor construction practices.

a) *Poor gradation*

In 1995, Sontowski reported: "raveling is primarily the result of too much -200 material in the aggregate gradation. This results in inadequate asphalt thickness around the aggregate particles, which in turn leads to a more rapid rate of oxidation". The reason is that a high percentage of very fine aggregates considerably increases the surface area to be coated and therefore results in a much thinner asphalt film which hardens prematurely as it is exposed to the elements.

b) Deficient Asphalt Content (or *lean mix*)

An asphalt cement content (AC content) that is low relative to the design value translates into an insufficient amount of binder, resulting in inadequate coating of the aggregates in the stone matrix. Therefore, the friction course is weakened due to the lack of cohesion and breaks down prematurely.

c) Segregation

Segregation can result in lack of fine (-200) material in localized areas of the friction course. The larger aggregates in these areas are then in contact with each other. Irregularities in the larger stone particles make for weak bonds when adequate amounts of fines are not present. Over time, the asphalt hardens, leading to the breakdown of the friction course.

d) Excessively Aged Asphalt Cement Binder (NCAT)

Like any material, aging asphalt naturally deteriorates over time. This process is accompanied by oxidation with exposure to the elements, eventually leading to hardening of the asphalt cement, which acts as the "glue" holding the aggregates together into one structure. The binding capabilities of the material are then seriously impaired and the friction course can no longer take traffic loads without breaking up.

e) Dormancy

Dormancy has been reported as a cause of raveling by the Florida DOT (FDOT, 1992). In a sort of 'kneading' action, tires help repair surface cracks by allowing the stones particles to rearrange themselves until the matrix becomes stable. This leads to a denser and more stable surface course.

Therefore, due to lack of 'kneading', dormant pavements such as less traveled highways and airport runways could present early signs of raveling.

During a phone conversation, William Greene, former Airport Engineer of the Iowa Department of Transportation remarked that when properly designed, busy highways should not experience premature raveling because of constant "massaging" by traffic.

f) *Water intrusion*

The problem of raveling can be exacerbated by water intrusion when the bond between aggregates and binder is broken. This is of concern here in Florida where it rains a lot and the water table is on the average approximately five feet below grade. When raveling occurs under these conditions, it is referred to as "stripping".

f) Dust or Clay Coating on Aggregate

It is very important that the aggregate used in asphaltic concrete be thoroughly cleaned prior to mixing with the asphalt cement. A thin film of dust or clay on aggregates that have not been properly washed can prohibit good contact between the stone particles and the binder, therefore leading to premature stripping and disintegration of the friction course.

h) *High Air Void Content or Lack of Compaction*

The National Center for Asphalt Technology stipulates that cohesion in HMA mixtures greatly depends on its in-place density (NCAT, 1996). The relation between air void content and extent of raveling is depicted in Figure 2.
The graph was reproduced from NCAT's textbook "Hot Mix Asphalt Materials, Mixture Design and Construction", written by Roberts et al.

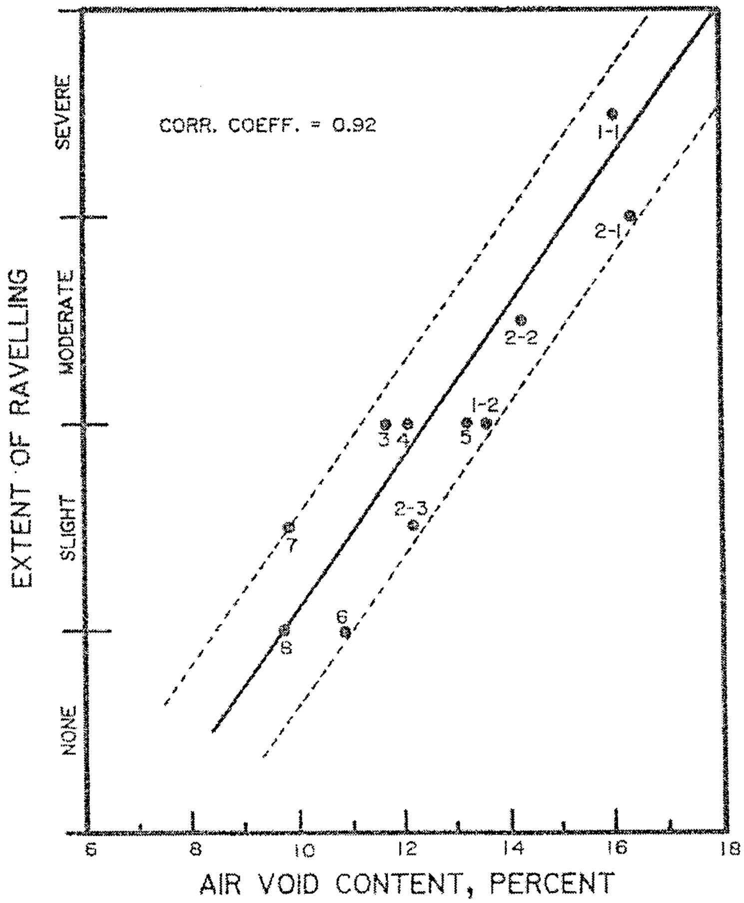

Figure 2. Air Void Content vs. Extent of Raveling (Source: NCAT, 1996)

i) *Construction-related problems*

- Improper application of tack material
- Low asphalt film thickness
- Low mix temperature

2.3 Prediction of raveling

Queiroz (1981) attempted to model the occurrence of raveling using a probabilistic failure-time approach on empirical data obtained from a Brazilian paved road deterioration study conducted by the Brazilian Transportation Planning Agency (Paterson, 1987). The deterioration process was divided into two phases labeled initiation and progression. Initiation was defined to occur when .5% of the total surface area was considered to be raveled. Subsequent to initiation, a probabilistic failure-time method of analysis was used to predict the progress of raveling. The relation between time and %raveled area is depicted in Figure 3 (Paterson, 1987) and takes the form of a sigmoidal (S-shaped) function.

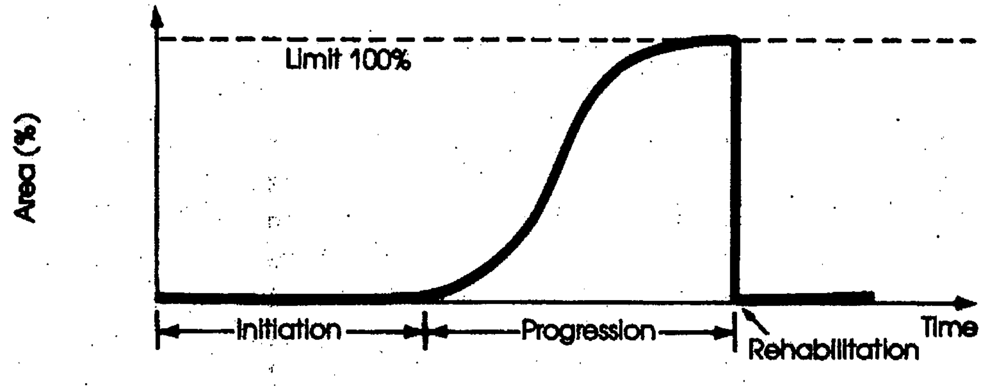

Figure 3. Mode of Raveling and trend with time (Source: Paterson, 1987)

The following empirical equations were developed to model the phases of the pavement life cycle (Paterson, 1987):

a) Initiation of raveling

$$TY_{rv} = K_p \, a_s \exp(-.655\ CQ - .156\ YAX)$$

with a_s = 10.5 (for surface treatment), 14.1 (for slurry seal) and 8.0 (for open-graded cold-mix)

b) Progression of raveling

$$\Delta A_{rv} = .24\ \Delta t; \text{ or } 4.42\ SA_{rv}^{\ .65}\ \Delta t,$$

where:

TY_{rv} = age of surfacing at initiation of raveling, years.

YAX = annual volume of traffic, million axles/lane/year.

ΔA_{rv} = Increment of raveling area, percent.

SA_{rv} = minimum (A_{rv}, 100-A_{rv}) where A_{rv} is the percent raveling area.

Δt = incremental time, years.

CQ = 1, if surface has original construction defects

0, otherwise.

The factor K_p was not identified.

2.4 Prevention of raveling

Sontowski (1995) listed a few simple rules that can be followed to help prevent raveling:

a) Increase the amount of mineral filler and dust in the mix in order to increase its stability.

b) Have a good quality asphalt paving mix of minimum aggregate film thickness 8.0 microns (this will reduce the susceptibility of the asphalt to oxidation, fatigue and cracking).

Atkins (1997) also reports that the amount of silt and clay particles (less than 75µm or 200-sieve size) must be controlled as they can weaken the bond between larger particles by filling voids and prohibiting contact.

CHAPTER 3. BACKGROUND

This chapter provides the technical background directly related to and affecting the performance of friction courses in flexible pavements.

Acronyms are used throughout for simplicity. Following are detailed explanations of these abbreviations:

- AC: Asphalt Cement
- AI: Asphalt Institute
- CQR: Florida DOT's Construction Quality Reporting System (CQR) database, started in mid-1991.
- DMI: Distance Measuring Instrument. It is an electronic device installed in a vehicle that serves to measure traveled distance. Distances can be measured in feet, miles, kilometers and can go increasing or decreasing. DMI's are currently routinely used by Civil Engineering firms, private and governmental agencies for various purposes including maintenance, surveying and construction.

- FDOT: Florida Department of Transportation.
- HMA: Hot Mix Asphalt. The hot-mixed and hot-laid mixture used for friction course on flexible pavements.
- NAPA: National Asphalt and Pavement Association
- NCAT: National Center for Asphalt Technology
- OGFC: Open-Graded Friction Courses. This abbreviation refers to flexible (or asphaltic) pavements in which a larger percentage of coarse aggregates is used, thereby creating a greater void ratio. These mixes are used and preferred in Florida for increased hydroplaning resistance. Added benefits of using such mixes are their antisplash properties, improved night visibility and noise reduction.
- PCS: Pavement Condition Survey printout of Florida DOT. The data is compiled and recorded annually.

3.1 Role and types of pavement

Pavements are of two general types:

- Flexible pavements (also called asphaltic) in which bituminous and granular materials are used,
- Rigid pavements built using Portland cement concrete (PCC).

A flexible pavement usually consists of four distinct layers:

- the friction course (also called surface course or wearing course), made of HMA,
- the structural course, also made of HMA,
- the base course (consisting of limerock) and
- the stabilized subgrade (compacted native or borrow soil).

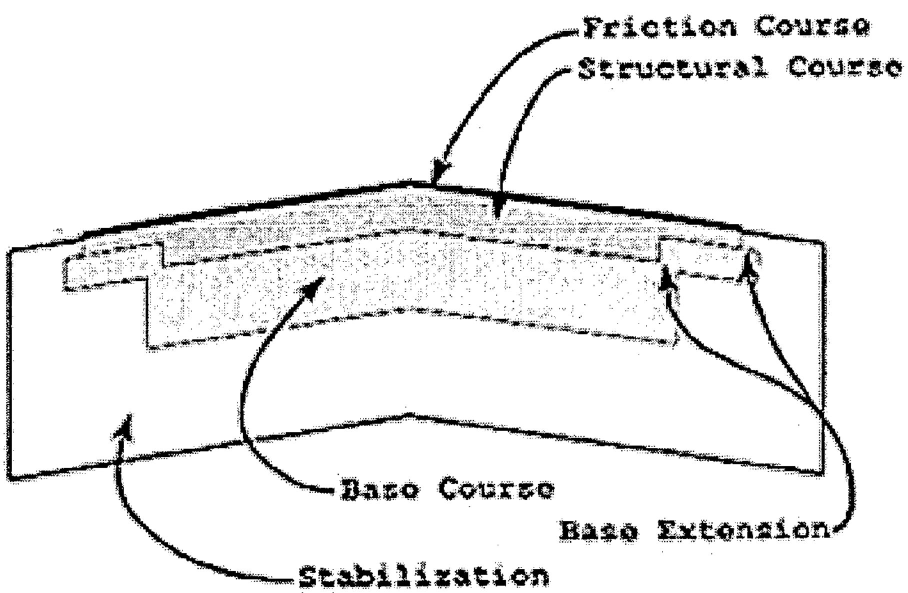

Figure 4. Typical roadway section

Due to differences in composition, different pavement types experience distresses specific to their type. Raveling is a distress particular to the friction course of flexible pavements. This component of the pavement system is studied in detail in the next section.

3.2 Friction Course in flexible pavements

The friction course (also called surface course or wearing course) is the top layer of a flexible pavement, the one directly in contact with traffic loads. It should be dense to better sustain the imposed stresses and safe for road users' safety and comfort.

3.2.1 Role

The friction course is the pavement layer directly in contact with the load. One of its functions is to transfer the imposed stresses onto the structure. These stresses are ultimately distributed over a larger area of the base. This process helps to minimize mechanical deformations by reducing stresses and transmitting them to the layers below.

Skid resistance and drainage are also a consideration as safety of the road users is of concern when designing a friction course.

3.2.2 Composition

Asphalt concrete is the main paving material used today. It is a mixture of asphalt cement and aggregates hot-mixed in an asphalt plant and then laid at a high temperature. The mixture is also called Hot-Mix Asphalt (HMA) or blacktop.

The relative proportions of the constituents are very important as they determine the physical properties of the mix and strongly influence the behavior of the friction course and the useful life of the pavement.

3.2.2.1 Asphalt Cement

Refined asphalt, called Asphalt Cement or bitumen is the high-quality material used to bind aggregates in flexible pavements. With its physical attributes, it provides adhesive properties and flexibility to the HMA mixture.

The Asphalt cement content of a HMA mix typically ranges between 4 and 8%. A low AC content usually results in a brittle friction course, causing premature raveling; a high AC content causes an unstable pavement, unable to resist deformation due to imposed loads.

Some of the asphalt cement in HMA is absorbed by the aggregates as the mixture is prepared. For that reason, there are two measures of AC content: total AC content and effective AC content, referring to the actual amount of asphalt used as binder in the blend. The following formulae are used to calculate these percentages:

*Total AC content = 100% * Total weight of AC / weight HMA*

*Effective AC content = 100% * Weight of effective binder/ weight HMA*

a) Origin/Chemistry

Asphalt cement is one of the oldest materials used in engineering projects. It was reported to have been used by ancient civilizations in the construction of public baths or tanks, for caulking ships, for mummification and structures (NCAT, 1996).

Asphalt is a hydrocarbon soluble in disulfate. It consists of asphaltenes, resins and oils in the form of five basic components: asphaltenes, polar compounds, first acidaffins, second acidaffins and saturated hydrocarbons. It is a product of the distillation of petroleum in which it is found in solution. The material can be found naturally occurring in geologic strata as Natural Asphalts or from the industrial distillation of crude oil as Petroleum Asphalts.

b) Physical properties

Asphalt cement is a very viscous, dark brown to black material. It is readily adhesive, waterproof and very durable. It is hard at normal temperatures but softens and flows when heated. While hot, its plastic consistency imparts flexibility to HMA, allowing for thorough mixing of the blend at the plant prior to paving. Asphalt is also very strong, durable and resistant to most acids and salts.

In order to serve satisfactorily as a binder, a material must remain plastic when exposed to the elements and various climatic conditions in a thin film. This makes asphalt the material of choice for paving jobs.

However, in spite of all its outstanding qualities, AC is no less subject to the effects of fatigue, time and exposure to the elements: it will eventually lose much of is plasticity and become brittle due to chemical and physical changes, such as evaporation and oxidation of its chemical components.

The physical properties of asphalt can be measured quantitatively by performing standard tests regulated by the American Society of Testing Materials (ASTM) such as:

- Consistency

  These tests measure the fluidity or viscosity of the material at a specific temperature. Examples of such tests are the absolute viscosity (ASTM D2171) and kinematic viscosity (ASTM D2170), softening point (ASTM D36), penetration (ASTM D5) and ductility (ASTM D113) tests.

The most common way to measure the consistency of an asphalt cement is its "grade", obtained by performing a penetration test. The penetration or grade number represents the depth to which a standard needle has penetrated an AC specimen (in units of .1 mm). For example, AC-30 represents asphalt cement in which the needle would penetrate 30*.1 mm or 3 millimeters.

- Durability

  Asphalt cement experiences hardening during hot in-plant mixing. Thin Film (ASTM D1754) and Rolling Thin Film Oven (ASTM D2872) tests can be used to estimate the extent of such aging.

- Purity (ASTM D2042)

  Purity tests approximate the very little amounts of impurities that are sometimes present in refined asphalt after distillation.

- Safety (ASTM D92)

This test helps approximate the flash point of an AC, or temperature at which it emits enough steam to ignite when in the presence of open flame.

- Specific gravity test (ASTM D70) and

- Spot test (not regulated), used to estimate damage (if any) resulting from overheating during the preparation of HMA.

3.2.2.2 Aggregates

Aggregates constitute the stone matrix of asphalt concrete. They can represent over 90% of the mix. Physical properties of the stones are particularly important because they carry the stresses and are exposed to extreme climatic conditions. For example, weak aggregates cannot withstand loads and impair the structural and functional integrity of the friction course. Soft or friable aggregates break under the impact of tires, resulting in disintegration of the structure. Aggregates should be hard (in order to resist wear), durable (to resist weathering) and strong (to sustain traffic loads).

Frictional resistance is also of great importance as interlocking makes for a stronger matrix: smooth or rounded aggregates can 'slide' against each other and make the framework unstable.

Some materials used as aggregates are natural sand and gravel deposits from quarries, crushed rock and even recycled concrete that has been pulverized into the required sizes.

Aggregates must be thoroughly washed and dried prior to use. This is because deleterious substances such as dust or clay on the surface can hinder bonding between the asphalt and the stone particles; also, residual moisture makes the friction course prematurely prone to stripping.

Aggregates are categorized into coarse and fine sizes. Coarse aggregates sometimes loosely termed gravel, refer to the larger size particles used, for example particles of sizes 19mm, 12.5mm, 9.5mm, 4.75mm, 425μm, 180μm. Fine aggregates are those passing sieve No.200 (size 75μm), also called 'fines'.

For each HMA mixture, the mix design will specify aggregate gradation by providing a range of acceptable passing percentages for each sieve size.

3.2.2.3 Air

During mixing of HMA, some air is usually absorbed. Air typically represents 2 to 6% of a HMA mix. The percentage of voids in large aggregates in asphalt cement is called 'voids in mineral aggregates' or VMA and the percent of the volume of the VMA that is filled with AC, called 'voids filled with asphalt' or VFA.

The presence of air helps prevent friction course distresses such as bleeding, shoving and rutting. A poorly graded mix results in a higher VMA and subsequently a higher AC content needed; the AC % is such blends can go as high as 35%. Conversely, a well-graded mix can have VMA lower than 20% (Wallace, 1967). In a mixture with high air content, weathering or aging is also called hardening.

3.2.3 Special HMA mixtures - Open-Graded Friction Courses (OGFC)

Hot Mix Asphalt can be designed to a variety of specifications in order to achieve an assortment of properties and to serve different needs. For example, gradation can be altered to achieve particular physical properties and density requirements of the friction course. Some examples of special HMA mixtures are Dense-Graded Friction Courses (DGFC) and Open-Graded Friction Courses (OGFC).

For the purpose of this research, Open-Graded Friction Courses are studied. These are used in Florida on highways where the design speed is 50 miles per hour or higher.

An Open-Graded Friction Course (OGFC) is a special HMA mix characterized by a higher percentage of larger size aggregates. This allows for a larger volume of voids (very pervious mix) in order to achieve better drainage through and over the friction course surface. This is particularly relevant in Florida where the rainfall amount is significant.

OGFC have also been proven to help with noise reduction and improve visibility, especially under wet conditions, where they can help reduce hydroplaning and splash and spray. This is important for the safety of road users as it lowers the occurrences of wet pavement accidents.

In 1974, the Federal Highway Administration (FHWA) developed a standard design procedure for such mixes in report number FHWA-RD-74-2 titled "Design of Open-Graded Friction Courses". Since the first publication, many improvements made to the procedure have been condensed into two supplements (Supplement no.1 from 1975 and Technical Advisory T 5040.31 from 1990).

Kandhal and Mallick (1998 and 1999) conducted two surveys for NCAT to assess the use and performance of OGFC. Eight states (16% of the 50 states) did not participate in the surveys. Of the 42 states surveyed, 19 (38%) had discontinued use of OGFC, 4 (8%) did not use them at all and 19 (38%) still used OGFC. One of the states still using

OGFC is Florida. Major performance problems associated with these mixes were reported to be raveling and stripping in underlying asphalt layers.

In the state of Florida, the design and construction of OGFC is regulated by the FDOT. These specifications are published in their 'Standard Specifications for Road and Bridge Construction' printed yearly (FDOT, 2000).

The following table shows the OGFC gradation recommended by the FHWA (Federal Highway Administration):

Sieve Size	*Percent Passing*
1/2" (12.5mm)	100
3/4" (9.5mm)	95-100
No.4 (4.75mm)	30-50
No.8 (2.36mm)	5-15
No.200 (.075mm)	2-5

Table 1. Open-Graded Friction Course gradation recommended by the FHWA (Source: Roberts et al., 1996)

3.2.4 Additives and Modifiers - Ground Tire Rubber (GTR)

Additives have been used in the production of asphalt concrete for decades. They can improve some of the more desirable qualities of the mixture like flexibility and resistance to distresses such as deformation, stripping, cracking and rutting. Examples of additives are polymers, plastics, fibers, antioxidants, oxidants (to improve stiffness), recycling, hardening and anti-stripping agents and lime additives.

In recent years, growing environmental concerns have also encouraged the use of recycled waste material as modifier options. Such items include roof shingles, waste glass, ground tire rubber and crushed concrete.

Elastomers, or rubber, are widely used in the construction of pavements. They increase the tensile strength of the pavement and improve the resistance to permanent deformation by allowing it to stretch under imposed stresses and then recover its initial shape.

Ground Tire Rubber (GTR) is an elastomer used as an asphalt concrete modifier. Oweis and Khera (1998) report that 250 million tires are scrapped yearly in the US and that approximately 25% of that amount go to recycling in industrial applications. C.H. McDonald first introduced the idea of using GTR in HMA mixes in the late 60's. This concept is doubly beneficial because not only does it help in the recycling of a large quantity of waste but it also allows for a thinner asphalt mat to be laid, making friction course construction much more economical. Florida is among the states where GTR is largely used. In fact, all the projects studied in this investigation contain ground tire rubber.

3.2.5 FDOT's Friction Course types FC-2 & FC-5

The Florida Department of Transportation is the agency that governs the design and construction of all Florida roads and highways. The rules and regulations that must be followed by interested parties such as consultants, builders and designers are published in the FDOT's 'Standard Specifications for Road and Bridge Construction'

(FDOT, 2000). All aspects of the design, construction and acceptance of HMA mixes are covered in the 'Standard Specifications', which undergo periodic modifications.

FC-2 & FC-5 are two types of open-graded friction courses currently used in Florida. While FC-2 has been in use for many years, FC-5 has only been included in the 'Standard Specifications for Road and Bridge Construction' since 1997. As a result, FC-5 highways are relatively new and, as per PCS, have not shown any signs of raveling. In fact, FC-5 has replaced FC-2 as the active mix type being designed currently for FDOT roads.

Design considerations (such as composition, asphalt cement content, gradation and mix design), construction issues (such as temperature, compaction requirements, thickness requirements or spread rate) and acceptance requirements for each friction course type are discussed and regulated in the Standard Specifications. However, requirements for each mix type vary from one year to the next. For example, 1996 design requirements for FC-2 may be different from the 2000 requirements for FC-2.

A synopsis of the 2000 Standard Specifications sections pertaining to the design of friction course types FC-2 and FC-5 is provided below. It must be noted that these requirements may not have applied for the projects investigated here as their design date from several years prior to the publication of the 2000 Specifications. For more details regarding the design of FC-2 and FC-5 mixes, please consult the 2000 edition of the Standard Specifications.

Gradation (percent passing)

Following are the gradation requirements for both friction course mix types:

	Size (percent passing)							
Mix	*19mm*	*12.5mm*	*9.5mm*	*4.75mm*	*2.00mm*	*425μm*	*180μm*	*75μm*
FC-2	--	100	85-100	10-40	4-12 *	--	--	2-5
FC-5	100	85-100	55-75	15-25	5-10	--	--	2-4

* Note: The percent passing 2.00mm may be increased if lightweight aggregates are used.

Table 2. Gradation Design Range for FC-2 and FC-5 (Source: FDOT Standard Specifications, 2000)

AC Content (%)

The asphalt cement in the mix depends upon the type of aggregates used. Tabulated values are percentages.

Aggregate type	*FC-2*	*FC-5*
Crushed granite	5.5-7.0	5.5-7.0
Crushed slag	6.0-8.0	--
Crushed limestone (oolithic)	6.5-7.5	6.5-7.5
Lightweight	12.5-15.0	--

Table 3. Asphalt Cement Content Range for FC-2 and FC-5

(Source: FDOT Standard Specifications, 2000)

Temperature

Temperature requirements include the air temperature at laydown and the temperature of the mixture.

Mix	*Air Temperature at laydown*	*Temperature of the mixture*
FC-2	60°F (15°C) or above	290°F (145°C) or as specified
FC-5	65°F (18°C) or above	320°F (160°C) or as specified

Table 4. Temperature requirements for FC-2 and FC-5

(Source: FDOT Standard Specifications, 2000)

Spread rate (Thickness)

The thickness of the friction course is based on the spread rate specified for each project. The ranges of spread rates are tabulated below, according to aggregate type:

Mix	Granite, Oolithic limestone or other conventional	Lightweight aggregate
FC-2	50-60 psy (27-34 kg/m^2)	28-35 psy (15-19 kg/m^2)
FC-5	70-80 psy (38-44 kg/m^2)	

Table 5. Range of spread rate for FC-2 and FC-5 (Source: FDOT Standard Specifications, 2000)

<u>Penetration Grade</u>

Viscosity grades of asphalt that are to be used depend on the mix type and are as follows:

Mix	*AC Grade*
FC-2	AC-30
FC-5	AC-30

Table 6. AC grades for FC-2 and FC-5 (Source: FDOT Standard Specifications, 2000)

CHAPTER 4. EXPERIMENTAL PROGRAM

4.1 Data Collection Plan

In order to achieve the goals of this project, it was decided to study ten raveled FC-2 projects and ten non-raveled projects (five FC-2 and five FC-5 sections), to be used as control sections.

The program was divided into the following steps, which would allow for elimination of inappropriate or otherwise unusable projects:

1) Select both raveled and non-raveled projects from the PCS printout, making sure most districts are represented, including the Turnpike.
2) Identify limits of all sections selected (both by mileposts and lane number) using straight-line diagrams.
3) Locate old construction plans (research at FDOT District V and contact other districts) and search CQR for construction information such as original AC

content, target AC content, paving dates, mix design, mix type and the use of GTR.

4) Decide on sections to be visited and eventually cored, depending on information retrieved in previous step.

5) Conduct site visits, in order to confirm section limits and identify five areas of significant raveling for each raveling project and three for each control project.

6) Convert milepost limits to station limits using old construction plans for all projects.

7) Select five 50-foot areas for each raveled section and three 50-foot areas for non-raveled sections.

8) Proceed with coring; obtain six cores from each 50-foot area (both raveled and non-raveled).

9) Conduct laboratory testing for AC content and gradation.

10) Complete data sheet using the information gathered during all previous steps and perform data analysis to draw conclusions.

4.2 Project Selection

Initial projects were selected based on several factors including accessibility, road condition and location. For example, turning lanes, ramps and their immediate vicinity were avoided, as maintenance of traffic would have been much more challenging and dangerous.

As can be seen from the final Data Collection Sheet in Appendix A, District 5 is better represented, due to the relevance of this research to that District and the proximity of these particular projects. In addition, availability of construction documents was a major factor in the final project selection as the statistical study entailed a comparison between original (at construction) and current AC contents. This information was only available for a limited number of projects.

4.2.1 Raveled Sections

These sections were initially selected from the 1998 PCS listings. Then, site visits were conducted in order to determine the exact locations of significant raveling and to decide on locations to be cored for further study.

4.2.2 Control Sections

Similarly, control sections were picked from the 1998 PCS listings. These road sections were reported to be in very good condition (no raveling reported).

4.3 Data Collection

It was originally decided to use approximately ten raveled projects and ten control projects for this study. Due to difficulties discussed in Section 4.3.3, it was impossible to gather enough information for all ten projects and the final study was completed with only 3 raveled FC-2 projects and 6 non-raveled projects (3 FC-5 and 3 FC-2 projects).

4.3.1 Straight-line Diagrams and Construction Plans for Selected Projects

Straight-line diagrams and construction plans for the selected projects were needed for several reasons:

(a) in order to locate the exact areas to be visited

(b) to convert milepost references (as reported in PCS and determined from the site visits) to stations and

(c) to account for any irregularities or discontinuities along the road stretch of interest. Station references are needed because test results from CQR entries are only available in stations.

FDOT District V straight-line Diagrams and Construction plans were obtained from the District V offices in DeLand. Other FDOT districts were contacted to request these items as well.

4.3.2 Site visits

A Distance Measuring Instrument (DMI) was purchased and installed on the vehicle used to conduct site visits. The starting and ending mileposts of specific raveling sections were collected during site visits. This data was saved then converted into stations with the help of construction plans and straight-line diagrams. Remarks such as degree and types of deterioration like cracks and rutting noted from visual observation were also recorded.

Figure 5 shows the installed DMI. The small screen is used to read locations and to confirm whether commands have been registered properly. The number pad is used to program the DMI for various operations such as counting forward, backward, starting at a location other than zero, among others.

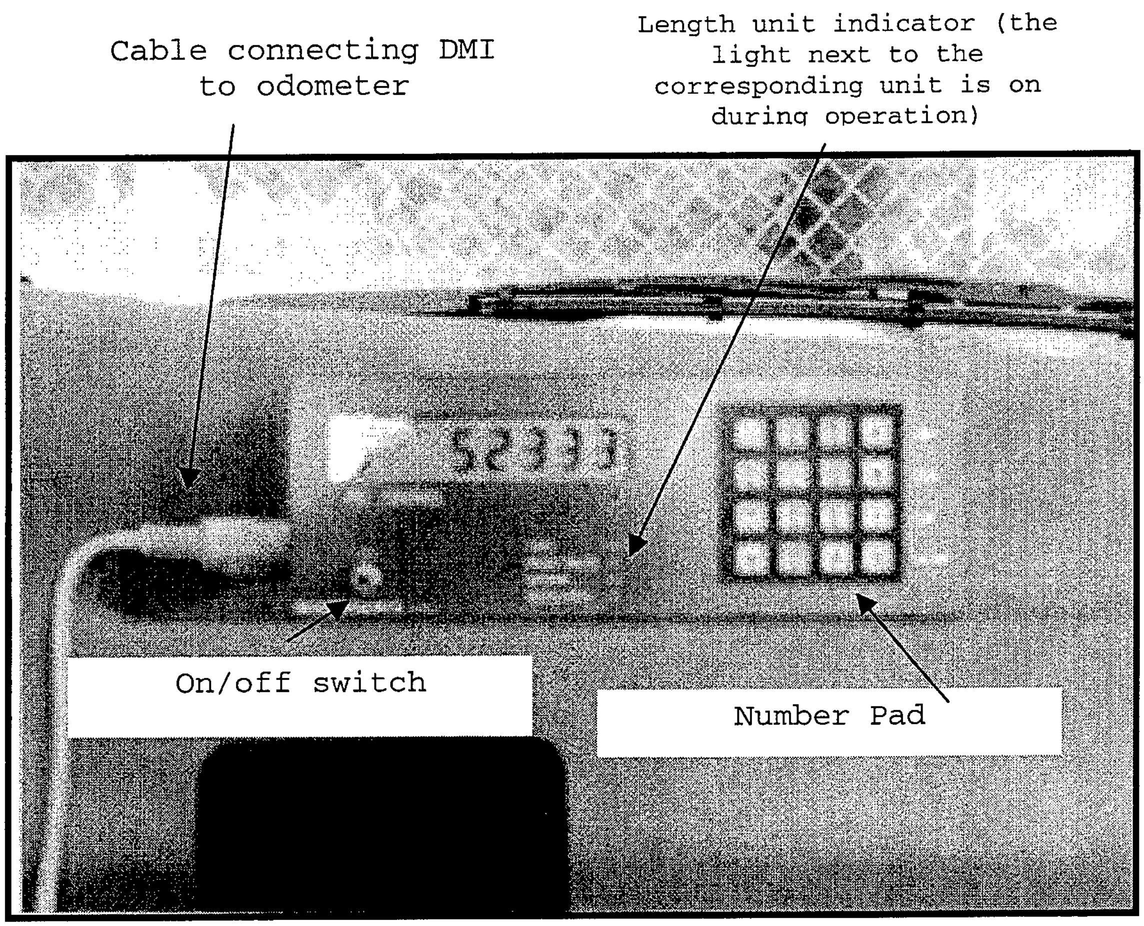

Figure 5. Distance Measuring Instrument (DMI)

4.3.3 Difficulties encountered

Many projects were removed from the selection for various reasons explained in the following paragraphs.

In some cases, selected raveling road sections had been recently resurfaced as determined by the site visits. Therefore, these could no longer be used for the study as the raveling sections had been rebuilt. Such projects were removed from the list.

Other projects that reported raveling as per PCS 1998 were visited and showed no raveling. Although other types of deterioration were observed, such as cracks, these sections were also removed from the list since only raveling was under consideration.

Yet other projects, though visited and confirmed to be raveling, were removed from the list as construction plans could not be retrieved. Several attempts to locate both hard and microfilm copies were also unsuccessful. FDOT headquarters in Tallahassee was also contacted but all efforts to locate plans for these projects were unsuccessful.

Lastly, in some cases, CQR information was missing and attempts to recover the information from the contractors were also unsuccessful.

4.3.4 Final list of projects and location

The final list of selected projects, corresponding district, county, road, lane number and location, with both raveling and non-raveling sections, is presented in Table 7 below. Figure 6 shows the selected locations on a map of Florida.

District	Category (Raveling or Control)	Type (FC-2 or FC-5)	County / Section	Road Section	County	SR #	US #
5	Raveling	FC-2	70225	3418	Brevard	9	95
5	Raveling	FC-2	70030	3503	Brevard	5	1
5	Raveling	FC-2	18130	3408	Sumter	93	75
7	Control	FC-2	08150	3404	Hernando	93	75
5	Control	FC-2	92030	3510	Osceola	500	192
5	Control	FC-2	79100	3532	Volusia	40	N/A
5	Control	FC-5	70006	3504	Brevard	407	N/A
5	Control	FC-5	73010	3523	Flagler	5	1
5	Control	FC-5	36002	3503	Marion	200	301

Table 7. Final list of projects and location

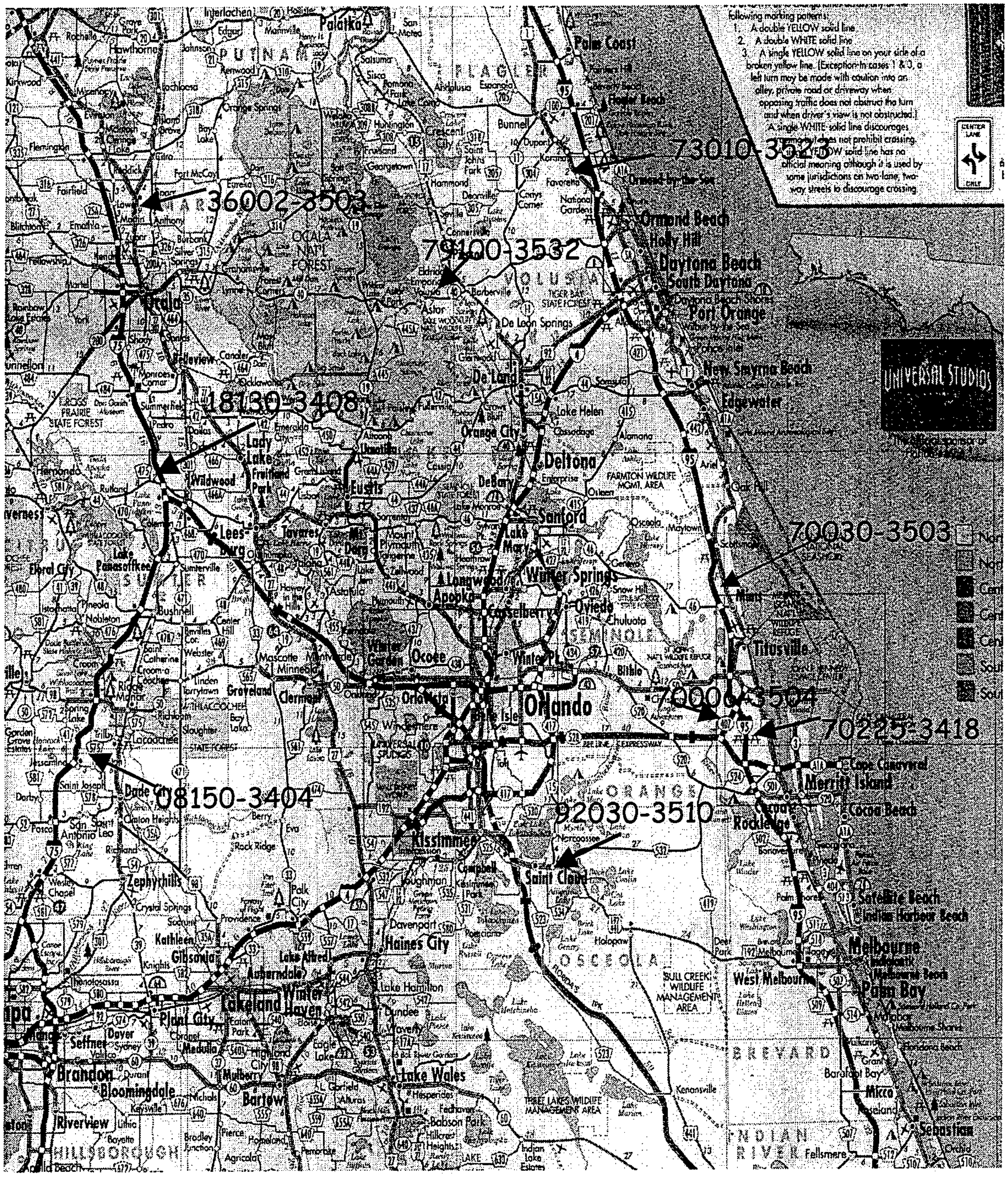

Figure 6. Selected Project locations

4.3.5 Coring Program

For coring purposes, five 50-foot (approximately .01 mile) locations were selected from each raveling project. Similarly, three locations were selected from each control project. Six cores were taken in each 50-foot lane location. The total number of cores taken was 168. For each location, cores were located diagonally in the lane, in the pattern shown in Figure 7 below:

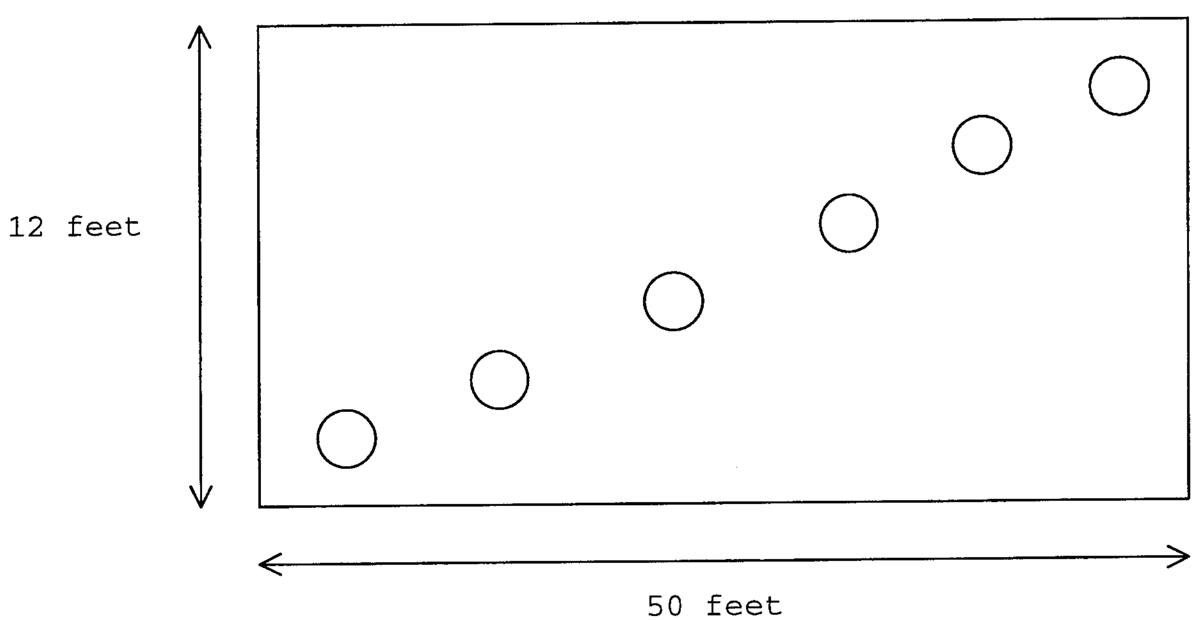

Figure 7. Coring pattern

Following are a series of pictures taken during the coring operations. They illustrate the sequence in which coring was performed.

A local Orlando geotechnical engineering and pavement material testing company (L.J. Nodarse and Associates) performed coring and subsequent laboratory testing. A copy of L.J. Nodarse and Associates' report is submitted here as an attachment.

Figure 8. Section in state of advanced raveling on I-75

Figure 8 shows a heavily raveled location on Interstate 75 prior to the beginning of operations.

Figure 9. Preparing for MOT (maintenance of traffic) on I-75

The same I-75 location as it is being prepared for maintenance of traffic and safety before coring begins is shown in Figure 9.

An off-duty police officer was present at each location in order to guarantee the safety of the workers as operations took place at night on heavily traveled highways such as I-75 and I-95.

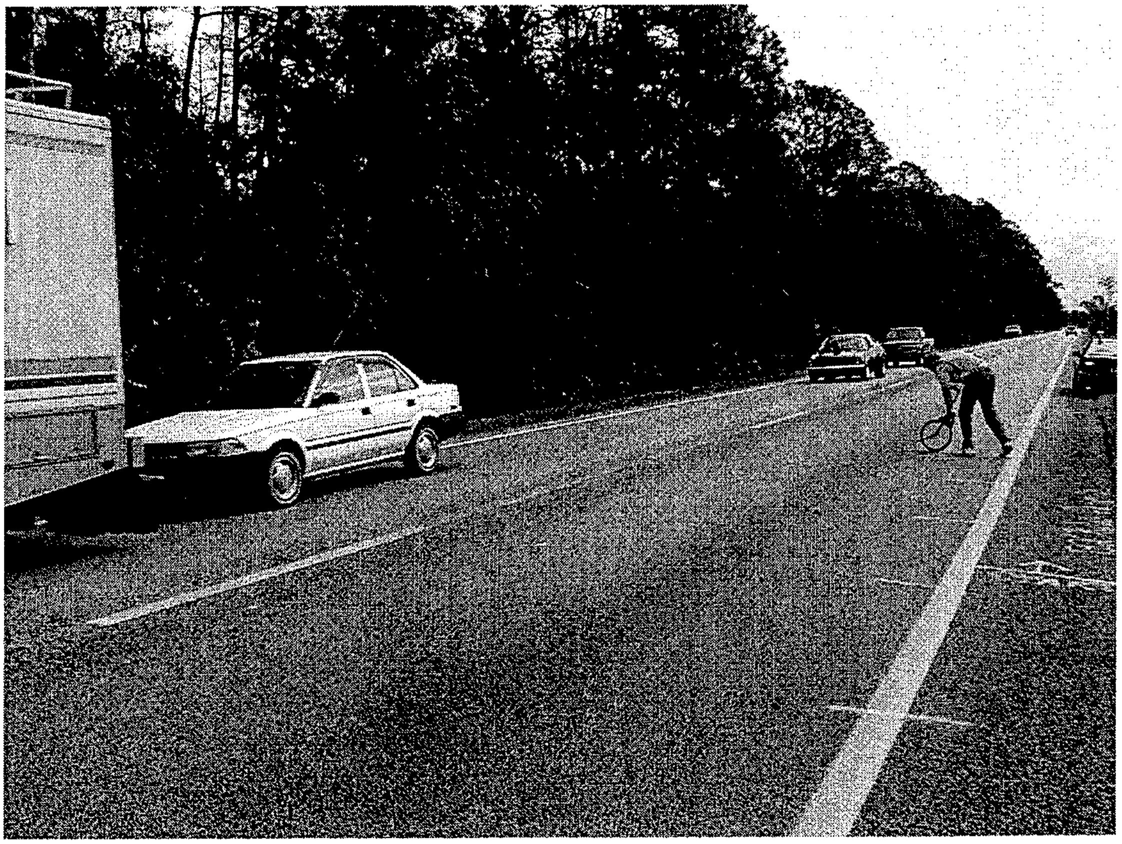

Figure 10. Preparing for coring: core layout on State Road 40, in Volusia County

Initial layout of coring locations was prepared by the subcontractor as shown in Figure 10.

Figure 11. Beginning of coring on S.R. 40, in Volusia County

After the location is labeled (using orange spray marks), the coring machine is used to proceed with the operations, as shown in Figure 11.

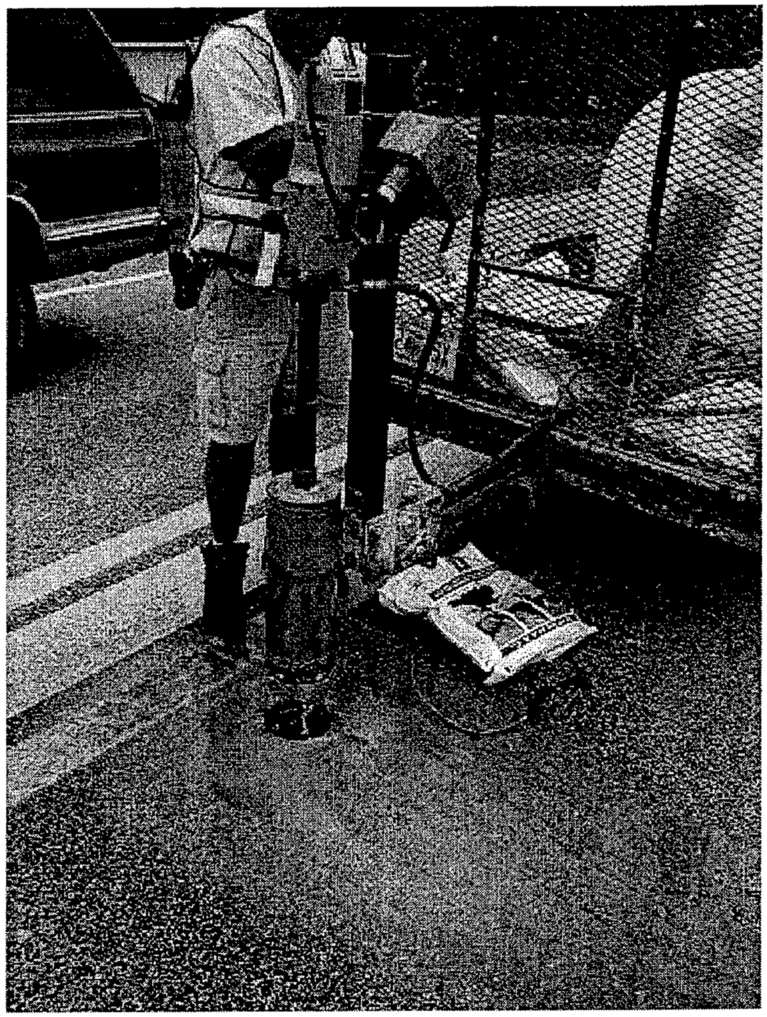

Figure 12. End of Coring: specimen to be removed from barrel (Location: S.R.40, Volusia County)

Finally, Figure 12 shows the completion of the coring operation. The specimen is about to be removed from the barrel. Cores were between 6 and 10 inches deep and measured 6 inches in diameter.

Figure 13. Core sample

Figure 13 shows a core sample after removal from the barrel. It is now ready for labeling, storage and then testing in the laboratory. Layer separations can be seen distinctly with different aggregate sizes and layer colors.

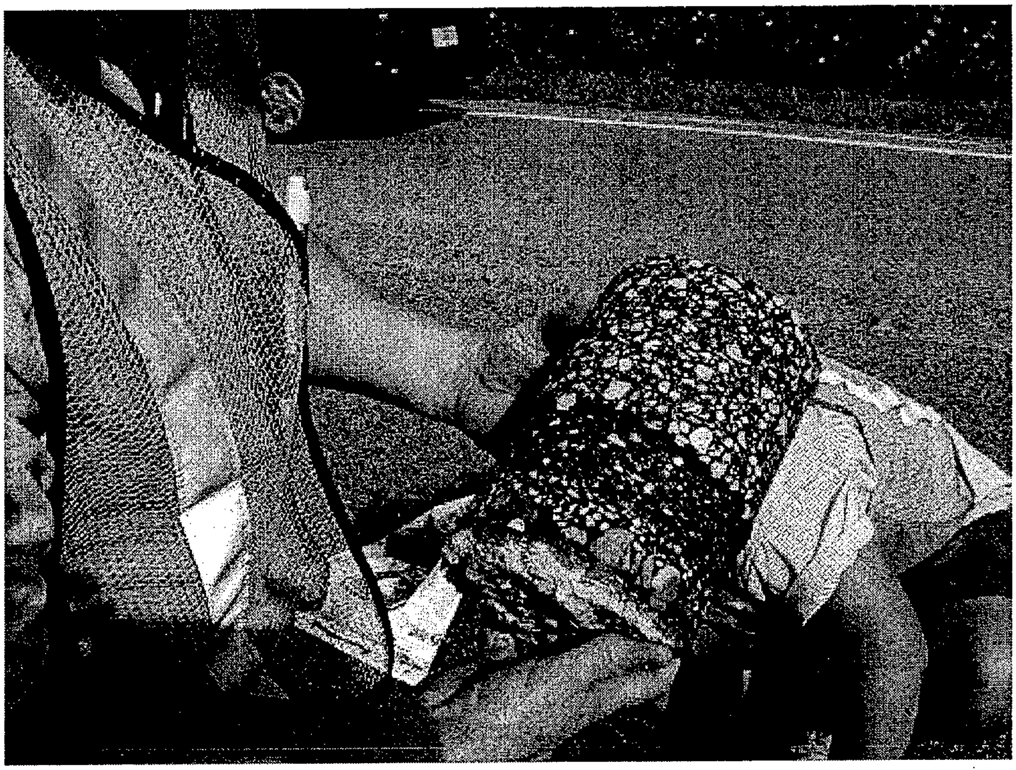

Figure 14. Core sample with visible pavement layers

Figure 14 shows another core where the layers can be easily recognized. The limerock base is also clearly visible.

Figure 15. Labeled Core

After coring, the samples were cautiously labeled with the road name, milepost location and core number in Figure 15. They were then individually stored in plastic cylinders before being transported to the testing laboratory in Orlando.

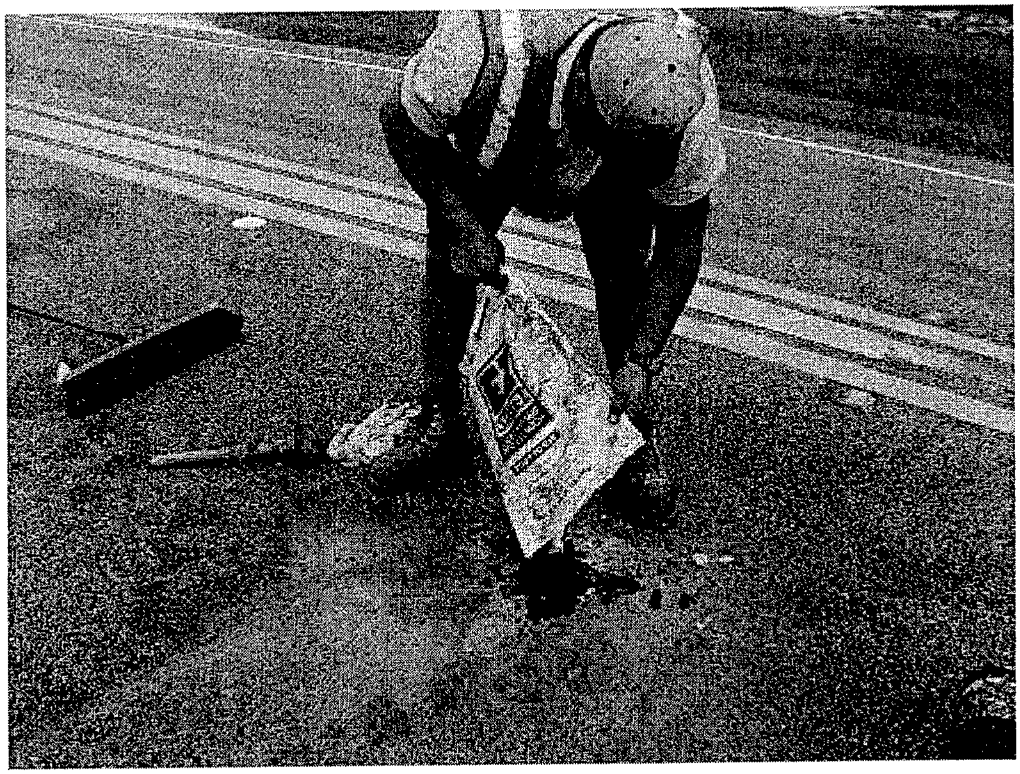

Figure 16. Patching a hole with cold-mix asphalt

The hole left after coring is completed must be filled to prevent accidents and accelerated localized deterioration of the pavement. EZ Street™, a cold-mix asphalt patch produced commercially was used in this project. The product is a polymer-enhanced permanent patching mix made by the Community Asphalt Corporation. Figure 16 shows the patching operation using cold-mix asphalt.

Figure 17. Compaction

The hole was filled in thirds of its depth and compacted after each stage using a compactor or a hammer, as shown in Figure 17.

Figure 18. Patched hole after compaction and cleaning

The hole is then patched, compacted and cleaned as shown in Figure 18.

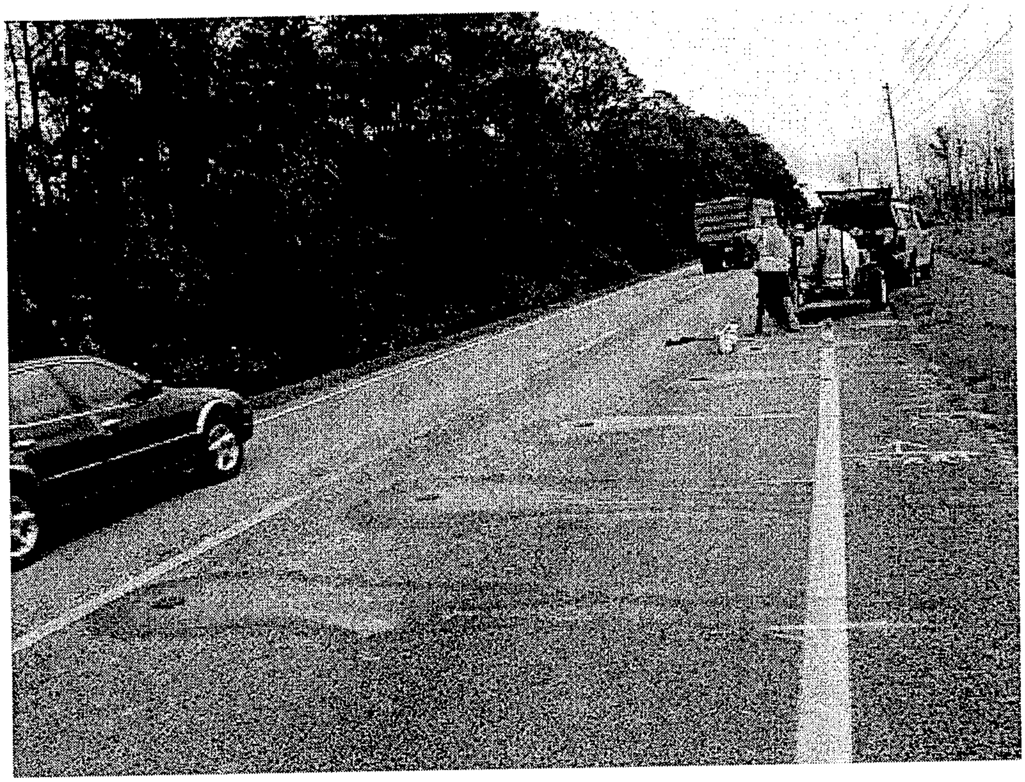

Figure 19. Cored, patched and cleaned section

Lastly, Figure 19 shows the pattern of core locations after they have all been completed and repaired.

4.3.6 Laboratory Testing

The laboratory testing program involved extraction or asphalt cement content testing and gradation testing. A special oven, the NCAT Asphalt Content Tester (Soil Test® Model No.85930), was used. The friction course samples were heated in the oven to about 1000°F (538°C), allowing for the binder to melt and the structure to break down and separate into its components. A sieve analysis was then performed in order to determine the gradation of the friction course.

Testing was done in accordance with Florida Test Methods FM5-563 for AC extraction (Ignition Method) and ASTM D-5444 for gradation. Results obtained were provided by the contractor in the form of a report, a copy of which is included as an attachment to this document. Some pictures of the testing procedures are presented in the next pages.

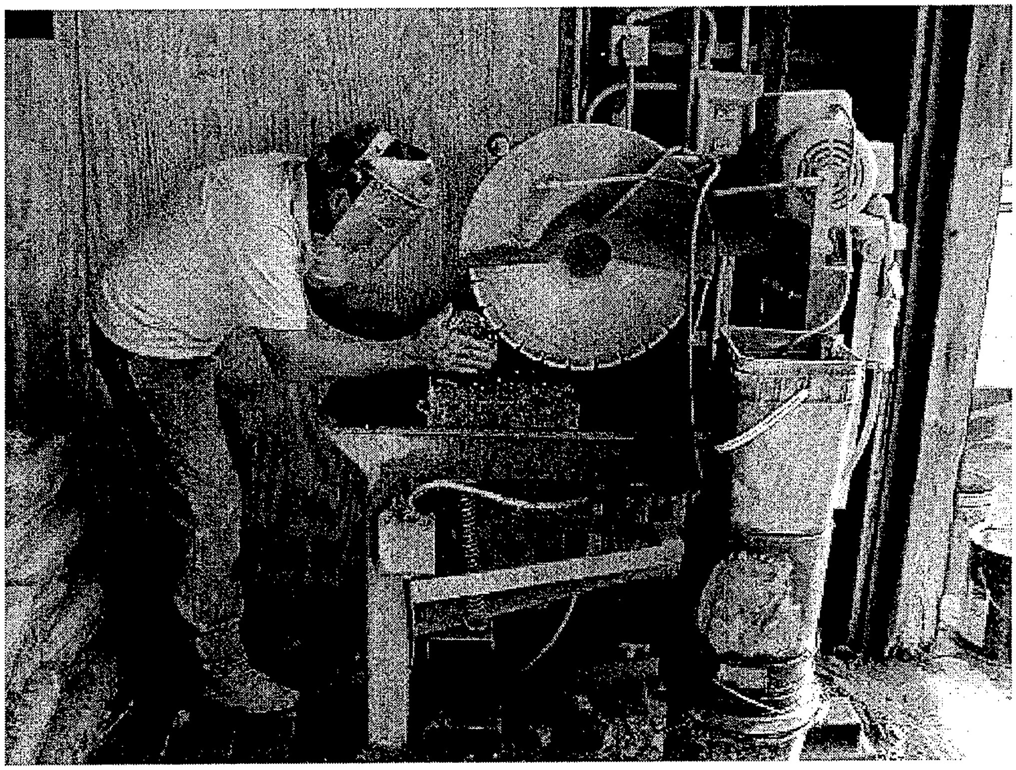

Figure 20. Cutting the friction course out of the core

The friction course layer was cut from the core sample by a technician using a hydraulic saw, as shown in Figure 20.

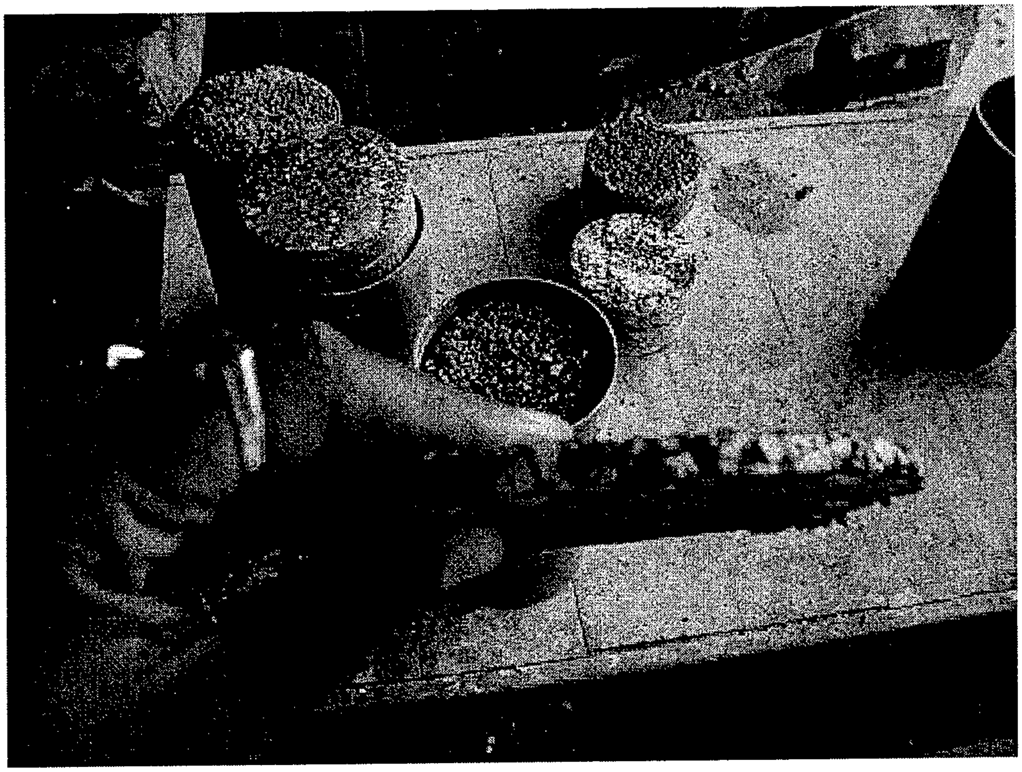

Figure 21. Friction course after cutting (approximately ½ " thick)

Next, the friction course was cut from the core. As shown in Figure 21, typically the friction course was about ½" thick, which is expected.

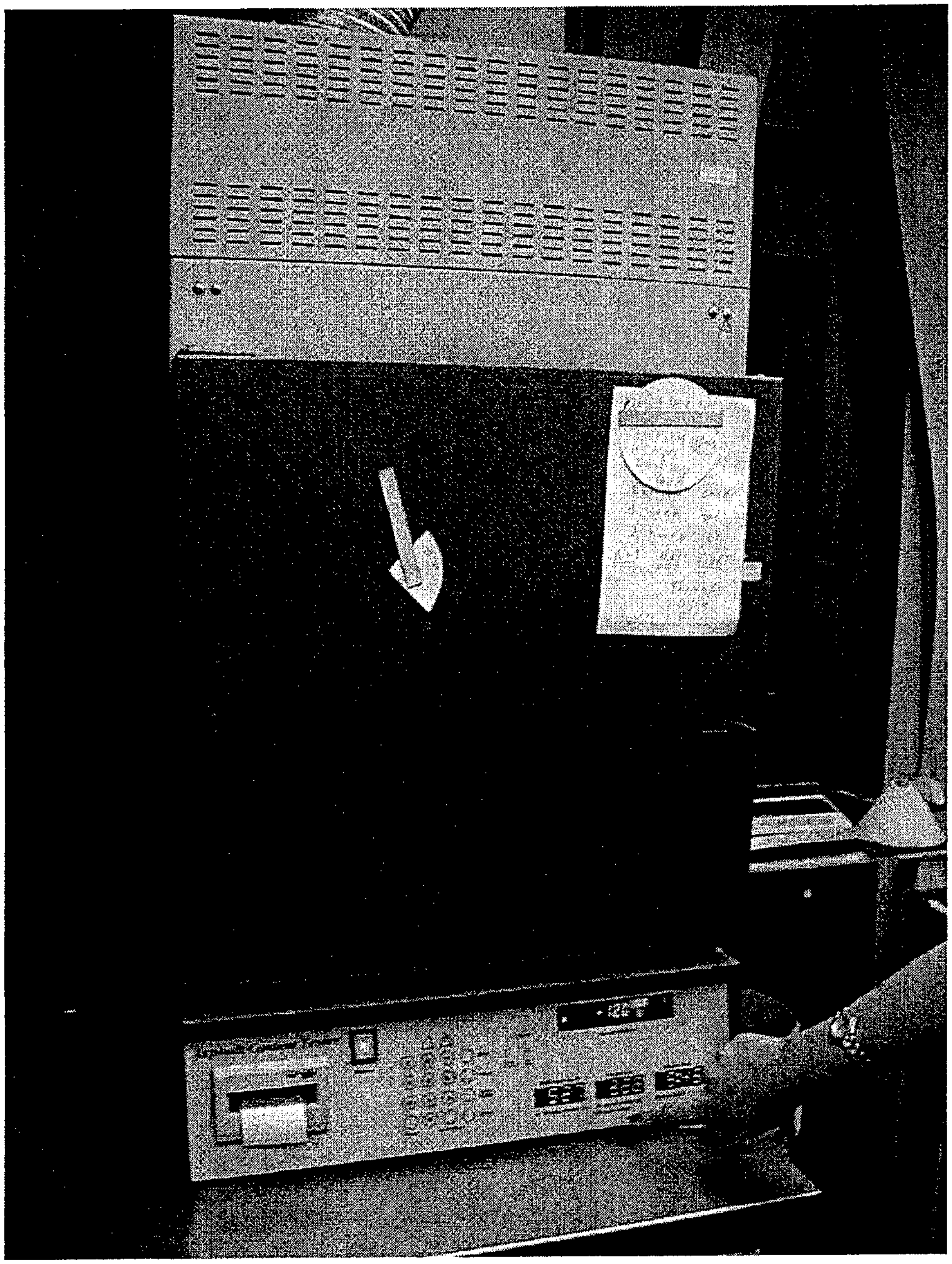

Figure 22. NCAT Asphalt Content Tester

Figure 22 shows the NCAT AC Tester used at the laboratory for extraction.

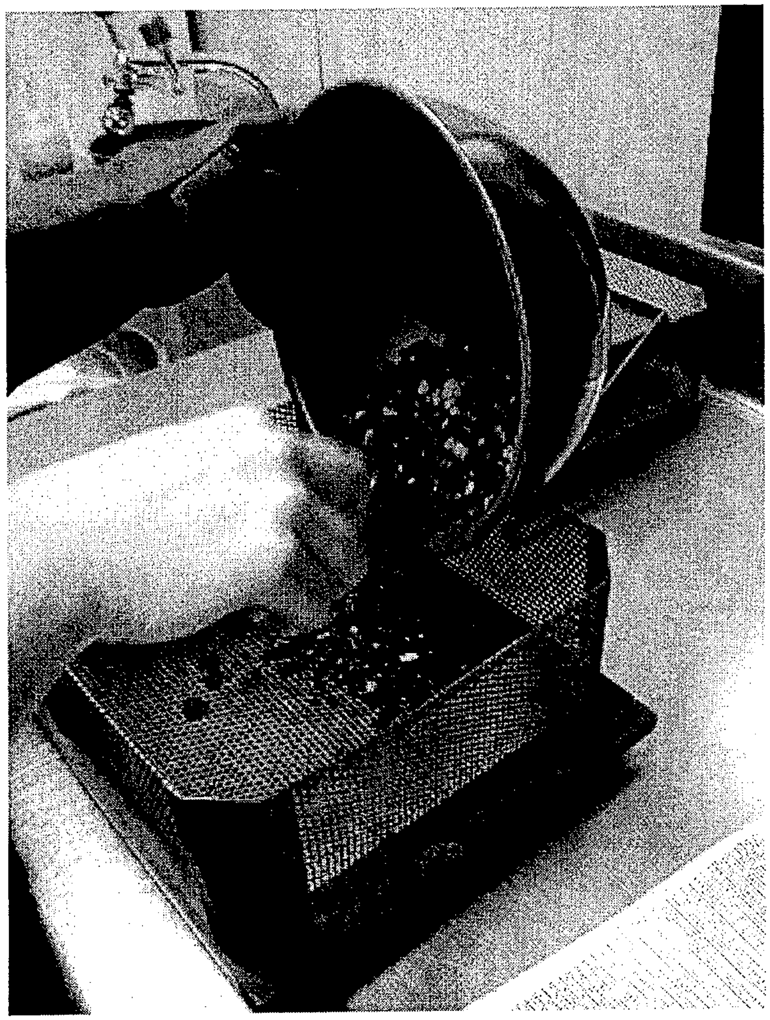

Figure 23. Friction course sample getting prepared for burning

The sample that has been broken up by preliminary warming is then transferred to a metal basket before being placed in the NCAT furnace for ignition as shown in Figure 23.

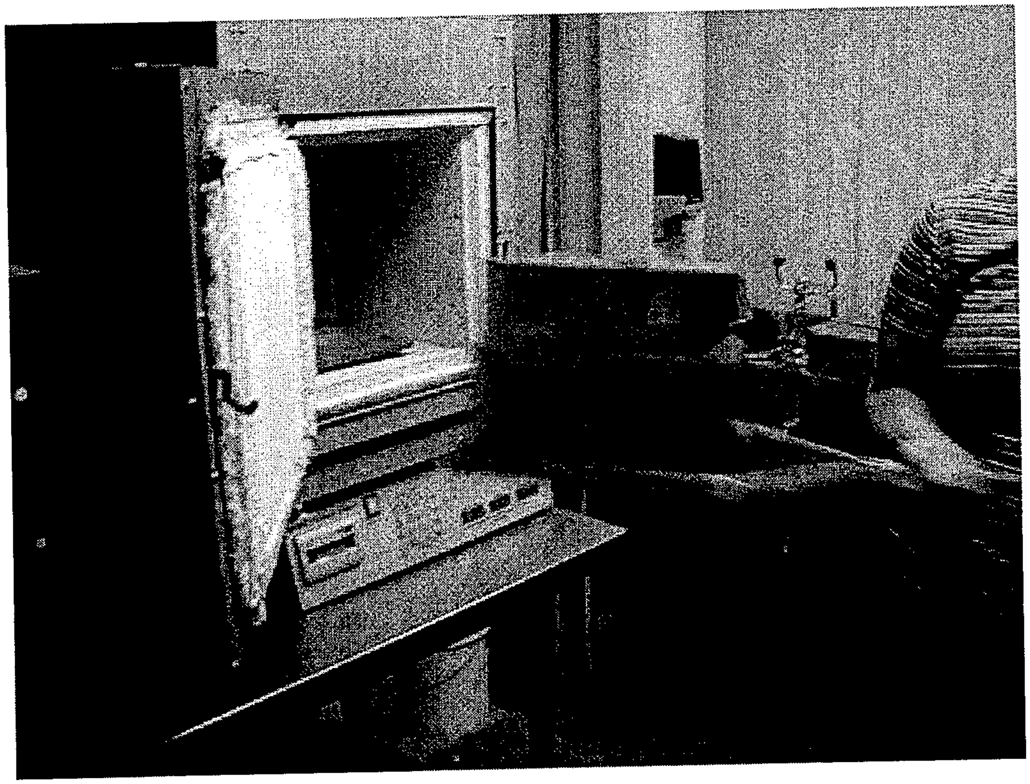

Figure 24. Sample in the NCAT Asphalt Content Tester

The NCAT tester is then warmed and the sample is ready to be heated as shown in Figure 24. The very high temperatures (538°C or 1000°F) allow for the HMA mix to completely break up, making it possible determine AC content and perform gradation tests.

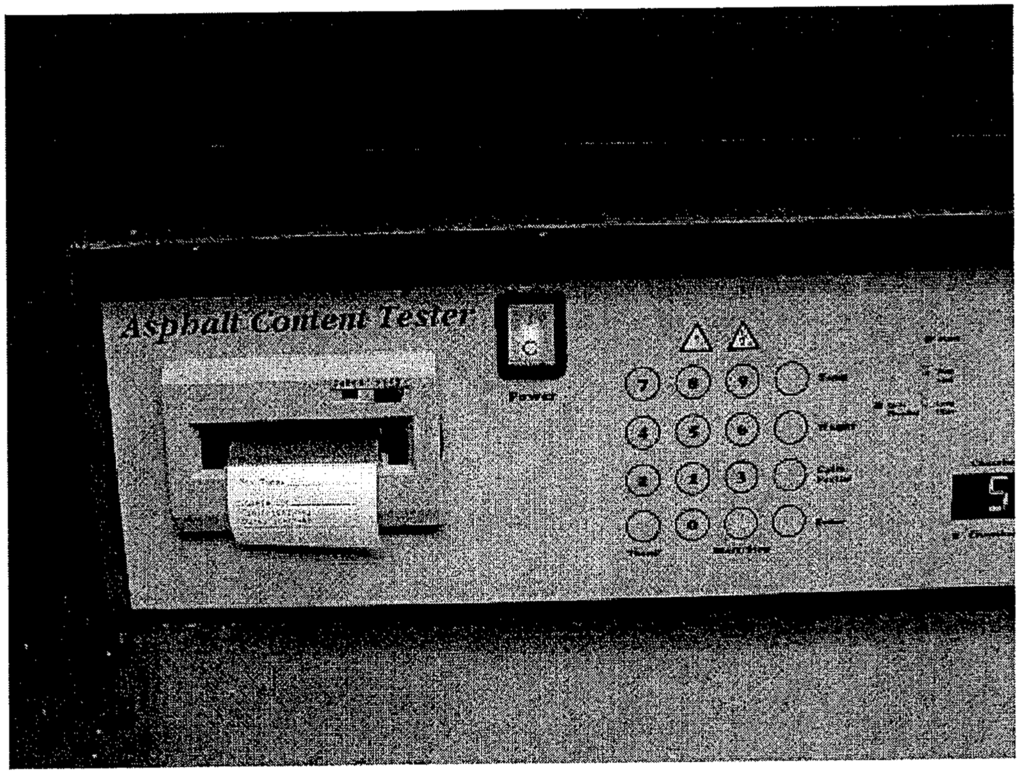

Figure 25. Output of the NCAT oven (AC%)

The NCAT Tester produces an output approximating the AC content of the sample that has undergone extraction testing. The printout from the AC Tester is shown in Figure 25.

4.3.7 Data Collection Sheet

The completed data collection sheet presents the information gathered in the study and includes all projects of interest, both raveling and non-raveling sections (FC-2 and FC-5 for control).

Two versions of the completed data sheet were produced. Version 1 is the complete set of data, including information for each core (it is 11 pages long) and version 2 is shorter and only includes information for each location (the AC content shown is an average for the whole section, 2 pages). Both versions are included in Appendix A.

A description of the information included in the final Data Collection sheet is provided below:

A) *Raveling Section Information*: all this information, with the exception of the last two columns, is obtained from FDOT's annual Pavement Condition Survey (PCS) Database.

- District: refers to the FDOT District number. The Florida DOT is subdivided into eight jurisdictions or districts. Figure 26 presents a map of Florida showing the districts limits (District numbers go from 1 through 7; District 8 is the Turnpike but it is not shown on the map). Also displayed on the map is a listing of all counties within each district and the corresponding county number.

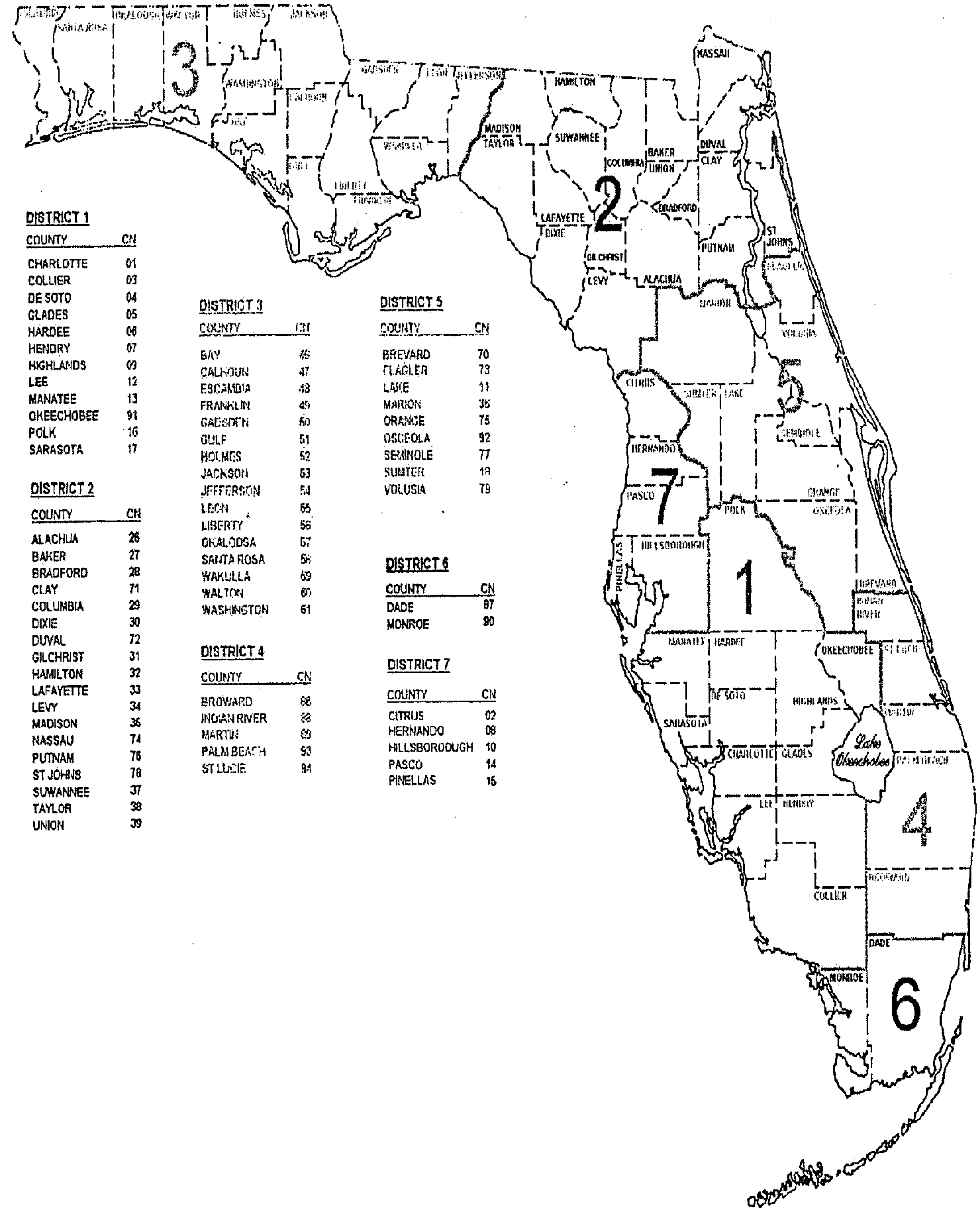

Figure 26. Florida DOT Districts with counties

- County/Section: the first two digits correspond to the County number and the last three to the section number. The numbering system is determined by FDOT.
- Road Section: four-digit number referring to road section as per FDOT numbering.
- Financial Project Number: new seven-digit number, used by the DOT as identification for the projects.
- SR#: State Road number, when applicable.
- US #: U. S. Road Number when applicable.
- FC type: Friction Course Type 2 or 5 from Mix Design.
- Last year without raveling: the year preceding first year of raveling as reported by PCS.
- Age at start of raveling: Number of years between construction and year when raveling was first reported.
- % Raveling in 1998: 1-5, 6-25, 25-50% as obtained from PCS 1998 printout.
- Lane: L1, L2, L3, or R1, R2, R3, obtained from PCS. When heading north or east, lane numbers increase from the center lane to the edge lane. Figure 27 is a schematic diagram explaining the system more clearly.

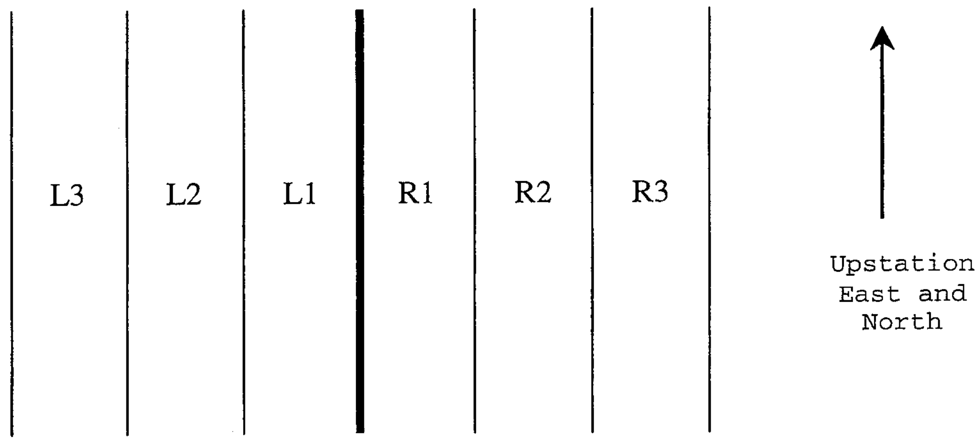

Figure 27. FDOT's Lane Numbering System

- Printout M.P. From: beginning milepost where raveling reported in PCS printout.
- Printout M.P. To: ending milepost where raveling reported in PCS printout.
- Field Visit M.P. From: beginning milepost where significant raveling seen during visit.
- Field Visit M.P. To: ending milepost where significant raveling seen during site visit.
- Sta. To: ending station where significant raveling seen during site visit (using the DMI).
- Sta. From: beginning station where significant raveling seen during site visit (using the DMI).

It must be noted that, for the same project, there is likely to be more than one of each of the last two entries as typical raveled road sections have been picked and there usually are more than one per project.

B) *Plant Lot Information*: all this information is obtained from FDOT's Construction Quality Reporting System (CQR) database. This information is initially reported by the FDOT inspectors and stored in CQR as Material Numbers 110A for Plant reports, 110C for Roadway reports and 110F for Independence Assurance (IA) reports.

FDOT defines a LOT as "an isolated quantity of a specified material produced from a single source or operation, or it is a measured amount of specified construction produced by the same process" (Standard Specifications for Road and Bridge Construction, 1996).

- Plant Lot Number: as reported by CQR.
- Start Date and

- End Date, beginning and ending dates of use of the plant lot, both reported in CQR.

C) *Test Section Selection*: from CQR

- Paving Date: paving date of the selected section.
- Sta. From: beginning station of selected section.
- Sta. To: ending station of selected section.
- Length: span of the section in feet or meters (difference between the previous two columns).
- Spread Rate (psy): rate at which the asphalt is spread. This number is found in CQR Test Results and is expressed in pounds per square yard (psy). If the project is in metric units, the spread rate is reported in kg/m^2. For purposes of this study, it is converted to psy according to the conversion factor: $1.84psy=1kg/m^2$.

D) *Sub Lot % AC Information*

- Sub Lots 1 through 6: asphalt cement content (AC content, expressed as a percentage) of each sub lot. Typically, there are 4 sub lots of 1,000 tons each; in rare instances, there may be 5 or 6. This information is obtained from CQR.

E) *Lot % AC Information*: from Mix Design.

- Av. Lot % AC: average asphalt cement content of sub lots (1 through 6, if applicable).
- Target %AC: target asphalt cement content from Mix Design.
- Mix Design: mix design number from the plant report. Format is a QA, then 2 digits representing the year of the design, a dash and a 4-digit number; this is sometimes followed by a one-letter extension (A or B). Ex: QA94-6830.
- GTR Used: Yes or No for use of Ground Tire Rubber in the mix. GTR use has become a standard in Florida, so the mix designs in all projects under investigation in this research include GTR.

F) *Core Information*: the contractor provided this information after coring and testing.

- Coring date: date core taken for testing.

- Core Age (days): Time elapsed (in days) between construction and coring.
- Station or Milepost: location where core was taken.
- FC Thickness: friction course core thickness (in inches) as reported by contractor.
- % AC: asphalt cement content as determined by laboratory results.

Rows of the non-raveling sections were not all filled, as some of the information is not applicable. For example, columns 8, 9 and 10, "Last year without raveling", "Age at start of raveling" and "% Raveling in 1998" respectively, in the Non-Raveled Control section are blank as the information is not applicable.

CHAPTER 5. DATA ANALYSIS AND RESULTS

The data obtained in the different stages of the research study was used to generate several graphs. From the completed data sheet, the following parameters were used to study the effect of AC content deficiency on raveling: initial, target (design) and current AC Content, target and current percent fines, core age and year when raveling first occurred, among others.

5.1 Analysis of Data

Prior to presenting the data analysis and results, some terms used to present the results are defined below:

1. % Initial Deficiency:

   % Initial Deficiency = 100% * (Target AC Content- Initial AC Content) / Target AC Content

2. % Current Deficiency:

   % Current Deficiency = 100% * (Target AC Content- Current AC Content) / Target AC Content

3. % AC loss:

% AC loss = 100% * (Initial AC Content - Current AC Content) / Initial AC Content

Also, it must be noted that all Current AC Content values were determined using the NCAT Extraction (Ignition Method) described in Chapter 4. On the other hand, Initial AC Content values were determined either by NCAT Extraction or by the flowmeter.

The following section shows the various graphs that are produced with the data obtained through the study, along with a discussion pertaining to each graph.

The following sections shows the various graphs that were produced with the data obtained through this study along with a discussion pertaining to each graph.

The analysis was divided into two parts: the first relates the AC content and the second to the effect of gradation on the occurrence of raveling.

A) Study of AC content

Design vs. Initial AC Content (average per project) - Figure 28.

Figure 28 shows a plot of the average initial AC content versus the target value (Design AC Content). As a visual aid, the 45-degree line (where Initial AC Content = Design AC Content) is also shown to allow for a comparison of the two values.

For the FC-2 projects, on the average, the initial asphalt cement determined at construction is either right at target or very close to design value. On the other hand, the FC-5 projects show a greater difference between the two.

It appears that the AC content values obtained by flowmeter are much closer to target value than the ones obtained by NCAT Extraction. This has to do with the way the flowmeter is used. In practice, the flowmeter is calibrated prior to each use to read the target value whereas the NCAT method calculates AC content by determining the mass percentage of AC present in the HMA, which is a more systematic and rigorous method. It is the impression of the author that the NCAT measurements are more reliable than those obtained by flowmeter.

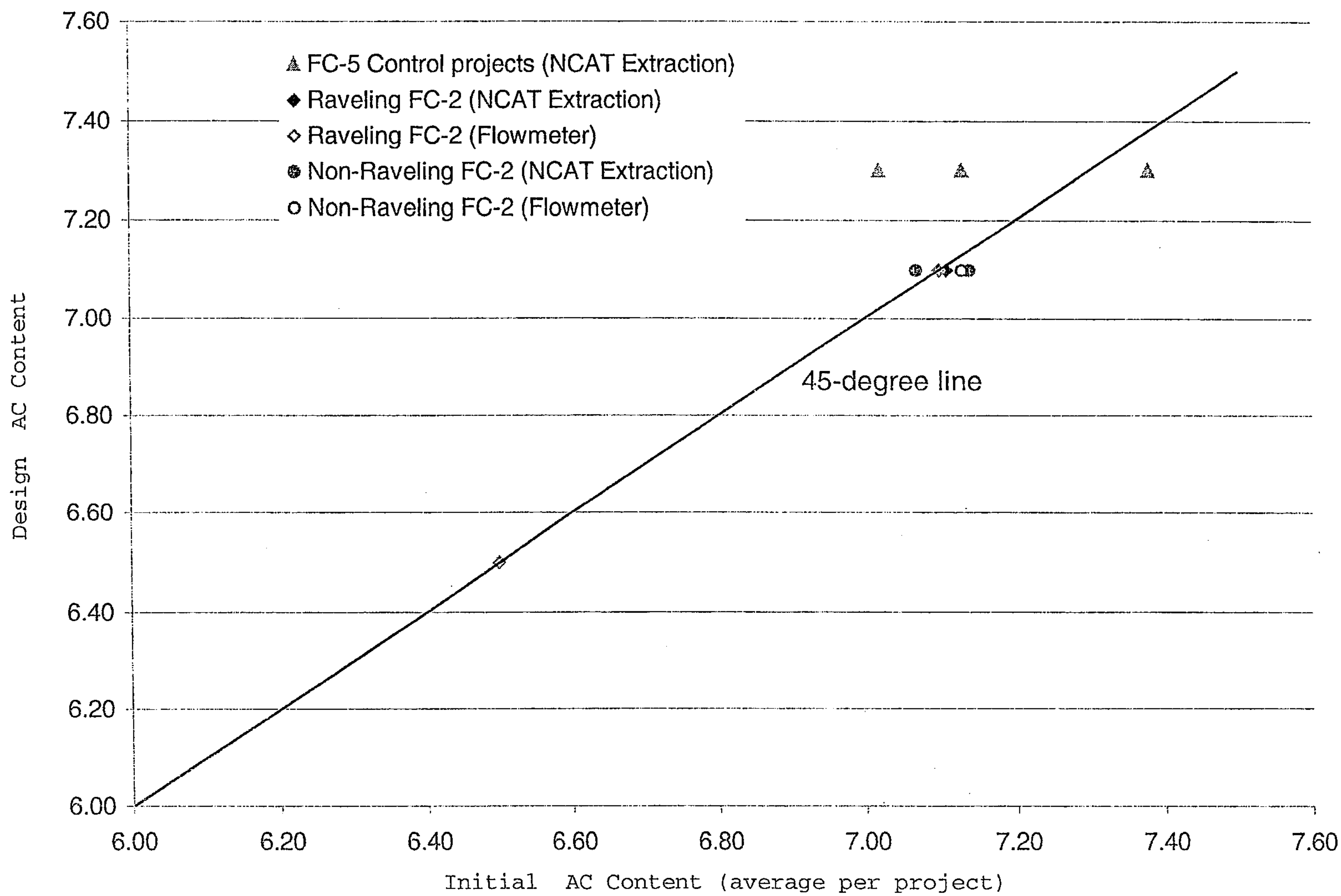

Figure 28. Design vs. Initial AC Content (average per project)

Current vs. Initial AC content - Figure 29

The average initial AC content per project is plotted against the current value as determined by laboratory results. Again, the 45-degree line (where initial AC% = current AC%) is also shown to facilitate comparison.

In eight out of nine cases, for raveled and control sections, FC-2 and FC-5, the initial AC content is greater than the current value. This seems to indicate that AC loss does take place over the life of the pavement, as expected.

Also, it is shown that raveling sections are considerably lower than control sections, indicating a greater loss of AC in the case of raveling projects.

In cases where Initial AC Content was determined by flowmeter (see corresponding symbols in legend), Initial AC Content is considerably greater than Current AC Content. On the other hand, where it was obtained by the NCAT method, the difference between Initial and Current AC is much smaller, indicated by the symbols being much closer to the

45-degree line. The remarks made previously also apply here.

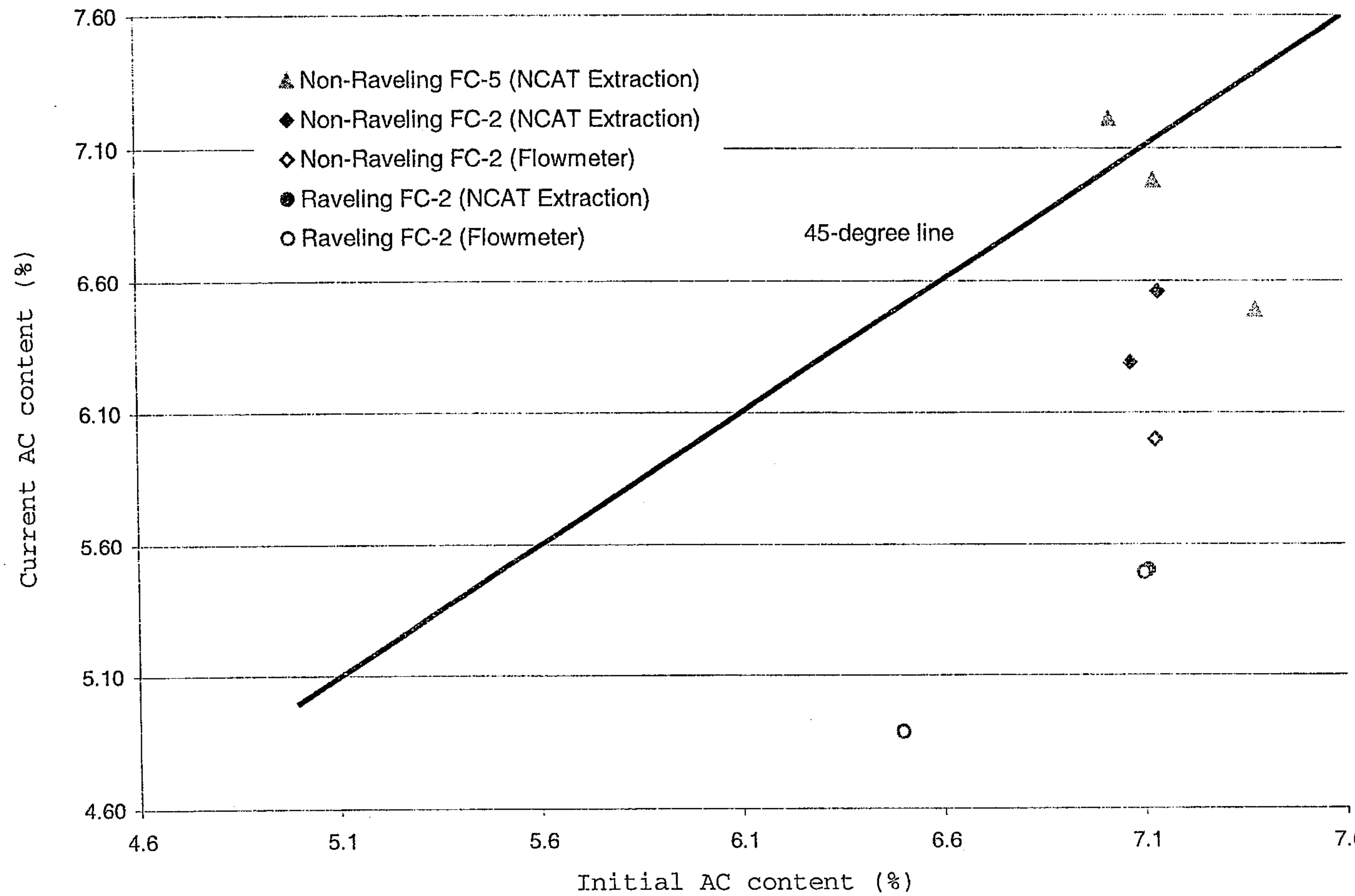

Figure 29. Current vs. Initial AC content

% Current Deficiency - Figure 30

As mentioned previously, the % Current Deficiency is defined as:

% Current Deficiency = 100 * (Target AC Content- Current AC Content) / Target AC Content

The % Current Deficiency is plotted for each core with different symbols to distinguish between project categories and between NCAT and flowmeter measurements.

As seen from examining Figure 30, the raveling projects are are, on the average, much higher than the control projects, indicating a greater % Current Deficiency. The demarcation line is located statistically at *16.12%* (see method described below), indicating that raveling occurs when % Current Deficiency reaches approximately 16% or, in other words, when the AC content is 16% below target. Raveling is triggered not by AC loss occurring over a long period of time, but rather by a total AC deficiency of 16%, regardless of the time taken to reach such deficiency. Therefore, a road section built with an initial AC content deficiency of 16% should start raveling soon after construction. Similarly, if a road section is built with a lean mix (original AC deficiency), its service life will be shortened as it will take less time to reach 16% deficiency than if the initial AC content had been at or above target value.

The method used to locate the demarcation line is explained next. The total number of samples is 174: there are 65 cores from raveling projects and 109 from control projects (one core was taken twice). Then, the raveling cores are given the same weight as the control cores as seen below:

- Total weight of raveled cores = .5*174 = 87
- Total weight of control cores = .5*174 = 87
- Weight of one (1) raveled core = 87/65 = 1.34
- Weight of one (1) control core = 87/109 = .8

Note that the weight of a raveled core is greater than 1 and that of a control core is less. This is due to the fact that there are more control cores than raveled ones.

Then, for each core, the % Current Deficiency (%CD) is multiplied by the weight of the core. The sum of these products is then calculated:

$$\sum_{n=1}^{65} 1.34 * (\%CD) + \sum_{n=1}^{109} .8 * (\%CD)$$

(Raveled) (Control)

Finally, the demarcation line is located by computing the average, dividing the sum by 174 (total number of cores).

The spreadsheet used to generate these values is included in Appendix B for review.

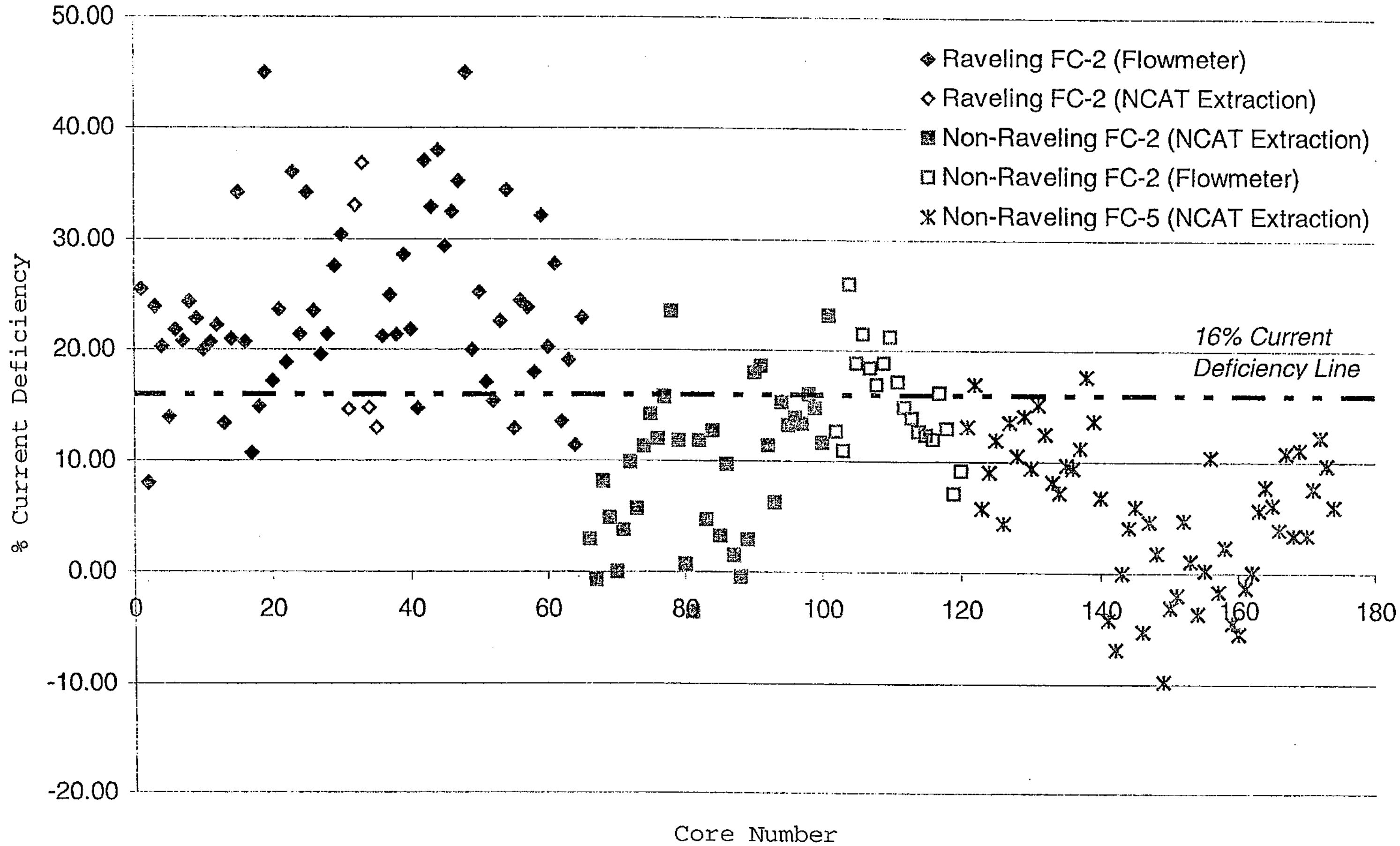

Figure 30. % Current Deficiency

% AC loss (per core) - Figure 31

In Figure 31, the % AC loss is plotted for each core. The plot is very similar to the graph shown in Figure 30, depicting % Current Deficiency. As seen before, raveling sections show a much greater change in AC content than control sections. This plot once again confirms the strong correlation between the occurrence of raveling and decrease in asphalt cement content.

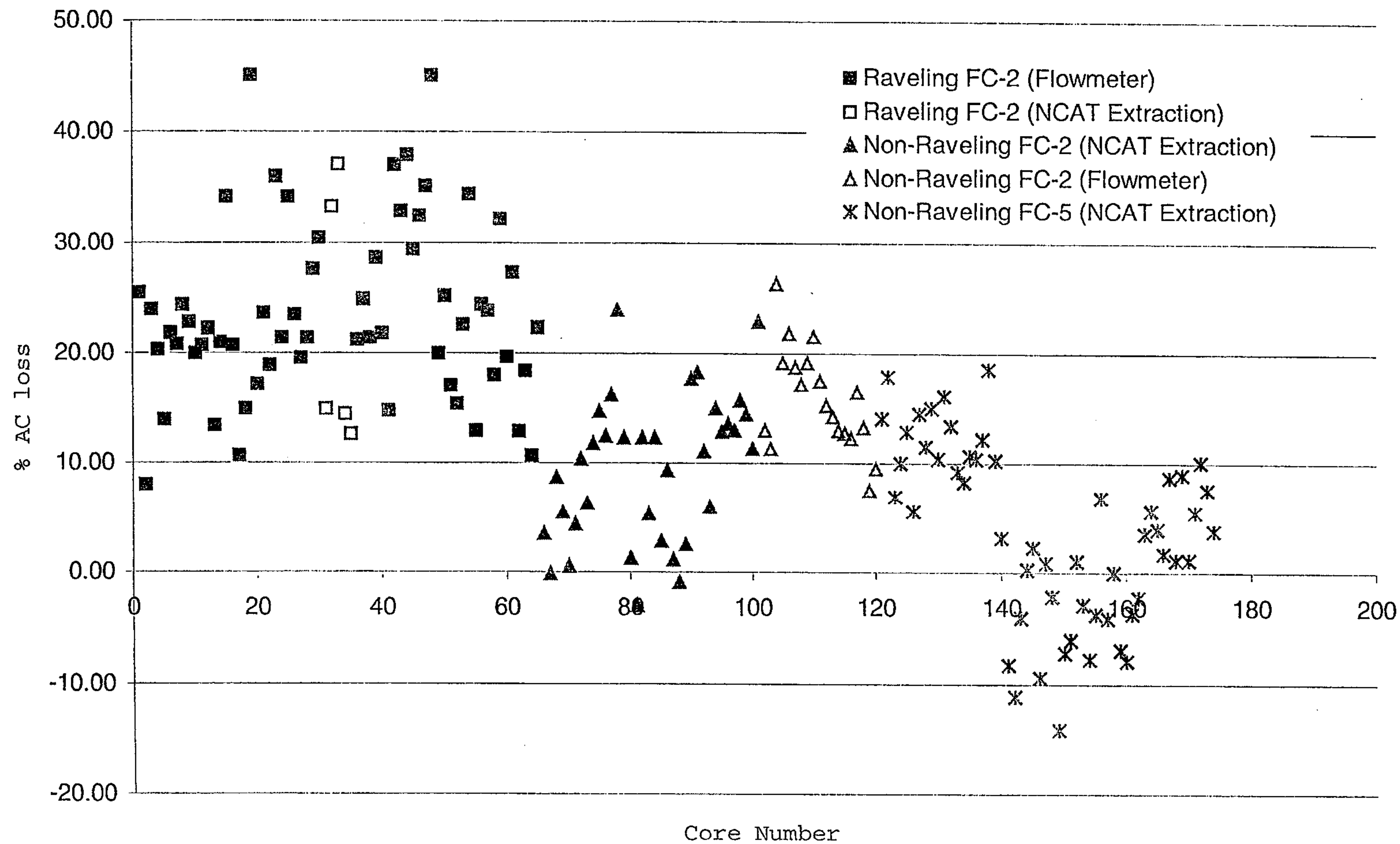

Figure 31. % AC Loss (per core)

% AC loss vs. Friction Course Age - Figure 32

In Figure 32, the % AC loss is plotted versus the friction course age for all projects. Raveled sections appear higher on the plot, indicating a greater loss of binder. Raveling sections show losses ranging from 13% to as high as 37% while control sections show losses going from 0 to 17%.

The negative values of % AC loss (from -1 to -5%) indicating increase in AC content can be attributed to the heterogeneity and gradation variations within the HMA mixture.

However, the relationship between loss of AC and time does not seem to follow any obvious pattern. A regression analysis to determine the relationship between AC loss and age is made more difficult by the presence of Project 70030 which started raveling soon after construction (see the raveled FC-2 NCAT Extraction located at approximately 100 days on the plot). This project is extraordinary and leads to skewing of the results. In the next three graphs, it is neglected for further analysis and a detailed regression analysis is attempted.

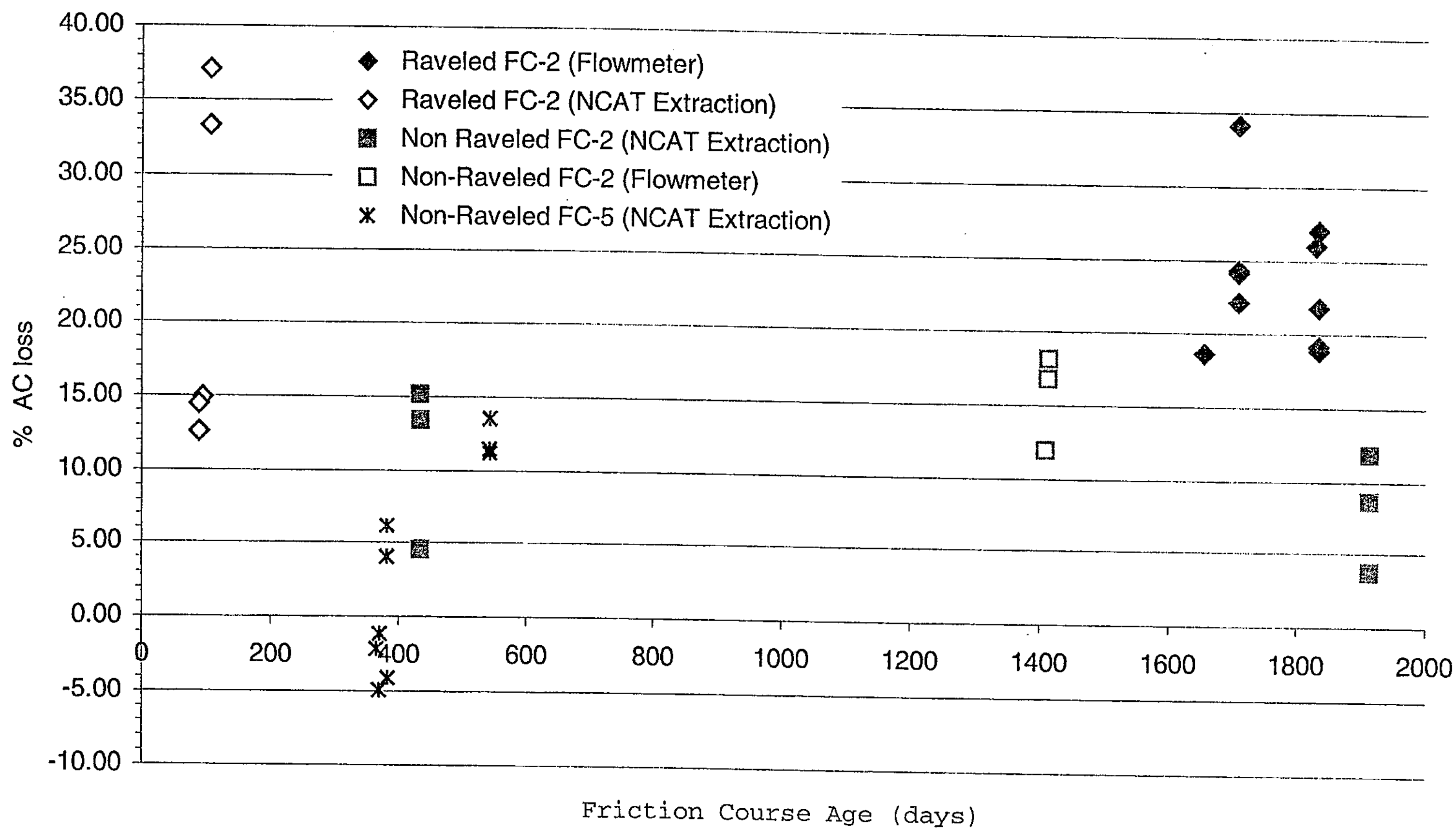

Figure 32. % AC loss vs. Friction Course Age, distinguishing between NCAT and flowmeter measurements

% AC loss vs. Friction Course Age (both NCAT and flowmeter measurements) - Figure 33.

% AC loss vs. Friction Course Age (NCAT measurements) - Figure 34.

% AC loss vs. Friction Course Age (Flowmeter measurements) - Figure 35.

As stated before, the next three plots are variations of Figure 32 where Project 70030 (with Friction Course Age approximately 100 days) has been removed. This allowed for easier and better curve fitting to correlate % AC loss and time.

Figure 33 includes projects with Initial AC Content determined using either NCAT or flowmeter. Figure 34 plots those with NCAT measurements only, whereas Figure 35 includes only flowmeter measurements.

Regression analysis was performed on all three graphs and yielded linear equations relating % AC loss and time. The analysis output sheets are provided in Appendix C for further review.

It should be noted that the equations of linear regression used to compute the annual loss of asphalt cement in the friction course are only applicable with the age parameter in units of days. Results are as follows:

1. % AC loss vs. Friction Course Age (both NCAT and flowmeter measurements) - Figure 33.

% AC loss = .0103 Friction Course Age (days) + 1.342*

This translates into an annual % AC loss of *5.1%.*

2. % AC loss vs. Friction Course Age (NCAT measurements) - Figure 34.

% AC loss = .0025 Friction Course Age (days) + 4.3089*

This translates into an annual % AC loss of *5.2%.*

3. % AC loss vs. Friction Course Age (Flowmeter measurements) - Figure 35.

% AC loss = .0182 Friction Course Age (days) - 8.9322*

This translates into an annual % AC loss of *6.6%.*

As expected, the annual % AC loss values obtained using the three plots are very close (5.1% for NCAT and flowmeter measurements, 5.2% for NCAT only and 6.6% for flowmeter only).

As discussed previously, flowmeter measurements yields values of % AC content that are not exact due to the fact that during testing procedures, the GTR (present in all mixes studied here) hardens and passes as aggregates, leading to incorrect data. The NCAT Extraction method seems to be more reliable. As a result, NCAT and flowmeter data are different and consequently, the equations obtained are not quite the same.

However, since the values calculated are so similar, it can be said that the annual loss of asphalt cement is within the range of 5% and 6%.

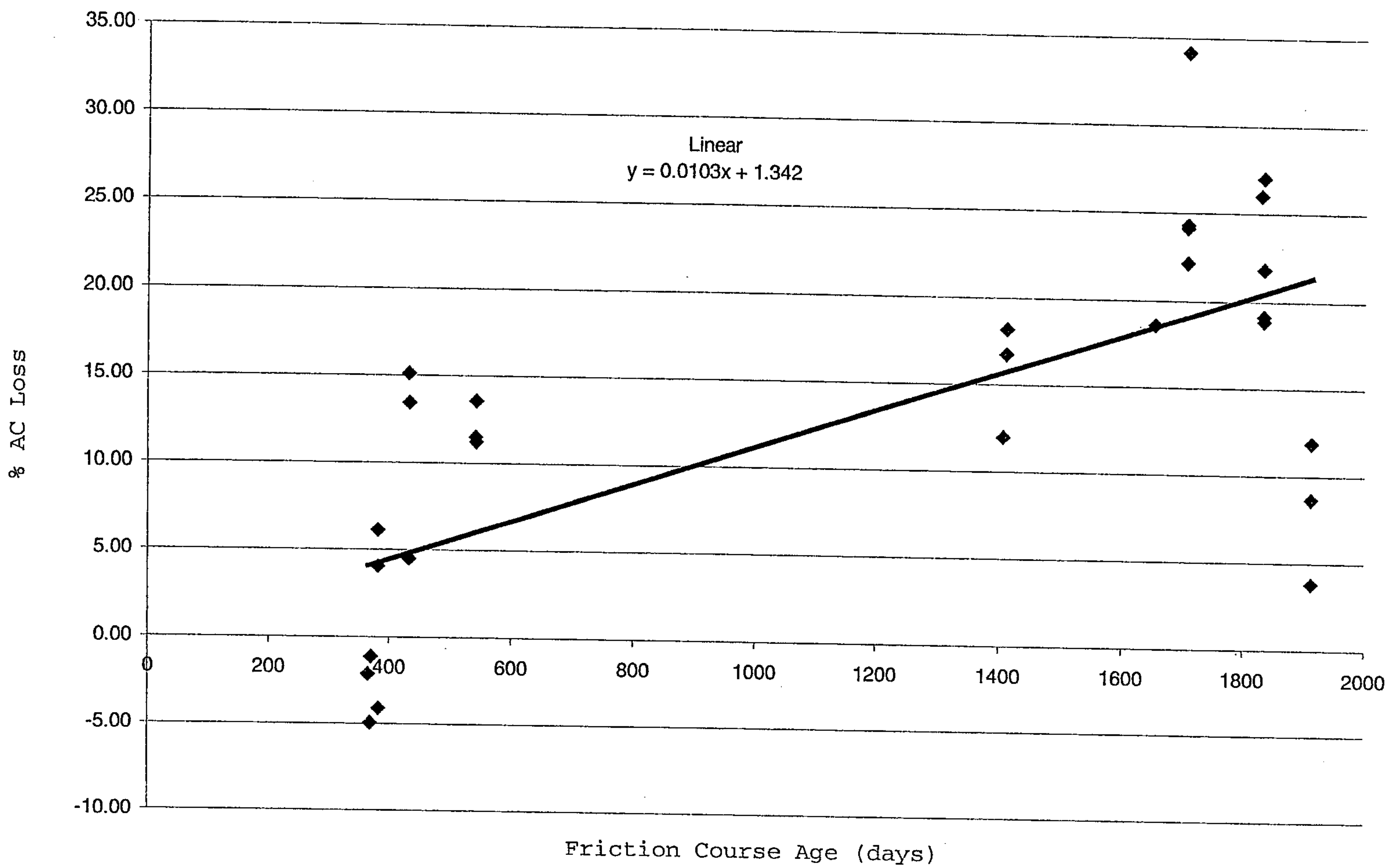

Figure 33. % AC Loss vs. Friction Course Age (both NCAT and Flowmeter measurements)

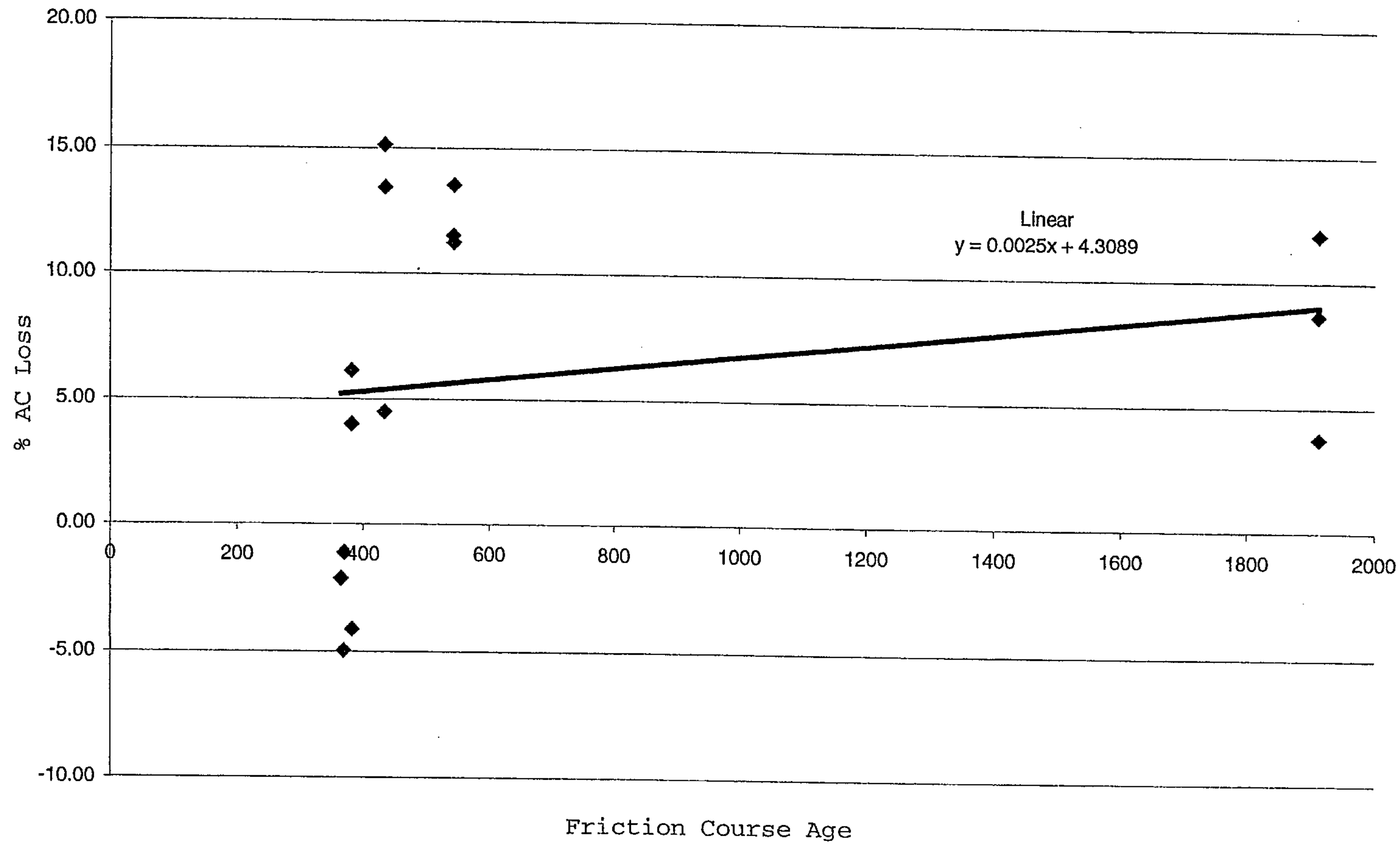

Figure 34. % AC Loss vs. Friction Course Age (NCAT measurements)

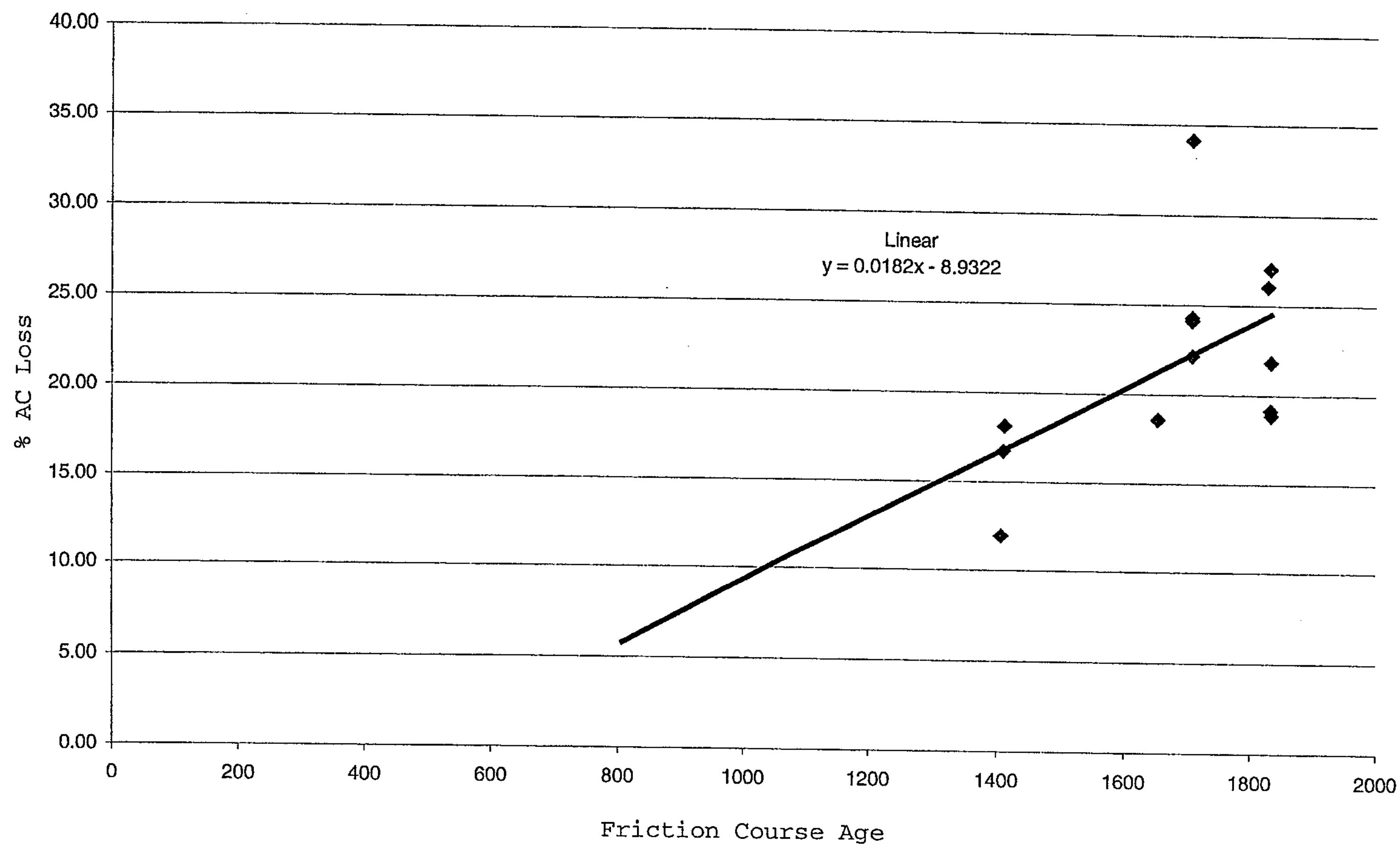

Figure 35. % AC Loss vs. Friction Course Age (Flowmeter measurements)

B) Effect of gradation

The gradation results obtained from the laboratory testing made it possible to produce the following plots. An assumption is made that the gradation of the friction course remains the same throughout the life of the pavement. This implies that the loss of aggregate is uniform over the friction course or that the same relative amount of aggregate is lost for each gradation size.

% Excess Fines - Figure 36

Percent Excess Fines is calculated using the formula:

% Excess Fines =

100 * (Current % fines - Job Mix Formula value)/

Job Mix Formula value

Percent fines, as mentioned previously in Chapter 3, refer to the percentage soil particles passing sieve no.200. The job mix formula value of the % fines is specified in the mix design. Each core has been taken into account individually in Figure 36.

Both raveling and control sections lie within the range of .5% and 1.5 % excess fines. An excess of fines does not seem to make a difference when it comes to deterioration of the friction course. For the raveling sections, this seems to corroborate the assertion of Sontowski (1995) that an excess of -200 material would invariably cause premature raveling. However, the non-raveling sections (both FC-2 and FC-5) lie within the same range of excess fines and have not yet shown signs of raveling.

An important factor to be considered in these observations is the age of the friction course. Raveled FC-2 sections (core numbers 1 through 60) were between 0 and 2 years old when raveling first occurred, FC-2 control sections were between 1.3 and 5 years old while the FC-5 projects (also control) are 1 to 1.5 years old. The % excess fines does not seem to have an obvious impact on the occurrence of raveling for FC-2 and FC-5 pavements.

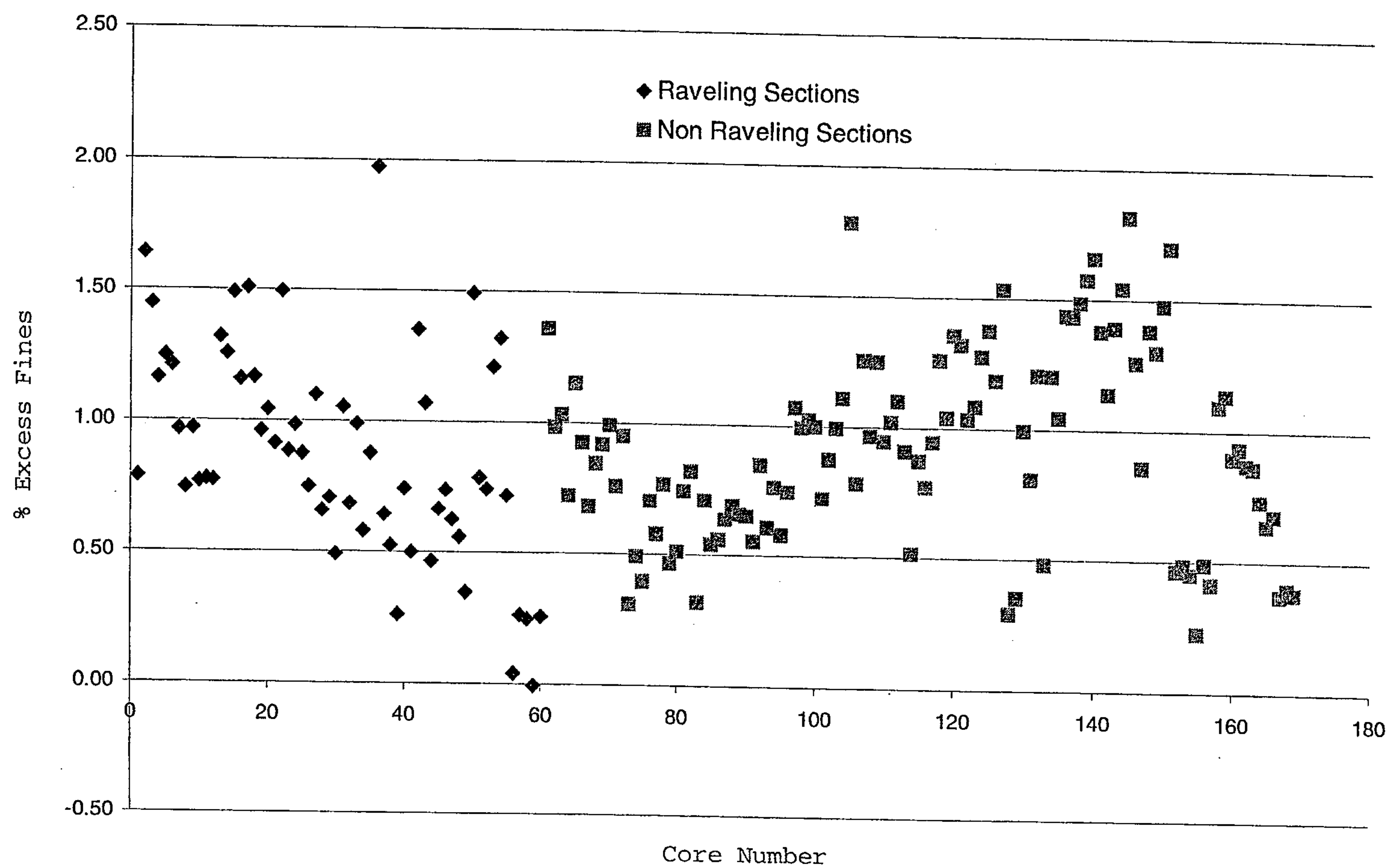

Figure 36. % Excess Fines

% below Gradation Design Range Maximum - Figure 37

The % below Gradation Design Range Maximum is calculated as:

% below Gradation Design Range Maximum = 100*(Gradation Design Range Maximum - Current % fines) / Gradation Design Range Maximum

Gradation Design Range Maximum (GDRM) is the largest percentage of fines allowed during the mix design. The value plotted tells how far below that value the actual percentage of fines is. Therefore, a negative value indicates a percent of fines above the Gradation Design Range Maximum (maximum allowed).

As can be seen, most of the FC-2 cores (both raveling and non-raveling) tend to be below the maximum percentage of fines allowed (indicated by most FC-2 points lying above the zero line). On the other hand, an overwhelming number of FC-5 cores contain a percentage of fines above the maximum (indicated by the large number of FC-5 data points below the zero line).

Also, it must be noted that the raveling FC-2 sections were one, five and six years old. The same holds true for FC-2 control sections. This makes the comparison of these two project categories very convenient.

Based on the limited amount of data available, observation of this graph seems to suggest that:

a) FC-2 mixtures tend to have a lower percentage of fines.
b) For FC-2 mixtures, the occurrence of raveling is independent from the fine content since both raveling and control cores show very similar fine content. Because both raveling and control sections are comparable in age, Sontowski's idea that a high fine content could yield to premature raveling is not corroborated.
c) FC-5 with a high fine content does not ravel during the first 1.5 year of its life.

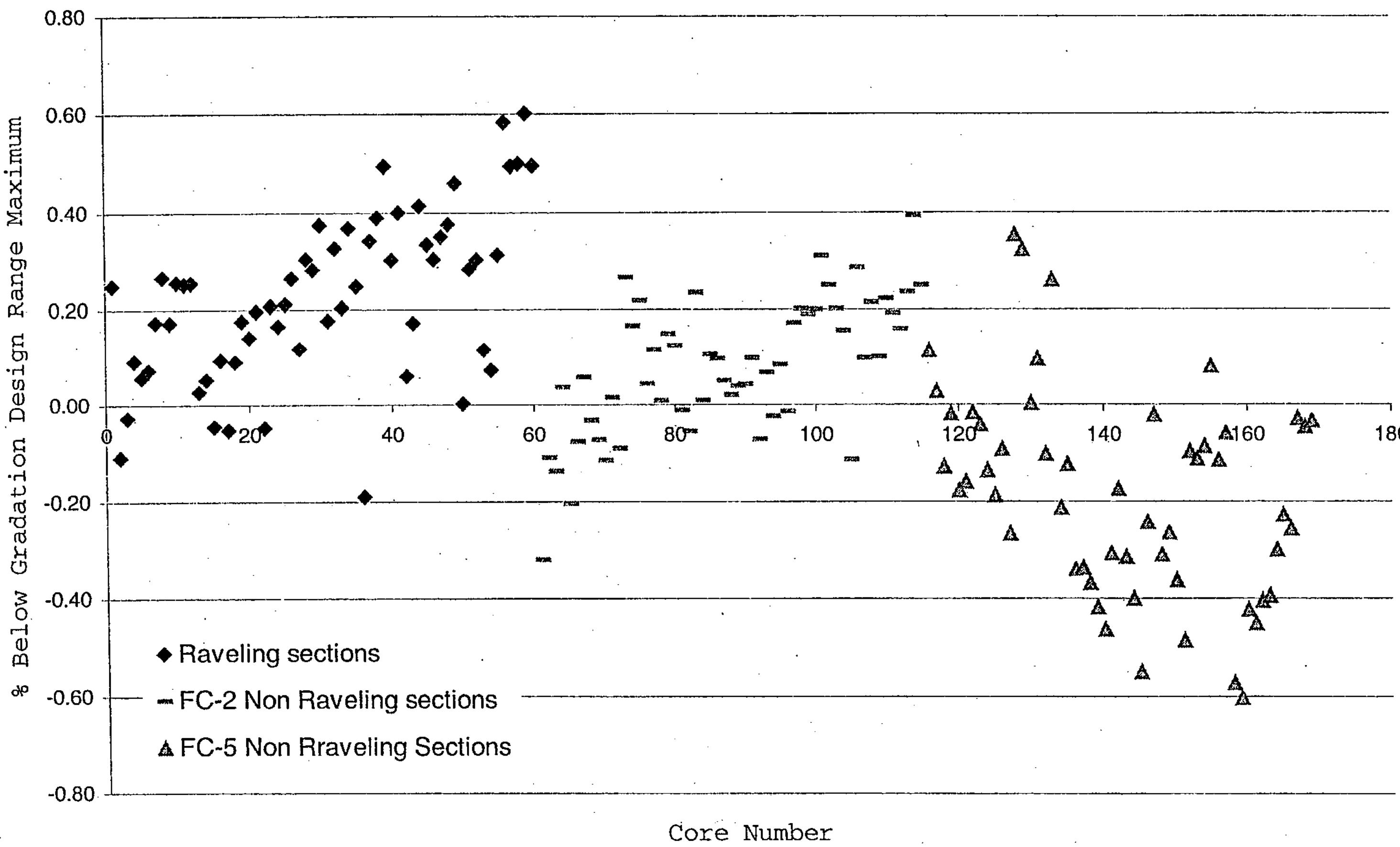

Figure 37. % below Gradation Design Range Maximum

5.2 Limitations

One should be aware of the important limitations inherent to this research study. Following is a discussion of such limitations and their possible impact on the results and the validity of the conclusions drawn.

- Sample size:

The number of raveling projects used in this research is down to only three from an initial selection set of twenty-five due to the obstacles encountered in the data collection process. For the very purpose of this study, historical data such as construction date and initial AC content was necessary. Florida DOT's Construction Quality Reporting System (CQR) is the database where this information is stored. For various reasons discussed previously, many of the selected projects were not included in CQR and attempts to retrieve the data through other means were unsuccessful.

It is understandable that many roads are resurfaced every year and this is a lot of information to keep track of and electronic storage space becomes scarce very rapidly. Some of the data must be destroyed periodically in order to make room for new projects.

Because of the small sample size, the conclusions drawn here may not be a good representation of the very large population of Florida highways.

- Lack of representation of other Florida districts:

Due to difficulties encountered in the collection of the data, it was impossible to retrieve information dating from the initial construction of many projects.

It was easier to collect information regarding projects within FDOT District V, which was sponsoring the study. As a result, an overwhelming proportion (eight out of nine) of the projects was from this jurisdiction.

The lack of variety hinders the accuracy of the results obtained in that they are not a good representation of Florida highways in all districts.

- Heterogeneous nature of asphalt concrete and gradation variations within the mix:

Asphalt concrete, as seen before, is a heterogeneous mixture. As a result, gradation variations, although hopefully minimal, are expected to occur within the friction course.

The HMA mix is carefully mixed before it is laid. However, due to the large amounts in which it is produced, it is possible that the various phases are not thoroughly mixed and that the proportions of material vary from location to location within the mix and the friction course.

Although the overall relative proportions of asphalt cement and aggregate may be within mix design ranges, the numbers recorded for initial construction and those obtained from the testing performed on core samples may not be indicative of the whole road sections tested.

- Subjectivity of PCS information:

The data compiled in PCS is gathered by FDOT employees as they drive along the road section under investigation. Its occurrence is estimated visually by experienced technicians. However, this information can be subjective due to human error and differences in perception particularly with regard to information such as the extent of raveling and the year when raveling first occurred.

- Inaccuracy of dates:

For each raveling project, the year when raveling first occurred is taken as the year when the distress was first reported in PCS. As a result, it is not possible to get a more accurate idea of the age of the friction course at the initiation of deterioration. The assumption in these calculations is that raveling first occurred at the beginning of the year.

- Inaccuracy of initial AC content:

In four cases out of a total of nine, the initial AC Content of the projects investigated was determined using a flowmeter. In all such cases, the values obtained were very close to the target (design). As discussed previously, these data may not be very reliable.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following is a summary of the conclusions drawn from the study:

1. There is a strong correlation between the occurrence of raveling and decrease in asphalt cement content.
2. The percent AC deficiency in raveling projects is greater than that in non-raveling projects.
3. AC loss does occur over the life of the pavement.
4. Initial AC content deficiency can accelerate raveling and reduce the effective life of the pavement.
5. Raveling seems to occur in FC-2 pavements when the asphalt cement deficiency reaches approximately 16% of the target value, regardless of time.
6. Equations relating % AC loss and time when considering both NCAT and flowmeter measurements:

   % AC loss = .0103 Friction Course Age (days) + 1.342*

   Annual % AC loss during the initial years of service life: *5.1%*.

7. Overall, the annual loss of asphalt cement is within the range of 5% and 6% during the initial years of service life.

8. FC-2 mixtures tend to have a lower percentage of fines.

9. For FC-2 mixtures, the occurrence of raveling is independent from the fine content.

10. The data used in this study is not sufficient to validate Sontowski's idea that a high fine content could yield to premature raveling.

11. For the projects used in this study, the % excess fines does not seem to have an impact on the occurrence of raveling.

12. FC-5 with a high fine content in this study does not ravel during the first 1.5 year of its life.

6.2 Recommendations and further studies

Due to the limitations discussed previously, this study is by no means a complete representation of all Florida OGFC highways. Conclusions were drawn based on the limited amount of information retrieved during the search of FDOT electronic databases.

Further research is needed to uphold the assumptions made here and to gather data that is more representative of the state's highway system. Based on the experience of this research project, we can make the following recommendations for further studies:

1. A larger study could be conducted over several years. Construction information, such as paving date and initial AC content, would be gathered for many projects throughout the state by all FDOT districts. This information would be stored in a special database set up for this purpose.

   This would reduce the problem of gathering initial construction data and eliminate the need for removing projects with no retrievable data and selecting new ones. It would also ensure that all districts would be fairly represented and that the results would be a good representation of OGFC roads throughout the state of Florida.

2. Due to the difficulties encountered over the course of this project, it is recommended to conduct a new long-

term study where AC content would be monitored over time in order to quantify the AC loss that occurs over time.

3. As mentioned earlier, FC-5 is a very new type of friction course and road sections using this OGFC have not started disintegrating. As FC-5 road sections age, they will begin to show signs of deterioration as they approach their service life. A similar study should be conducted on these friction courses once they have raveled to allow better understanding of the mix and the preparation of guidelines for acceptance.

4. The use of the NCAT Extraction (Ignition Method) is recommended over the flowmeter method to determine AC Content anytime is it convenient and possible. Of course, the drawback to the Ignition method is that it is more time consuming, but it seems to yield better and more accurate results.

Appendix A

COMPLETED DATA COLLECTION SHEETS

(BOTH VERSIONS)

DATA FOR DEPARTMENT OF TRANSPORTATION PROJECT 1620799

Raveling Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information										Core Information					
	Project Number										Printout		Field Visit												Sub Lot % AC Information						Lot % AC Information									
District	County / Section	Road Section	Fin Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	FC Thickness (in)	%AC	% Current AC Deficiency
5	70225	3418	2423061	9	95	FC-2	1996	2	1–5	L2	5.332	13.797	13.997	13.633	2811+95.2 ft	2803+29.28 ft	1	10/12/94	10/18/94	10/12/94	2811+65. ft	2756+50. ft	5862 ft	52.250	7.060	7.090	7.070	7.180			7.10	7.1	QA94-6830	Y	10/21/99	1834	13.987	0.5	5.29	25.49
																																			10/21/99	1834		0.4	6.53	8.03
																																			10/21/99	1834		0.4	5.4	23.94
																																			10/21/99	1834		0.4	5.66	20.28
																																			10/21/99	1834		0.5	6.11	13.94
																																			10/21/99	1834		0.4	5.55	21.83
																																			Average AC%				5.76	18.92
				"	"	"	"	"	"	L2	"	"	13.561	13.499	2799+49.12 ft	2796+25.46 ft	1	10/12/94	10/18/94	10/12/94	2811+65. ft	2756+50. ft	5862 ft	52.250	7.060	7.090	7.070	7.180			7.10	7.1	QA94-6830	Y	10/21/99	1834	13.551	0.7	5.62	20.85
																																			10/21/99	1834		0.7	5.37	24.37
																																			10/21/99	1834		0.7	5.48	22.82
																																			10/21/99	1834		0.8	5.68	20.00
																																			10/21/99	1834		0.7	5.63	20.70
																																			10/21/99	1834		0.6	5.52	22.25
																																			Average AC%				5.55	21.83
				"	"	"	"	"	"	L2	"	"	12.210	11.988	2728+15.84 ft	2716+43.68 ft	1	10/12/94	10/18/94	10/13/94	2756+50. ft	2706+50. ft	5000 ft	40.950	7.060	7.090	7.070	7.180			7.10	7.1	QA94-6830	Y	10/21/99	1833	12.200	0.5	6.15	13.38
																																			10/21/99	1833		0.5	5.61	20.99
																																			10/21/99	1833		0.4	4.67	34.23
																																			10/21/99	1833		0.5	5.63	20.70
																																			10/21/99	1833		0.5	6.34	10.70
																																			10/21/99	1833		0.6	6.04	14.93
																																			Average AC%				5.74	19.15
				"	"	"	"	"	"	L2	"	"	11.841	10.760	2708+69.23 ft	2651+62.48 ft	1	10/12/94	10/18/94	10/13/94	2706+50 ft	2656+50. ft	5000 ft	40.950	7.060	7.090	7.070	7.180			7.10	7.1	QA94-6830	Y	10/21/99	1833	11.831	0.2	3.9	45.07
																																			10/21/99	1833		0.5	5.88	17.18
																																			10/21/99	1833		0.7	5.42	23.66
																																			10/21/99	1833		0.6	5.76	18.87
																																			10/21/99	1833		0.3	4.54	36.06
																																			10/21/99	1833		0.5	5.58	21.41
																																			Average AC%				5.18	27.04

				"	"	"	"	"	"	L1	"	"	13.020	12.906	2770+92.64 ft	2767+92.64 ft	1	10/12/94	10/18/94	10/17/94	2768+00. ft	2767+79.01 ft	2473 ft	42.110	7.060	7.090	7.070	7.180	X	X	7.10	7.1	QA94-6830	Y	10/21/99	1829	13.010	0.5	4.67	34.23
																													X	X					10/21/99	1829		0.7	5.43	23.52
																													X	X					10/21/99	1829		0.7	5.71	19.58
																													X	X					10/21/99	1829		0.7	5.58	21.41
																													X	X					10/21/99	1829		0.7	5.14	27.61
																													X	X					10/21/99	1829		0.7	4.94	30.42
																																			Average AC%				5.25	26.13

Raveling Section Information

District	Project Number: County / Section	Project Number: Road Section	Project Number: Fin Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	Printout: M.P. From	Printout: M.P. To	Field Visit: M.P. From	Field Visit: M.P. To	Field Visit: Sta. From	Field Visit: Sta. To
5	70030	3503	2376031	5	1	FC-2	1997	0	6--25	L2	8.840	17.528	11.419	11.419	183+76.596 m	183+76.596 m
				"	"	"	1997	"	6--25	L1	"	"	13.961	13.961	224+67.437 m	224+67.437 m
				"	"	"	1997	"	6--25	L1	"	"	13.948	13.948	224+46.516 m	224+46.516 m
				"	"	"	1997	"	6--25	R1	"	"	17.547	17.547	282+38.387 m	282+38.387 m
				"	"	"	1997	"	6--25	R1	"	"	17.560	17.560	282+59.308 m	282+59.308 m

Plant Lot Information / **Test Section Selection (List each day's operation in separate row)**

Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)
1	10/26/98	11/6/98	11/6/98	142+26 m	187+00 m	4474 m	55.200
1	10/26/98	11/6/98	10/26/98	214+00 m	282+09 m	6809 m	68.080
1	10/26/98	11/6/98	10/26/98	214+00 m	282+09 m	6810 m	68.080
2	11/7/98	11/12/98	11/12/98	202+00 m	282+09 m	8009 m	49.680
2	11/7/98	11/12/98	11/12/98	202+00 m	282+09 m	8009 m	49.680

Asphalt Content Information

Sub Lot % AC Information: Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Lot % AC Information: Av. Lot % AC	Target % AC	Mix Design	GTR Used ?
7.480	7.340	6.940	6.740			7.125	7.1	QA96-7899B	Y
7.480	7.340	6.940	6.740			7.125	7.1	QA96-7899B	Y
7.480	7.340	6.940	6.740			7.125	7.1	QA96-7899B	Y
6.940	7.250	6.920	7.260	7.000		7.074	7.1	QA96-7899B	Y
6.940	7.250	6.920	7.260	7.000		7.074	7.1	QA96-7899B	Y

Core Information

Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
02/10/99	94	183+76.596 m	2.95	6.06	14.65
02/10/99	105	224+67.437 m	3.8	4.75	33.10
02/10/99	105	224+46.516 m	3.1	4.48	36.90
02/10/99	88	282+38.387 m	2.9	6.05	14.79
02/10/99	88	282+59.308 m	3.6	6.18	12.96
Average AC%				**5.50**	**22.48**

Raveling Section Information / Plant Lot Information / Test Section Selection / Asphalt Content Information

District	Project Number: County / Section	Project Number: Road Section	Project Number: Fin Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	Printout: M.P. From	Printout: M.P. To	Field Visit: M.P. From	Field Visit: M.P. To	Field Visit: Sta. From	Field Visit: Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?
5	18130	3408	2426251	93	75	FC-2	1997	2	1--5	L3	21.73	28.997	28.3402	28.3344	1496+31.75 ft	1496+01.12 ft	2	2/15/95	2/16/95	2/16/95	1377+00 ft	1530+98.88 ft	12834 ft	52.229	6.500	6.500					6.500	6.5	QA94-6862	Y
				"	"	"	"	"	"	L3	"	"	28.2200	28.1990	1489+97.09 ft	1488+86.21 ft	2	2/15/95	2/16/95	2/16/95	1377+00 ft	1530+98.88 ft	12835 ft	52.229	6.500	6.500					6.500	6.5	QA94-6862	Y
				"	"	"	"	"	"	L3	"	"	27.2106	27.1962	1436+67.46 ft	1435+91.43 ft	2	2/15/95	2/16/95	2/16/95	1377+00 ft	1530+98.88 ft	12836 ft	52.229	6.500	6.500					6.500	6.5	QA94-6862	Y
				"	"	"	"	"	"	L3	"	"	27.0654	27.0412	1429+00.80 ft	1427+73.03 ft	2	2/15/95	2/16/95	2/16/95	1377+00 ft	1530+98.88 ft	12837 ft	52.229	6.500	6.500					6.500	6.5	QA94-6862	Y

Core Information

Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
10/25/99	1709	28.330		5.12	21.23
10/25/99	1709			4.88	24.92
10/25/99	1709			5.11	21.38
10/25/99	1709			4.64	28.62
10/25/99	1709			5.08	21.85
10/25/99	1709			5.54	14.77
Average AC%				5.06	22.13
10/25/99	1709	28.210	0.4	4.09	37.08
10/25/99	1709		0.6	4.36	32.92
10/25/99	1709		0.5	4.03	38.00
10/25/99	1709		0.6	4.59	29.38
10/25/99	1709		0.6	4.39	32.46
10/25/99	1709		0.4	4.21	35.23
Average AC%				4.28	34.18
10/25/99	1709	27.200		3.57	45.08
10/25/99	1709			5.2	20.00
10/25/99	1709			4.86	25.23
10/25/99	1709		0.5	5.39	17.08
10/25/99	1709		0.35	5.5	15.38
10/25/99	1709		0.5	5.03	22.62
Average AC%				4.93	24.23
10/25/99	1709	27.055	0.5	4.26	34.46
10/25/99	1709		0.6	5.66	12.92
10/25/99	1709		0.5	4.91	24.46
10/25/99	1709		0.5	4.95	23.85
10/25/99	1709		0.5	5.33	18.00
10/25/99	1709		0.4	4.41	32.15
Average AC%				4.92	24.31

				"	"	"	"	"	"	L3	"	"	24.7202	24.6192	1305+18.15 ft	1299+84.87 ft	3	4/5/95	4/10/95	4/10/95	1248+62 ft	1377+00 ft	12838 ft	63.175	6.500	6.400					6.450	6.5	QA94-6862	Y	10/25/99	1655	24.710	0.4	5.18	20.31
																																			10/25/99	1655		0.6	4.69	27.85
																																			10/25/99	1655		0.8	5.62	13.54
																																			10/25/99	1655		0.6	5.26	19.08
																																			10/25/99	1655		0.6	5.76	11.38
																																			10/25/99	1655		0.6	5.01	22.92
																																			Average AC%				**5.25**	**19.18**

Non Raveling FC-2 Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information										Core Information					
	Project Number										Printout		Field Visit												Sub Lot % AC Information						Lot % AC Information									
District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
7	08150	3404	2584821	93	75	FC-2				R2	0.000	3.846	0	2.642	0 ft	139+51 ft	1	7/19/94	7/28/94	7/26/94	0 ft	139+51 ft	13951 ft	43.3	7.1	7.14	7.18				7.14	7.1	QA94-6553	Y	10/25/99	1914	0.000	0.3	6.89	2.96
																																			10/25/99	1914		0.5	7.15	-0.70
																																			10/25/99	1914		0.3	6.52	8.17
																																			10/25/99	1914		0.4	6.75	4.93
																																			10/25/99	1914		0.5	7.1	0.00
																																			10/25/99	1914		0.6	6.83	3.80
																																			Average AC%				6.87	3.19
				"	"	"				R2	"	"	0	2.642	0 ft	139+51 ft	1	7/19/94	7/28/94	7/26/94	0 ft	139+51 ft	13951 ft	43.3	7.1	7.14	7.18				7.14	7.1	QA94-6553	Y	10/25/99	1914	2.000	0.6	6.4	9.86
																																			10/25/99	1914		0.5	6.69	5.77
																																			10/25/99	1914		0.5	6.3	11.27
																																			10/25/99	1914		0.5	6.09	14.23
																																			10/25/99	1914		0.4	6.25	11.97
																																			10/25/99	1914		0.4	5.98	15.77
																																			Average AC%				6.29	11.48
				"	"	"				R2	"	"	2.64	3.84	139+51 ft	202+74 ft	1	7/19/94	7/28/94	7/27/94	139+51 ft	202+74 ft	6323ft	41.2	7.1	7.14	7.18				7.14	7.1	QA94-6553	Y	10/25/99	1913	3.800	0.7	5.43	23.52
																																			10/25/99	1913		0.9	6.26	11.83
																																			10/25/99	1913		1.0	7.05	0.70
																																			10/25/99	1913		0.8	7.35	-3.52
																																			10/25/99	1913		0.8	6.26	11.83
																																			10/25/99	1913		1.0	6.76	4.79
																																			Average AC%				6.52	8.19

Non Raveling FC-2 Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information										Core Information					
	Project Number										Printout		Field Visit												Sub Lot % AC Information						Lot % AC Information									
District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
5	92030	3510	2397391	500	192	FC-2				R2	9.948	12.832	9.948	12.627	160+09 m	203+20 m	1	8/10/98	8/11/98	8/10/98	160+09 m	203+20 m	4311 m	51.15	7.36	6.78					7.07	7.1	QA94-6674	Y	10/18/99	433	9.950	0.4	6.2	12.68
																																			10/18/99	433		0.5	6.87	3.24
																																			10/18/99	433		0.4	6.41	9.72
																																			10/18/99	433		0.5	6.99	1.55
																																			10/18/99	433		1.0	7.13	-0.42
																																			10/18/99	433		0.8	6.89	2.96
																																			Average AC%				**6.75**	**4.95**
				"	"	"				R2	"	"	9.948	12.627	160+09 m	203+20 m	1	8/10/98	8/11/98	8/10/98	160+09 m	203+20 m	4311 m	51.15	7.36	6.78					7.07	7.1	QA94-6674	Y	10/18/99	433	11.000	0.5	5.82	18.03
																																			10/18/99	433		0.5	5.78	18.59
																																			10/18/99	433		0.4	6.29	11.41
																																			10/18/99	433			6.65	6.34
																																			10/18/99	433			6.01	15.35
																																			10/18/99	433			6.16	13.24
																																			Average AC%				**6.12**	**13.83**
				"	"	"				R2	"	"	12.627	12.832	203+20 m	206+50 m	1	8/10/98	8/11/98	8/11/98	203+20 m	206+50 m	330 m	48.15	7.36	6.78					7.07	7.1	QA94-6674	Y	10/18/99	432	12.520	0.5	6.11	13.94
																																			10/18/99	432		0.2	6.15	13.38
																																			10/18/99	432		0.3	5.96	16.06
																																			10/18/99	432		0.5	6.05	14.79
																																			10/18/99	432		0.5	6.27	11.69
																																			10/18/99	432		0.4	5.45	23.24
																																			Average AC%				**6.00**	**15.52**

Non Raveling FC-2 Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information: Sub Lot % AC Information						Lot % AC Information				Core Information					
	Project Number			-							Printout		Field Visit																											
District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
5	79100	3532	2409391	40		FC-2				R1	0.015	6.543	0.015	6.543	0+79.08 ft	345+47.04 ft	1	11/21/95	12/4/95	11/27/95	21+73.00	89+58.00 m	13215 m	50.9	7.12	7.13	No Test	No Test			7.125	7.1	QA93-6994	Y	10/15/99	1413	3.000	0.7	6.2	12.68
																																			10/15/99	1413		0.4	6.32	10.99
																																			10/15/99	1413		0.3	5.25	26.06
																																			10/15/99	1413		0.6	5.76	18.87
																																			10/15/99	1413		0.4	5.57	21.55
																																			10/15/99	1413		0.6	5.79	18.45
																																			10/15/99	1413		0.6	5.9	16.90
																																			Average AC%				5.83	17.93
				"	"	"				R1	"	"	0.015	6.543	0+79.08 ft	345+47.04 ft	1	11/21/95	12/4/95	11/28/95	89+58.00 m	0+78.00 m	8880 m	49.9	7.12	7.13	No Test	No Test			7.125	7.1	QA93-6994	Y	10/15/99	1412	1.000	0.5	5.76	18.87
																																			10/15/99	1412		0.4	5.59	21.27
																																			10/15/99	1412		0.4	5.88	17.18
																																			10/15/99	1412		0.5	6.04	14.93
																																			10/15/99	1412		0.5	6.11	13.94
																																			10/15/99	1412		0.6	6.2	12.68
																																			Average AC%				5.93	16.48
				"	"	"				L1	"	"	0.015	6.543	0+79.08 ft	345+47.04 ft	1	11/21/95	12/4/95	12/1/95	36+69.00 m	88+75.00 m	15206 m	46.5	7.12	7.13	No Test	No Test			7.125	7.1	QA93-6994	Y	10/15/99	1408	3.300	0.5	6.22	12.39
																																			10/15/99	1408		0.5	6.25	11.97
																																			10/15/99	1408		0.4	5.95	16.20
																																			10/15/99	1408		0.4	6.18	12.96
																																			10/15/99	1408		0.5	6.59	7.18
																																			10/15/99	1408		0.5	6.45	9.15
																																			Average AC%				6.27	11.64

Non Raveling FC-5 Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information										Core Information					
	Project Number										Printout		Field Visit												Sub Lot % AC Information						Lot % AC Information									
District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
5	70006	3504	2376331	407		FC-5				R1	0.080	6.211	0.08	6.211	10+65.067m	109+30.22 m	1	4/22/98	5/1/98	4/23/98	70+43 m	99+80 m	3204 m	68.84	7.64	7.06	7.490	7.330			7.38	7.3	QA98-8680A	Y	10/21/99	543	4.100	0.8	6.34	13.15
																																			10/21/99	543		0.6	6.06	16.99
																																			10/21/99	543		0.6	6.87	5.89
																																			10/21/99	543		0.7	6.64	9.04
																																			10/21/99	543		0.6	6.43	11.92
																																			10/21/99	543		0.7	6.97	4.52
																																			Average AC%				**6.55**	**10.25**
				"	"	"				R1	"	"	0.08	6.211	10+65.067m	109+30.22 m	1	4/22/98	5/1/98	4/23/98	70+43 m	99+80 m	521 m	68.84	7.64	7.06	7.490	7.330			7.38	7.3	QA98-8680A	Y	10/21/99	543	5.000	0.8	6.31	13.56
																																			10/21/99	543		0.7	6.53	10.55
																																			10/21/99	543		0.6	6.27	14.11
																																			10/21/99	543		0.7	6.61	9.45
																																			10/21/99	543		0.6	6.19	15.21
																																			10/21/99	543		0.5	6.39	12.47
																																			Average AC%				**6.38**	**12.56**
				"	"	"				R1	"	"	0.08	6.211	10+65.067m	109+30.22 m	1	4/22/98	5/1/98	4/24/98	99+80 m	109+33 m	953 m	80.06	7.64	7.06	7.490	7.330			7.38	7.3	QA98-8680A	Y	10/21/99	542	5.900	1.0	6.7	8.22
																																			10/21/99	542		0.8	6.77	7.26
																																			10/21/99	542		0.9	6.59	9.73
																																			10/21/99	542		1.0	6.61	9.45
																																			10/21/99	542		0.3	6.48	11.23
																																			10/21/99	542		0.4	6.01	17.67
																																			Average AC%				**6.53**	**10.59**

Non Raveling FC-5 Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information										Core Information					
	Project Number										Printout		Field Visit												Sub Lot % AC Information						Lot % AC Information									
District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
5	73010	3523	2379521	5	1	FC-5				R2	0.000	4.938	0.000	0.392	0 m	6+47.00 m	1	10/14/98	10/20/98	10/15/98	0 m	6+47.00 m	647 m	69.92	7.03	6.8	6.91	7.35			7.0225	7.3	QA98-8860A	Y	10/20/99	370	0.300	0.5	6.3	14.38
																																			10/20/99	370		0.7	6.8	6.30
																																			10/20/99	370		1.0	7.6	-3.42
																																			10/20/99	370		0.8	7.8	-6.58
																																			10/20/99	370		0.9	7.3	0.55
																																			10/20/99	370		0.6	7.0	4.66
																																			Average AC%				7.1	2.6
				"	"	"				R2	"	"	0.392	3.326	6+47.00 m	54+90.00 m	1	10/14/98	10/20/98	10/16/98	6+47.00 m	54+90.00 m	4843 m	79.856	7.03	6.8	6.91	7.35			7.0225	7.3	QA98-8860A	Y	10/20/99	369	2.500	0.7	6.86	6.03
																																			10/20/99	369		0.8	7.68	-5.21
																																			10/20/99	369		1.0	6.96	4.66
																																			10/20/99	369		0.7	7.17	1.78
																																			10/20/99	369		0.9	8.01	-9.73
																																			10/20/99	369		0.7	7.52	-3.01
																																			Average AC%				7.37	-0.91
				"	"	"				R2	"	"	3.326	4.938	54+90.00 m	81+51.763 m	1	10/14/98	10/20/98	10/20/98	54+90.00 m	87+52.00 m	2662 m	82.064	7.03	6.8	6.91	7.35			7.0225	7.3	QA98-8860A	Y	10/20/99	365	4.000	0.8	7.44	-1.92
																																			10/20/99	365		1.0	6.95	4.79
																																			10/20/99	365		0.8	7.22	1.10
																																			10/20/99	365		0.6	7.56	-3.56
																																			10/20/99	365		1.0	7.28	0.27
																																			10/20/99	365		0.5	6.54	10.41
																																			Average AC%				7.17	1.85

Non Raveling FC-5 Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information										Core Information					
	Project Number										Printout		Field Visit												Sub Lot % AC Information						Lot % AC Information									
District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (years)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Sub Lot 6	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (Days)	Mile Post	C Thickness (in)	%AC	% Current AC Deficiency
5	36002	3503	2387491	200	301	FC-5				L2	0.000	4.91	3.753	3.626	60+39.5 m	58+35.0 m	2	9/30/98	10/9/98	10/1/98	60+39.5 m	58+35.0 m	204.5 m	72.22	7.52	6.8	7.2	7.07	7.05	No Test	7.128	7.3	QA98-88758	Y	10/19/99	383	3.690	0.6	7.42	-1.64
																																			10/19/99	383		0.5	7.13	2.33
																																			10/19/99	383		0.6	7.62	-4.38
																																			10/19/99	383		0.9	7.69	-5.34
																																			10/19/99	383		0.7	7.39	-1.23
																																			10/19/99	383		0.5	7.29	0.14
																																			Average AC%				**7.42**	**-1.69**
				"	"	"				L2	"	"	3.626	.16656	58+35.0 m	2+68.0 m	2	9/30/98	10/9/98	10/2/98	58+35.0 m	2+68.0 m	5567 m	74.704	7.52	6.8	7.2	7.07	7.05	No Test	7.128	7.3	QA98-88758	Y	10/19/99	383	2.990	0.5	6.88	5.75
																																			10/19/99	383		0.6	6.73	7.81
																																			10/19/99	383		0.7	6.85	6.16
																																			10/19/99	383		0.9	7.01	3.97
																																			10/19/99	383		0.6	6.51	10.82
																																			10/19/99	383		0.7	7.05	3.42
																																			Average AC%				**6.84**	**6.32**
				"	"	"				L2	"	"	3.626	.16656	58+35.0 m	2+68.0 m	2	9/30/98	10/9/98	10/2/98	58+35.0 m	2+68.0 m	5567 m	74.704	7.52	6.8	7.2	7.07	7.05	No Test	7.128	7.3	QA98-88758	Y	10/19/99	382	1.500	0.4	6.49	11.10
																																			10/19/99	382		0.5	7.05	3.42
																																			10/19/99	382		0.4	6.74	7.67
																																			10/19/99	382		0.6	6.41	12.19
																																			10/19/99	382		0.4	6.59	9.73
																																			10/19/99	382		0.6	6.86	6.03
																																			Average AC%				**6.69**	**8.36**

DATA FOR DEPARTMENT OF TRANSPORTATION PROJECT 1620799

Raveling Section Information																	Plant Lot Information			Test Section Selection (List each day's operation in separate row)					Asphalt Content Information									Core Information				
	Project Number										Printout		Field Visit												Sub Lot % AC Information					Lot % AC Information								
District	County / Section	Road Section	Fin Project #	SR #	US #	FC type (FC-2, FC-5)	Last yr w/o raveling	Age at start of raveling (yrs)	% Rav. in '98	Lane	M.P. From	M.P. To	M.P. From	M.P. To	Sta. From	Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (days)	Mile Post	FC Thickness (in)	%AC
5	70225	3418	2423061	9	95	FC-2	1996	2	1--5	L2	5.332	13.797	13.997	13.633	2811+95.2 ft	2803+29.28 ft	1	10/12/94	10/18/94	10/12/94	2811+65. ft	2756+50. ft	5862 ft	52.250	7.06	7.09	7.070	7.180		7.10	7.1	QA94-6830	Y	10/21/99	1834	13.987		5.76
				"	"	"	"	2	"	L2	"	"	13.561	13.499	2799+49.12 ft	2796+25.46 ft	1	10/12/94	10/18/94	10/12/94	2811+65. ft	2756+50. ft	5862 ft	52.250	7.06	7.09	7.070	7.180		7.10	7.1	QA94-6830	Y	10/21/99	1834	13.551		5.55
				"	"	"	"	2	"	L2	"	"	12.210	11.988	2728+15.84 ft	2716+43.68 ft	1	10/12/94	10/18/94	10/13/94	2756+50. ft	2706+50. ft	5000 ft	40.950	7.06	7.09	7.070	7.180		7.10	7.1	QA94-6830	Y	10/21/99	1833	12.200		5.74
				"	"	"	"	2	"	L2	"	"	11.841	10.760	2708+69.23 ft	2651+62.48 ft	1	10/12/94	10/18/94	10/13/94	2706+50 ft	2656+50. ft	5000 ft	40.950	7.06	7.09	7.070	7.180		7.10	7.1	QA94-6830	Y	10/21/99	1833	11.831		5.18
				"	"	"	"	2	"	L1	"	"	13.020	12.906	2770+92.64 ft	2767+92.64 ft	1	10/12/94	10/18/94	10/17/94	2768+00. ft	2767+79.01 ft	2473 ft	42.110	7.06	7.09	7.070	7.180		7.10	7.1	QA94-6830	Y	10/21/99	1829	13.010		5.25
5	70030	3503	2376031	5	1	FC-2	1998	0	6--25	L2	8.840	17.528	11.419	11.419	183+76.596 m	183+76.596 m	1	10/26/98	11/06/98	11/06/98	142+26 m	187+00 m	4474 m	55.200	7.48	7.34	6.940	6.740		7.13	7.1	QA96-78998	Y	02/10/99	94	183+76.596 m	2.95	6.06
				"	"	"	"	0	6--25	L1	"	"	13.961	13.961	224+67.437 m	224+67.437 m	1	10/26/98	11/06/98	10/26/98	214+00 m	282+09 m	6809 m	68.080	7.48	7.34	6.940	6.740		7.13	7.1	QA96-78998	Y	02/10/99	105	224+67.437 m	3.8	4.75
				"	"	"	"	0	6--25	L1	"	"	13.948	13.948	224+46.516 m	224+46.516 m	1	10/26/98	11/06/98	10/26/98	214+00 m	282+09 m	6810 m	68.080	7.48	7.34	6.940	6.740		7.13	7.1	QA96-78998	Y	02/10/99	105	224+46.516 m	3.1	4.48
				"	"	"	"	0	6--25	R1	"	"	17.547	17.547	282+38.387 m	282+38.387 m	2	11/07/98	11/12/98	11/12/98	202+00 m	282+09 m	8009 m	49.680	6.94	7.25	6.920	7.260	7.000	7.07	7.1	QA96-78998	Y	02/10/99	88	282+38.387 m	2.9	6.05
				"	"	"	"	0	6--25	R1	"	"	17.560	17.560	282+59.308 m	282+59.308 m	2	11/07/98	11/12/98	11/12/98	202+00 m	282+09 m	8009 m	49.680	6.94	7.25	6.920	7.260	7.000	7.07	7.1	QA96-78998	Y	02/10/99	88	282+59.308 m	3.6	6.18
5	18130	3408	2426251	93	75	FC-2	1997	2	1--5	L3	21.73	28.997	28.3402	28.3344	1496+31.75 ft	1496+01.12 ft	2	02/15/95	02/16/95	02/16/95	1377+00 ft	1530+98.88 ft	12834 ft	52.229	6.50	6.50				6.50	6.5	QA94-6862	Y	10/25/99	1709	28.330		5.06
				"	"	"	"	2	"	L3	"	"	28.2200	28.1990	1489+97.09 ft	1488+86.21 ft	2	02/15/95	02/16/95	02/16/95	1377+00 ft	1530+98.88 ft	12835 ft	52.229	6.50	6.50				6.50	6.5	QA94-6862	Y	10/25/99	1709	28.210		4.28
				"	"	"	"	2	"	L3	"	"	27.2106	27.1962	1436+67.46 ft	1435+91.43 ft	2	02/15/95	02/16/95	02/16/95	1377+00 ft	1530+98.88 ft	12836 ft	52.229	6.50	6.50				6.50	6.5	QA94-6862	Y	10/25/99	1709	27.200		4.93
				"	"	"	"	2	"	L3	"	"	27.0654	27.0412	1429+00.80 ft	1427+73.03 ft	2	02/15/95	02/16/95	02/16/95	1377+00 ft	1530+98.88 ft	12837 ft	52.229	6.50	6.50				6.50	6.5	QA94-6862	Y	10/25/99	1709	27.055		4.92
				"	"	"	"	2	"	L3	"	"	24.7202	24.6192	1305+18.15 ft	1299+84.87 ft	3	04/05/95	04/10/95	04/10/95	1248+62 ft	1377+00 ft	12838 ft	63.175	6.50	6.40				6.45	6.5	QA94-6862	Y	10/25/99	1655	24.710		5.25

District	County / Section	Road Section	Fin. Project #	SR #	US #	FC type (FC-2, FC-5)	Lane	Printout M.P. From	Printout M.P. To	Field Visit M.P. From	Field Visit M.P. To	Field Visit Sta. From	Field Visit Sta. To	Plant Lot Number	Start Date	End Date	Paving Date	Sta. From	Sta. To	Length	Spread Rate (psy)	Sub Lot 1	Sub Lot 2	Sub Lot 3	Sub Lot 4	Sub Lot 5	Av. Lot % AC	Target % AC	Mix Design	GTR Used ?	Coring Date	Core Age (days)	Mile Post	FC Thickness (in)	%AC
Non-raveling FC-2 Section Information																																			
7	08150	3404	2584821	93	75	FC-2	R2	0.000	3.846	0	2.642	0 ft	139+51 ft	1	7/19/94	7/28/94	07/26/94	0 ft	139+51 ft	13951 ft	43.3	7.1	7.14	7.18			7.14	7.1	QA94-6553	Y	10/25/99	1914	0.000		6.87
				"	"	"	R2	"	"	0	2.642	0 ft	139+51 ft	1	7/19/94	7/28/94	07/26/94	0 ft	139+51 ft	13951 ft	43.3	7.1	7.14	7.18			7.14	7.1	QA94-6553	Y	10/25/99	1914	2.000		6.29
				"	"	"	R2	"	"	2.64	3.84	139+51 ft	202+74 ft	1	7/19/94	7/28/94	07/27/94	139+51 ft	202+74 ft	6323ft	41.2	7.1	7.14	7.18			7.14	7.1	QA94-6553	Y	10/25/99	1913	3.800		6.52
5	92030	3510	2397391	500	192	FC-2	R2	9.948	12.832	9.948	12.627	160+09 m	203+20 m	1	8/10/98	8/11/98	08/10/98	160+09 m	203+20 m	4311 m	51.15	7.36	6.78				7.07	7.1	QA94-6674	Y	10/18/99	433	9.950		6.75
				"	"	"	R2	"	"	9.948	12.627	160+09 m	203+20 m	1	8/10/98	8/11/98	08/10/98	160+09 m	203+20 m	4311 m	51.15	7.36	6.78				7.07	7.1	QA94-6674	Y	10/18/99	433	11.000		6.12
				"	"	"	R2	"	"	12.627	12.832	203+20 m	206+50 m	1	8/10/98	8/11/98	08/11/98	203+20 m	206+50 m	330 m	48.15	7.36	6.78				7.07	7.1	QA94-6674	Y	10/18/99	432	12.520		6.00
5	79100	3532	2409391	40		FC-2	R1	0.015	6.543	0.015	6.543	0+79.08 ft	345+47.04 ft	1	11/21/95	12/4/95	11/27/95	221+73.00 m	89+58.00 m	13215 m	50.9	7.12	7.13	No Test	No Test		7.13	7.1	QA93-6994	Y	10/15/99	1413	3.000		5.83
				"	"	"	R1	"	"	0.015	6.543	0+79.08 ft	345+47.04 ft	1	11/21/95	12/4/95	11/28/95	89+58.00 m	0+78.00 m	8880 m	49.9	7.12	7.13	No Test	No Test		7.13	7.1	QA93-6994	Y	10/15/99	1412	1.000		5.93
				"	"	"	L1	"	"	0.015	6.543	0+79.08 ft	345+47.04 ft	1	11/21/95	12/4/95	12/01/95	36+69.00 m	188+75.00 m	15206 m	46.5	7.12	7.13	No Test	No Test		7.13	7.1	QA93-6994	Y	10/15/99	1408	3.300		6.27
Non-raveling FC-5 Section Information																																			
5	70006	3504	2376331	407		FC-5	R1	0.080	6.211	0.08	6.211	10+65.067m	109+30.22 m	1	4/22/98	5/1/98	04/23/98	70+43 m	99+80 m	3204 m	68.84	7.64	7.06	7.490	7.330		7.38	7.3	QA98-8680A	Y	10/21/99	543	4.100		6.55
				"	"	"	R1	"	"	0.08	6.211	10+65.067m	109+30.22 m	1	4/22/98	5/1/98	04/23/98	70+43 m	99+80 m	521 m	68.84	7.64	7.06	7.490	7.330		7.38	7.3	QA98-8680A	Y	10/21/99	543	5.000		6.38
				"	"	"	R1	"	"	0.08	6.211	10+65.067m	109+30.22 m	1	4/22/98	5/1/98	04/24/98	99+80 m	109+33 m	953 m	80.06	7.64	7.06	7.490	7.330		7.38	7.3	QA98-8680A	Y	10/21/99	542	5.900		6.53
5	73010	3523	2379521	5	1	FC-5	R2	0.000	4.938	0.000	0.392	0 m	6+47.00 m	1	10/14/98	10/20/98	10/15/98	0 m	6+47.00 m	647 m	69.92	7.03	6.8	6.91	7.35		7.02	7.3	QA98-8860A	Y	10/20/99	370	0.300		7.10
				"	"	"	R2	"	"	0.392	3.326	6+47.00 m	54+90.00 m	1	10/14/98	10/20/98	10/16/98	6+47.00 m	54+90.00 m	4843 m	79.856	7.03	6.8	6.91	7.35		7.02	7.3	QA98-8860A	Y	10/20/99	369	2.500		7.37
				"	"	"	R2	"	"	3.326	4.938	54+90.00 m	81+51.763 m	1	10/14/98	10/20/98	10/20/98	54+90.00 m	87+52.00 m	2662 m	82.064	7.03	6.8	6.91	7.35		7.02	7.3	QA98-8860A	Y	10/20/99	365	4.000		7.17
5	36002	3503	2387491	200	301	FC-5	L2	0.000	4.91	3.753	3.626	60+39.5 m	58+35.0 m	2	9/30/98	10/9/98	10/01/98	60+39.5 m	58+35.0 m	204.5 m	72.22	7.52	6.8	7.2	7.07	7.05	7.13	7.3	QA98-8875B	Y	10/19/99	383	3.690		7.42
				"	"	"	L2	"	"	3.626	.16656	58+35.0 m	2+68.0 m	2	9/30/98	10/9/98	10/02/98	58+35.0 m	2+68.0 m	5567 m	74.704	7.52	6.8	7.2	7.07	7.05	7.13	7.3	QA98-8875B	Y	10/19/99	383	2.990		6.84
				"	"	"	L2	"	"	3.626	.16656	58+35.0 m	2+68.0 m	2	9/30/98	10/9/98	10/02/98	58+35.0 m	2+68.0 m	5567 m	74.704	7.52	6.8	7.2	7.07	7.05	7.13	7.3	QA98-8875B	Y	10/19/99	382	1.500		6.69

Appendix B

SPREADSHEET USED TO LOCATE RAVELING DEMARCATION LINE

Spreadsheet used to compute location of demarcation line in Figure 30

NB: N represents NCAT Extraction test
F represents Flowmeter test

Type	Test	Core #	Design %AC	Initial %AC	Current %AC	% Current Deficiency	% AC Loss	% Initial Deficiency	Weighted %Current Deficiency
FC-2 Rav	F	1	7.1	7.1	5.29	25.49	25.49	0.00	34.16
FC-2 Rav	F	2	7.1	7.1	6.53	8.03	8.03	0.00	10.76
FC-2 Rav	F	3	7.1	7.1	5.4	23.94	23.94	0.00	32.08
FC-2 Rav	F	4	7.1	7.1	5.66	20.28	20.28	0.00	27.18
FC-2 Rav	F	5	7.1	7.1	6.11	13.94	13.94	0.00	18.68
FC-2 Rav	F	6	7.1	7.1	5.55	21.83	21.83	0.00	29.25
FC-2 Rav	F	7	7.1	7.1	5.62	20.85	20.85	0.00	27.93
FC-2 Rav	F	8	7.1	7.1	5.37	24.37	24.37	0.00	32.65
FC-2 Rav	F	9	7.1	7.1	5.48	22.82	22.82	0.00	30.57
FC-2 Rav	F	10	7.1	7.1	5.68	20.00	20.00	0.00	26.80
FC-2 Rav	F	11	7.1	7.1	5.63	20.70	20.70	0.00	27.74
FC-2 Rav	F	12	7.1	7.1	5.52	22.25	22.25	0.00	29.82
FC-2 Rav	F	13	7.1	7.1	6.15	13.38	13.38	0.00	17.93
FC-2 Rav	F	14	7.1	7.1	5.61	20.99	20.99	0.00	28.12
FC-2 Rav	F	15	7.1	7.1	4.67	34.23	34.23	0.00	45.86
FC-2 Rav	F	16	7.1	7.1	5.63	20.70	20.70	0.00	27.74
FC-2 Rav	F	17	7.1	7.1	6.34	10.70	10.70	0.00	14.34
FC-2 Rav	F	18	7.1	7.1	6.04	14.93	14.93	0.00	20.01
FC-2 Rav	F	19	7.1	7.1	3.9	45.07	45.07	0.00	60.39
FC-2 Rav	F	20	7.1	7.1	5.88	17.18	17.18	0.00	23.03
FC-2 Rav	F	21	7.1	7.1	5.42	23.66	23.66	0.00	31.71
FC-2 Rav	F	22	7.1	7.1	5.76	18.87	18.87	0.00	25.29
FC-2 Rav	F	23	7.1	7.1	4.54	36.06	36.06	0.00	48.32
FC-2 Rav	F	24	7.1	7.1	5.58	21.41	21.41	0.00	28.69
FC-2 Rav	F	25	7.1	7.1	4.67	34.23	34.23	0.00	45.86
FC-2 Rav	F	26	7.1	7.1	5.43	23.52	23.52	0.00	31.52
FC-2 Rav	F	27	7.1	7.1	5.71	19.58	19.58	0.00	26.23
FC-2 Rav	F	28	7.1	7.1	5.58	21.41	21.41	0.00	28.69
FC-2 Rav	F	29	7.1	7.1	5.14	27.61	27.61	0.00	36.99
FC-2 Rav	F	30	7.1	7.1	4.94	30.42	30.42	0.00	40.77
FC-2 Rav	F	36	6.5	6.5	5.12	21.23	21.23	0.00	28.45
FC-2 Rav	F	37	6.5	6.5	4.88	24.92	24.92	0.00	33.40
FC-2 Rav	F	38	6.5	6.5	5.11	21.38	21.38	0.00	28.66
FC-2 Rav	F	39	6.5	6.5	4.64	28.62	28.62	0.00	38.34
FC-2 Rav	F	40	6.5	6.5	5.08	21.85	21.85	0.00	29.27
FC-2 Rav	F	41	6.5	6.5	5.54	14.77	14.77	0.00	19.79
FC-2 Rav	F	42	6.5	6.5	4.09	37.08	37.08	0.00	49.68
FC-2 Rav	F	43	6.5	6.5	4.36	32.92	32.92	0.00	44.12
FC-2 Rav	F	44	6.5	6.5	4.03	38.00	38.00	0.00	50.92
FC-2 Rav	F	45	6.5	6.5	4.59	29.38	29.38	0.00	39.38
FC-2 Rav	F	46	6.5	6.5	4.39	32.46	32.46	0.00	43.50
FC-2 Rav	F	47	6.5	6.5	4.21	35.23	35.23	0.00	47.21
FC-2 Rav	F	48	6.5	6.5	3.57	45.08	45.08	0.00	60.40

FC-2 Rav	F	49	6.5	6.5	5.2	20.00	20.00	0.00	26.80
FC-2 Rav	F	50	6.5	6.5	4.86	25.23	25.23	0.00	33.81
FC-2 Rav	F	51	6.5	6.5	5.39	17.08	17.08	0.00	22.88
FC-2 Rav	F	52	6.5	6.5	5.5	15.38	15.38	0.00	20.62
FC-2 Rav	F	53	6.5	6.5	5.03	22.62	22.62	0.00	30.30
FC-2 Rav	F	54	6.5	6.5	4.26	34.46	34.46	0.00	46.18
FC-2 Rav	F	55	6.5	6.5	5.66	12.92	12.92	0.00	17.32
FC-2 Rav	F	56	6.5	6.5	4.91	24.46	24.46	0.00	32.78
FC-2 Rav	F	57	6.5	6.5	4.95	23.85	23.85	0.00	31.95
FC-2 Rav	F	58	6.5	6.5	5.33	18.00	18.00	0.00	24.12
FC-2 Rav	F	59	6.5	6.5	4.41	32.15	32.15	0.00	43.09
FC-2 Rav	F	60	6.5	6.45	5.18	20.31	19.69	0.77	27.21
FC-2 Rav	F	61	6.5	6.45	4.69	27.85	27.29	0.77	37.31
FC-2 Rav	F	62	6.5	6.45	5.62	13.54	12.87	0.77	18.14
FC-2 Rav	F	63	6.5	6.45	5.26	19.08	18.45	0.77	25.56
FC-2 Rav	F	64	6.5	6.45	5.76	11.38	10.70	0.77	15.26
FC-2 Rav	F	65	6.5	6.45	5.01	22.92	22.33	0.77	30.72
FC-2 Rav	N	31	7.1	7.125	6.06	14.65	14.95	-0.35	19.63
FC-2 Rav	N	32	7.1	7.125	4.75	33.10	33.33	-0.35	44.35
FC-2 Rav	N	33	7.1	7.125	4.48	36.90	37.12	-0.35	49.45
FC-2 Rav	N	34	7.1	7.074	6.05	14.79	14.48	0.37	19.82
FC-2 Rav	N	35	7.1	7.074	6.18	12.96	12.64	0.37	17.36
FC-2 NR	N	66	7.1	7.14	6.89	2.96	3.50	-0.56	2.37
FC-2 NR	N	67	7.1	7.14	7.15	-0.70	-0.14	-0.56	-0.56
FC-2 NR	N	68	7.1	7.14	6.52	8.17	8.68	-0.56	6.54
FC-2 NR	N	69	7.1	7.14	6.75	4.93	5.46	-0.56	3.94
FC-2 NR	N	70	7.1	7.14	7.1	0.00	0.56	-0.56	0.00
FC-2 NR	N	71	7.1	7.14	6.83	3.80	4.34	-0.56	3.04
FC-2 NR	N	72	7.1	7.14	6.4	9.86	10.36	-0.56	7.89
FC-2 NR	N	73	7.1	7.14	6.69	5.77	6.30	-0.56	4.62
FC-2 NR	N	74	7.1	7.14	6.3	11.27	11.76	-0.56	9.01
FC-2 NR	N	75	7.1	7.14	6.09	14.23	14.71	-0.56	11.38
FC-2 NR	N	76	7.1	7.14	6.25	11.97	12.46	-0.56	9.58
FC-2 NR	N	77	7.1	7.14	5.98	15.77	16.25	-0.56	12.62
FC-2 NR	N	78	7.1	7.14	5.43	23.52	23.95	-0.56	18.82
FC-2 NR	N	79	7.1	7.14	6.26	11.83	12.32	-0.56	9.46
FC-2 NR	N	80	7.1	7.14	7.05	0.70	1.26	-0.56	0.56
FC-2 NR	N	81	7.1	7.14	7.35	-3.52	-2.94	-0.56	-2.82
FC-2 NR	N	82	7.1	7.14	6.26	11.83	12.32	-0.56	9.46
FC-2 NR	N	83	7.1	7.14	6.76	4.79	5.32	-0.56	3.83
FC-2 NR	N	84	7.1	7.07	6.2	12.68	12.31	0.42	10.14
FC-2 NR	N	85	7.1	7.07	6.87	3.24	2.83	0.42	2.59
FC-2 NR	N	86	7.1	7.07	6.41	9.72	9.34	0.42	7.77
FC-2 NR	N	87	7.1	7.07	6.99	1.55	1.13	0.42	1.24
FC-2 NR	N	88	7.1	7.07	7.13	-0.42	-0.85	0.42	-0.34
FC-2 NR	N	89	7.1	7.07	6.89	2.96	2.55	0.42	2.37
FC-2 NR	N	90	7.1	7.07	5.82	18.03	17.68	0.42	14.42
FC-2 NR	N	91	7.1	7.07	5.78	18.59	18.25	0.42	14.87
FC-2 NR	N	92	7.1	7.07	6.29	11.41	11.03	0.42	9.13
FC-2 NR	N	93	7.1	7.07	6.65	6.34	5.94	0.42	5.07
FC-2 NR	N	94	7.1	7.07	6.01	15.35	14.99	0.42	12.28

FC-2 NR	N	95	7.1	7.07	6.16	13.24	12.87	0.42	10.59
FC-2 NR	N	96	7.1	7.07	6.11	13.94	13.58	0.42	11.15
FC-2 NR	N	97	7.1	7.07	6.15	13.38	13.01	0.42	10.70
FC-2 NR	N	98	7.1	7.07	5.96	16.06	15.70	0.42	12.85
FC-2 NR	N	99	7.1	7.07	6.05	14.79	14.43	0.42	11.83
FC-2 NR	N	100	7.1	7.07	6.27	11.69	11.32	0.42	9.35
FC-2 NR	N	101	7.1	7.07	5.45	23.24	22.91	0.42	18.59
FC-2 NR	F	102	7.1	7.125	6.2	12.68	12.98	-0.35	10.14
FC-2 NR	F	103	7.1	7.125	6.32	10.99	11.30	-0.35	8.79
FC-2 NR	F	104	7.1	7.125	5.25	26.06	26.32	-0.35	20.85
FC-2 NR	F	105	7.1	7.125	5.76	18.87	19.16	-0.35	15.10
FC-2 NR	F	106	7.1	7.125	5.57	21.55	21.82	-0.35	17.24
FC-2 NR	F	107	7.1	7.125	5.79	18.45	18.74	-0.35	14.76
FC-2 NR	F	108	7.1	7.125	5.9	16.90	17.19	-0.35	13.52
FC-2 NR	F	109	7.1	7.125	5.76	18.87	19.16	-0.35	15.10
FC-2 NR	F	110	7.1	7.125	5.59	21.27	21.54	-0.35	17.01
FC-2 NR	F	111	7.1	7.125	5.88	17.18	17.47	-0.35	13.75
FC-2 NR	F	112	7.1	7.125	6.04	14.93	15.23	-0.35	11.94
FC-2 NR	F	113	7.1	7.125	6.11	13.94	14.25	-0.35	11.15
FC-2 NR	F	114	7.1	7.125	6.2	12.68	12.98	-0.35	10.14
FC-2 NR	F	115	7.1	7.125	6.22	12.39	12.70	-0.35	9.92
FC-2 NR	F	116	7.1	7.125	6.25	11.97	12.28	-0.35	9.58
FC-2 NR	F	117	7.1	7.125	5.95	16.20	16.49	-0.35	12.96
FC-2 NR	F	118	7.1	7.125	6.18	12.96	13.26	-0.35	10.37
FC-2 NR	F	119	7.1	7.125	6.59	7.18	7.51	-0.35	5.75
FC-2 NR	F	120	7.1	7.125	6.45	9.15	9.47	-0.35	7.32
FC-5 NR	N	121	7.3	7.38	6.34	13.15	14.09	-1.10	10.52
FC-5 NR	N	122	7.3	7.38	6.06	16.99	17.89	-1.10	13.59
FC-5 NR	N	123	7.3	7.38	6.87	5.89	6.91	-1.10	4.71
FC-5 NR	N	124	7.3	7.38	6.64	9.04	10.03	-1.10	7.23
FC-5 NR	N	125	7.3	7.38	6.43	11.92	12.87	-1.10	9.53
FC-5 NR	N	126	7.3	7.38	6.97	4.52	5.56	-1.10	3.62
FC-5 NR	N	127	7.3	7.38	6.31	13.56	14.50	-1.10	10.85
FC-5 NR	N	128	7.3	7.38	6.53	10.55	11.52	-1.10	8.44
FC-5 NR	N	129	7.3	7.38	6.27	14.11	15.04	-1.10	11.29
FC-5 NR	N	130	7.3	7.38	6.61	9.45	10.43	-1.10	7.56
FC-5 NR	N	131	7.3	7.38	6.19	15.21	16.12	-1.10	12.16
FC-5 NR	N	132	7.3	7.38	6.39	12.47	13.41	-1.10	9.97
FC-5 NR	N	133	7.3	7.38	6.7	8.22	9.21	-1.10	6.58
FC-5 NR	N	134	7.3	7.38	6.77	7.26	8.27	-1.10	5.81
FC-5 NR	N	135	7.3	7.38	6.59	9.73	10.70	-1.10	7.78
FC-5 NR	N	136	7.3	7.38	6.61	9.45	10.43	-1.10	7.56
FC-5 NR	N	137	7.3	7.38	6.48	11.23	12.20	-1.10	8.99
FC-5 NR	N	138	7.3	7.38	6.01	17.67	18.56	-1.10	14.14
FC-5 NR	N	139	7.3	7.02	6.3	13.70	10.26	3.84	10.96
FC-5 NR	N	140	7.3	7.02	6.8	6.85	3.13	3.84	5.48
FC-5 NR	N	141	7.3	7.02	7.6	-4.11	-8.26	3.84	-3.29
FC-5 NR	N	142	7.3	7.02	7.8	-6.85	####	3.84	-5.48
FC-5 NR	N	143	7.3	7.02	7.3	0.00	-3.99	3.84	0.00
FC-5 NR	N	144	7.3	7.02	7	4.11	0.28	3.84	3.29
FC-5 NR	N	145	7.3	7.02	6.86	6.03	2.28	3.84	4.82

FC-5 NR	N	146	7.3	7.02	7.68	-5.21	-9.40	3.84	-4.16
FC-5 NR	N	147	7.3	7.02	6.96	4.66	0.85	3.84	3.73
FC-5 NR	N	148	7.3	7.02	7.17	1.78	-2.14	3.84	1.42
FC-5 NR	N	149	7.3	7.02	8.01	-9.73	####	3.84	-7.78
FC-5 NR	N	150	7.3	7.02	7.52	-3.01	-7.12	3.84	-2.41
FC-5 NR	N	151	7.3	7.02	7.44	-1.92	-5.98	3.84	-1.53
FC-5 NR	N	152	7.3	7.02	6.95	4.79	1.00	3.84	3.84
FC-5 NR	N	153	7.3	7.02	7.22	1.10	-2.85	3.84	0.88
FC-5 NR	N	154	7.3	7.02	7.56	-3.56	-7.69	3.84	-2.85
FC-5 NR	N	155	7.3	7.02	7.28	0.27	-3.70	3.84	0.22
FC-5 NR	N	156	7.3	7.02	6.54	10.41	6.84	3.84	8.33
FC-5 NR	N	157	7.3	7.13	7.42	-1.64	-4.07	2.33	-1.32
FC-5 NR	N	158	7.3	7.13	7.13	2.33	0.00	2.33	1.86
FC-5 NR	N	159	7.3	7.13	7.62	-4.38	-6.87	2.33	-3.51
FC-5 NR	N	160	7.3	7.13	7.69	-5.34	-7.85	2.33	-4.27
FC-5 NR	N	161	7.3	7.13	7.39	-1.23	-3.65	2.33	-0.99
FC-5 NR	N	162	7.3	7.13	7.29	0.14	-2.24	2.33	0.11
FC-5 NR	N	163	7.3	7.13	6.88	5.75	3.51	2.33	4.60
FC-5 NR	N	164	7.3	7.13	6.73	7.81	5.61	2.33	6.25
FC-5 NR	N	165	7.3	7.13	6.85	6.16	3.93	2.33	4.93
FC-5 NR	N	166	7.3	7.13	7.01	3.97	1.68	2.33	3.18
FC-5 NR	N	167	7.3	7.13	6.51	10.82	8.70	2.33	8.66
FC-5 NR	N	168	7.3	7.13	7.05	3.42	1.12	2.33	2.74
FC-5 NR	N	169	7.3	7.13	6.49	11.10	8.98	2.33	8.88
FC-5 NR	N	170	7.3	7.13	7.05	3.42	1.12	2.33	2.74
FC-5 NR	N	171	7.3	7.13	6.74	7.67	5.47	2.33	6.14
FC-5 NR	N	172	7.3	7.13	6.41	12.19	10.10	2.33	9.75
FC-5 NR	N	173	7.3	7.13	6.59	9.73	7.57	2.33	7.78
FC-5 NR	N	174	7.3	7.13	6.86	6.03	3.79	2.33	4.82
						14.19			**16.12**

Appendix C

REGRESSION ANALYSIS OUTPUT

Regression Analysis for % AC Loss vs. Age (NCAT and Flowmeter measurements) in Figure 33

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.68
R Square	0.47
Adjusted R Square	0.45
Standard Error	7.48
Observations	28

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1272.53	1272.53	22.76	0.00
Residual	26	1453.72	55.91		
Total	27	2726.25			

	Coefficients	*Standard Erroi*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Jpper 95.0%*
Intercept	1.34	2.89	0.46	0.65	-4.61	7.29	-4.61	7.29
X Variable 1	0.01	0.00	4.77	0.00	0.01	0.01	0.01	0.01

Regression Analysis for % AC Loss vs. Age (NCAT measurements) in Figure 34

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.23
R Square	0.05
Adjusted R Squa	-0.02
Standard Error	6.86
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	32.80	32.80	0.70	0.42
Residual	13	611.63	47.05		
Total	14	644.43			

	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	4.31	2.80	1.54	0.15	-1.73	10.35	-1.73	10.35
X Variable 1	0.00	0.00	0.83	0.42	0.00	0.01	0.00	0.01

Regression Analysis for % AC Loss vs. Age (Flowmeter measurements) in Figure 35

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.55
R Square	0.30
Adjusted R Squar	0.24
Standard Error	4.84
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	112.34	112.34	4.79	0.05
Residual	11	258.06	23.46		
Total	12	370.40			

	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-8.93	14.10	-0.63	0.54	-39.97	22.11	-39.97	22.11
X Variable 1	0.02	0.01	2.19	0.05	0.00	0.04	0.00	0.04

LIST OF REFERENCES

Atkins, H. N.(1997). *Highway Materials, Soils and Concretes* (3rd Ed.). Upper Saddle River, NJ: Prentice-Hall, Inc.

Huang, Y.H.(1993). *Pavement Analysis and Design*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Kandhal, P.S. & Mallick, R.B. (1999). *Design of New-Generation Open Graded Friction Courses*. National Center for Asphalt Technology: Auburn University (NCAT Report No. 99-3).

Kandhal, P.S. & Mallick, R.B. (1998). *Open Graded Asphalt Friction Course: State of the Practice*. National Center for Asphalt Technology: Auburn University (NCAT Report No. 98-7).

National Asphalt Pavement Association (1999). *Hot Mix Asphalt Research and Technology (Special Report 178).*

Oweis, Issa S. & Khera, Raj P. (1998). *Geotechnology of Waste Management* (2nd Ed.). Boston, MA: PWS Publishing Company.

Page, G.C., Murphy, K.H., Musselman, J.A., West, R.C. (1992). *An Assessment of Flexible Pavement Distresses on Florida's Highways* (Research Report No. FL/DOT/SMO/92-393). Gainesville, FL: Florida Department of Transportation.

Paterson, William D.(1987). *The Highway Design and Maintenance Standard Series: Road Deterioration and Maintenance Effects - Models for Planning and Management*. Baltimore, MD: The Johns Hopkins University Press.

Roberts, F.L., Kandhal, P.S., Brown E.R., Lee, D. & Kennedy, T.W. (1996). *Hot Mix Asphalt Materials, Mixture Design and Construction* (2nd Ed). Landham, MD: NAPA Education Foundation.

Sontowski, Peter (1995, March). How to Prevent Asphalt Pavement Raveling. *Better Roads,* 65, 23-24.

Florida Department of Transportation (2000). *Standard Specifications for Road and Bridge Construction.* Tallahassee, FL: Florida Department of Transportation.