Quality Base Material Produced Using Full Depth Reclamation on Existing Asphalt Pavement Structure

DTFH61-06-C-00038
(October 2006 – September 2011)

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South Dakota Department of Transportation

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AEMA-ARRA-ISSA
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Project Scope

- Full Depth Reclamation (FDR) involves milling the entire existing asphalt pavement section plus some thickness of the underlying base. This combined material is mixed and placed back on the roadway as the new base.

- There are a number of ways to stabilize this mixed material to increase the capacity and life of the pavement structure:

  - Unstabilized
  - Mechanically stabilized
  - Chemically stabilized
  - Bituminous stabilized

Project Scope

- Examine as many different combinations of in-situ material types and stabilizers in the laboratory to determine the best FDR method.

- Construct field test sections using in-situ materials and different stabilization techniques to compare construction methods and long term pavement performance.

- Recommend and establish final laboratory testing protocol and mix design procedures for the FDR process.

Project Technical Panel

- Randy Battey, Mississippi DOT
- Todd Casey, Base Construction Co. (ARRA)
- John Epps, Granite Construction, Inc.
- Joe Feller, SDDOT
- Gary Goff, FHWA ND Division
- David Gress, Univ. of New Hampshire
- Gregory Halsted, PCA (ARRA)
- Brett Hestdalen, FHWA SD Division
- John Huffman, Terex Roadbuilding (ARRA)
- Tim Kowalski, Wirtgen America
- David Lee, Univ. of Iowa
- Chuck Luedders, FHWA Direct Federal Lands
- Ken Skorseth, SDSU
- Ken Swedeen, Dakota Asphalt Pavement Association
- Todd Thomas, Road Science LLC (ARRA)
- Mike Voth, Central Federal Lands Division, FHWA

Research Tasks

1. Literature Review
2. Document State Specifications & Construction Experiences
3. Condition Survey of Existing Test Sections
4. Develop FDR Mix Design Guide
5. Develop Standardized Laboratory Testing Method
6. Field Procedures to Produce Base Material Meeting Asphalt Content and Gradation Specifications
7. Basic Construction Details for Field Test Strip
8. Monitor Construction of Test Sections
9. Establish Laboratory Testing and Design Procedures
10. Information Exchange
11. Final Report

Current Status

- Task 1 (Literature Review) Completed.
- Task 2 (Document State Specifications & Experiences) Completed.
- Task 3 (Condition Survey of Existing Test Sections) Under review by FHWA.
- Task 4 (FDR Mix Design Guide) 100% completed. Report under internal review.
- Task 5 (Lab Testing Methods) 75% completed.
- Tasks 6 and 7 (Test Sections) Completed.
- Task 8 (Test Section Monitoring) Ongoing.

Task 2

FHWA Survey Results

- Preliminary survey to determine the extent of FDR use throughout the country.

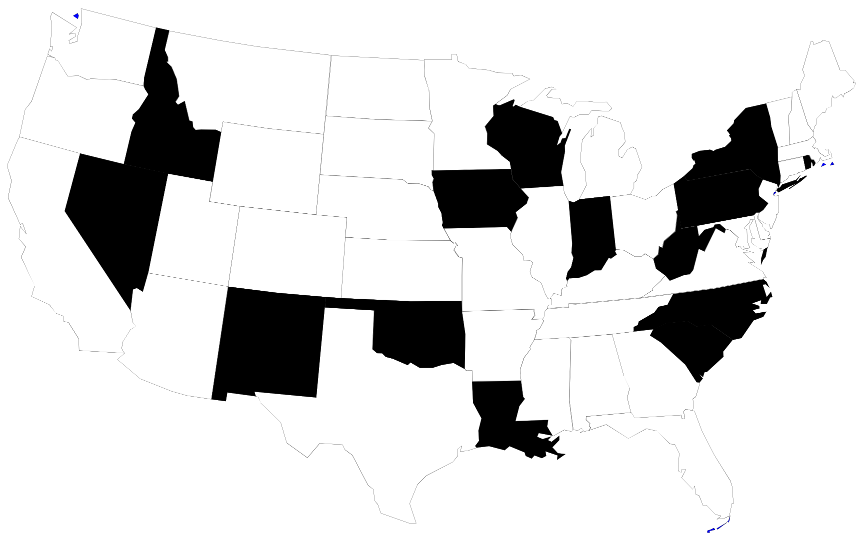
- 19 total responses
  - 17 States
  - Puerto Rico
  - Federal Lands Highway

FHWA Survey Results

- Is your agency currently using FDR?
  - 10 yes (9 states and Federal Lands Highway)
  - 7 no
  - 2 maybe
- If yes, to what extent?
  - Results varied from very little to extensive.
- Has FDR been used in the past, but not now?
  - Only two states said yes, but gave no indication for the discontinued use.

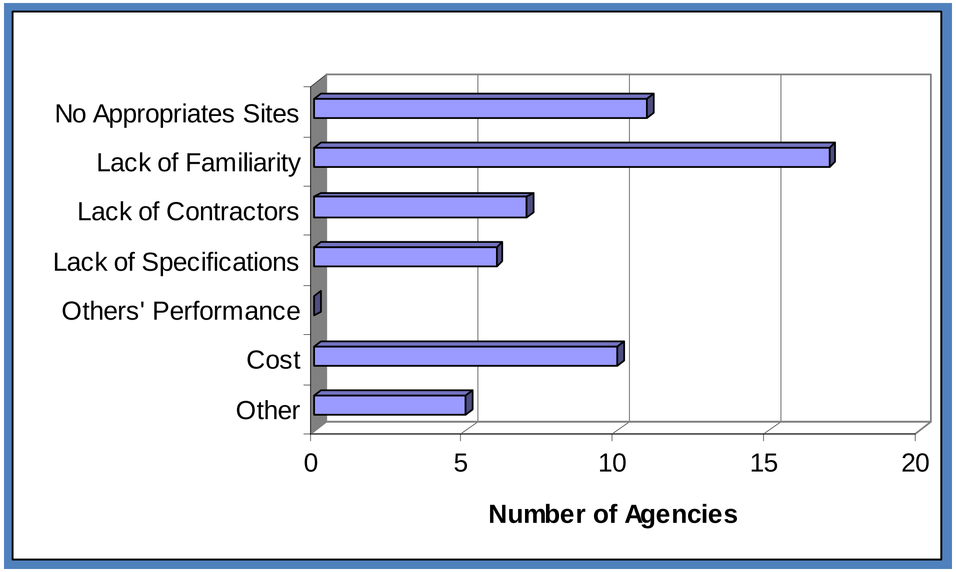
SDDOT Survey Results

- Survey was sent out to all 50 states, 10 Canadian provinces, and numerous local governments.
- 118 responses
  - 34 State DOT's
  - 5 Canadian Provinces
  - 65 County highway departments
  - 14 other agencies (cities, townships, etc.)



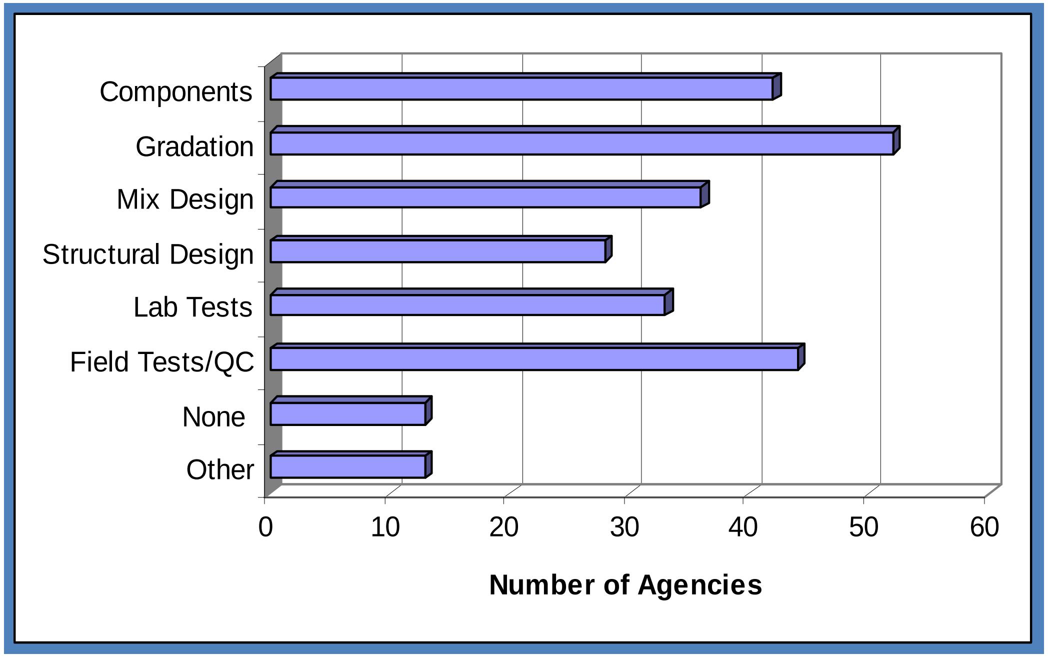
SDDOT Survey Results

- Of the 118 agencies that responded to the survey
  - 83 continue the use of FDR
  - 31 have never used FDR
  - 4 have discontinued the used of FDR.
- Of the 31 respondents that have never used FDR, the reasons included:



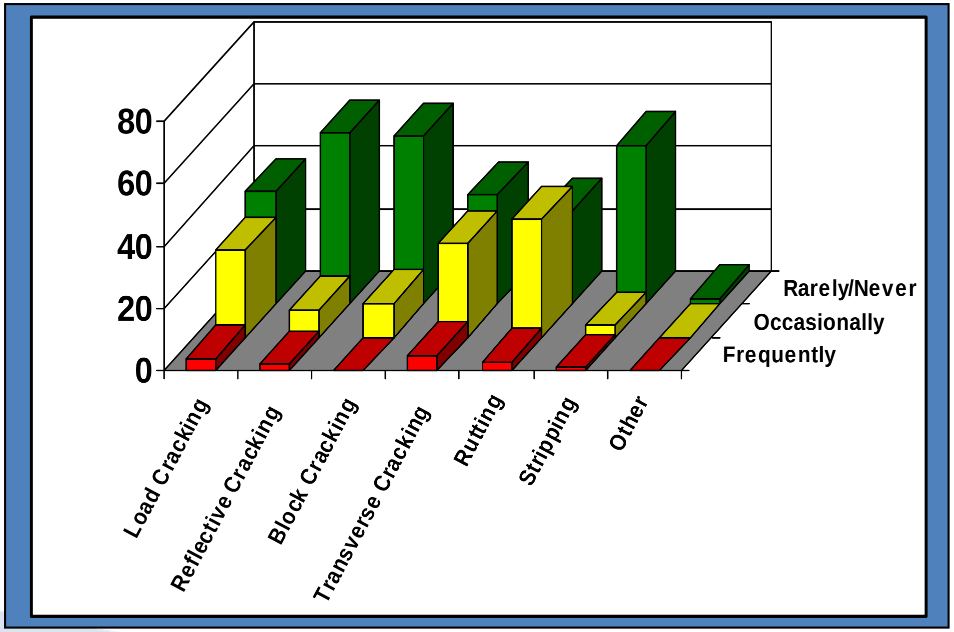
SDDOT Survey Results

- A total of 66 agencies responded that they did have specifications for FDR.
- The 6 types of specifications listed in the survey were:
  - Field testing and quality control
  - Material Components
  - Gradations
  - Mix Designs
  - Structural designs
  - Lab testing



SDDOT Survey Results

- The types of stabilization and percentages of agencies indicating their experience with included:
  - Bituminous stabilization – 71%
  - Mechanical stabilization – 65%
  - Chemical stabilization – 34%
- 61% of respondents reported that the FDR performed about the same as conventionally constructed pavements. The common distress types reported are:
  - Reflective cracking
  - Block cracking
  - Stripping
  - Load cracking
  - Transverse cracking
  - Rutting



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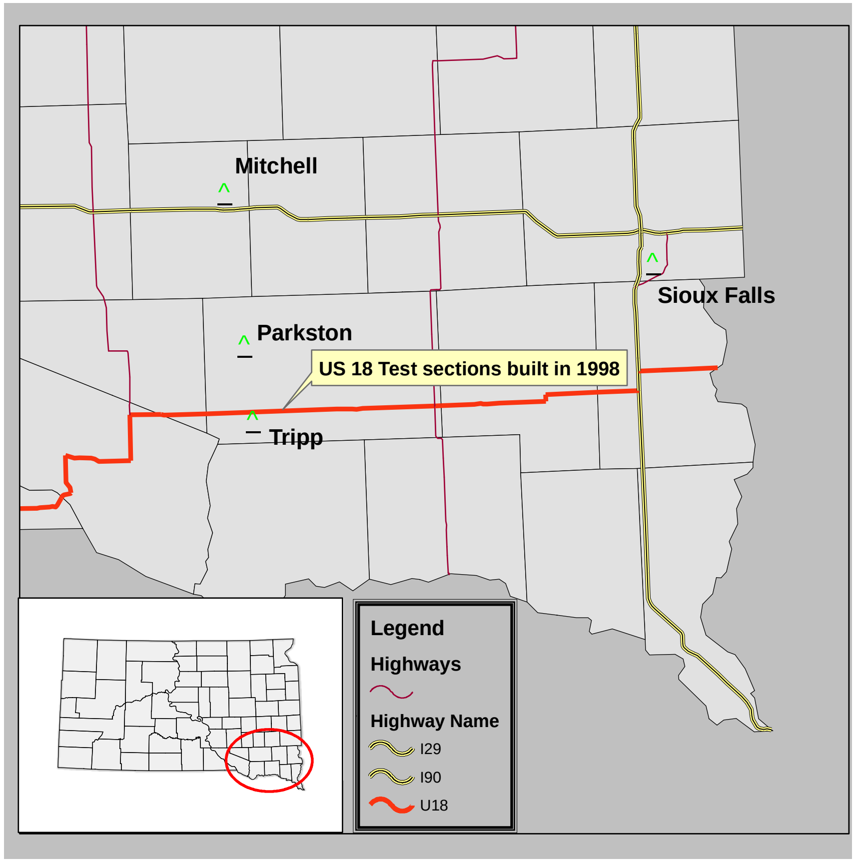
Task 3

Condition Survey of US Highway 18

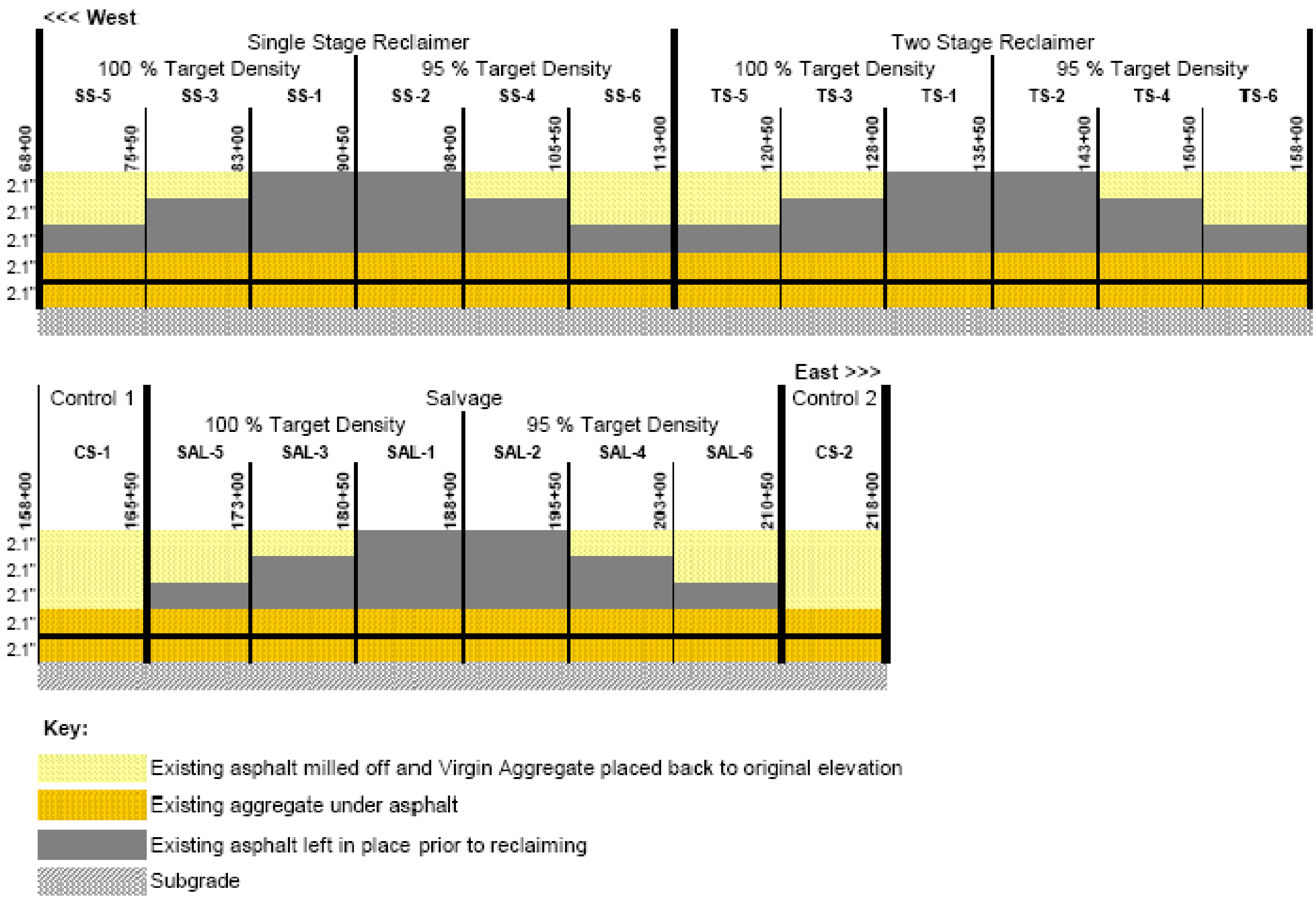


- Location: south east corner of SD and begins 1 mile east of Tripp.
- Extends 3 miles east.

US 18 Test Sections

- 12 test sections were constructed in 1998.
- 6 single stage sections
  - 3 percentages of RAP (25%, 50%, 75%)
  - 2 compaction efforts
- 6 two stage sections
  - 3 percentages of RAP (25%, 50%, 75%)
  - 2 compaction efforts
- 2 control sections
  - Each control section was to be constructed of 100% base with no asphalt millings.

US 18 Test Sections

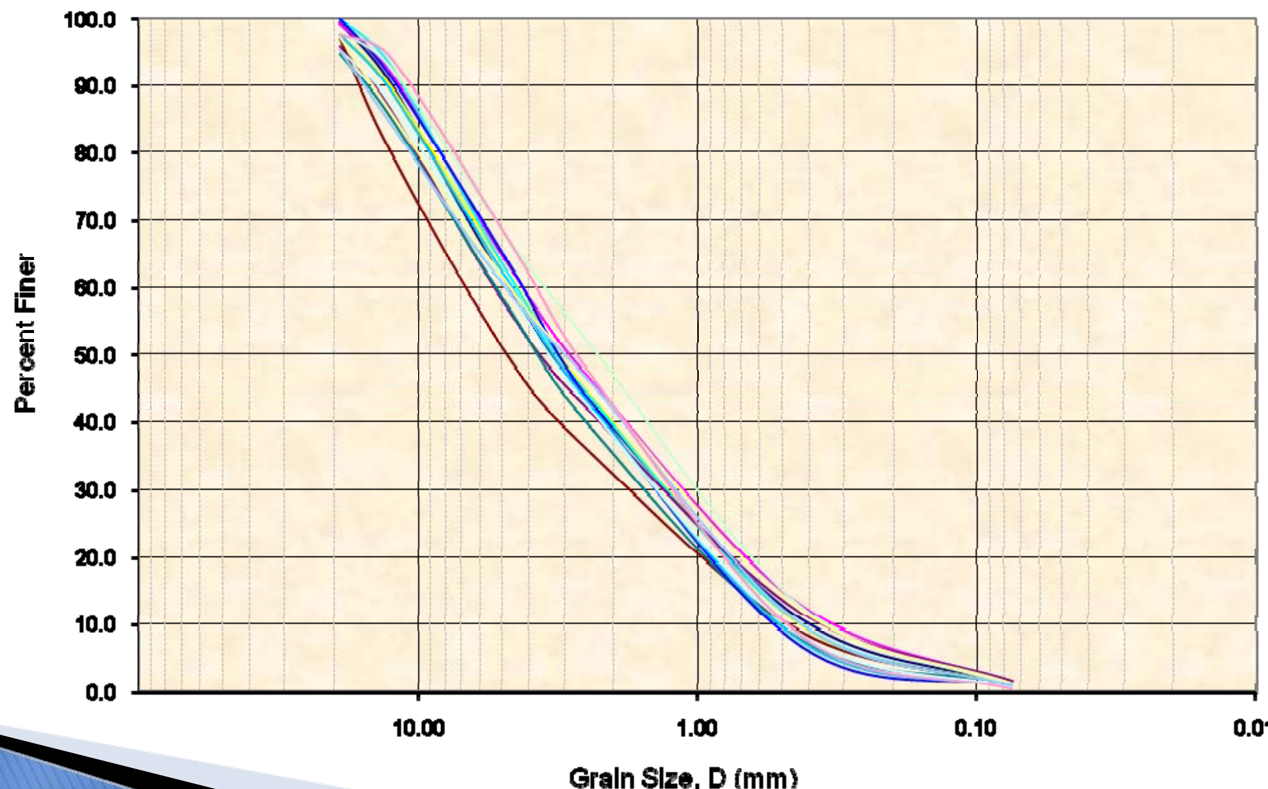


Sampling of Roadway Materials

- Coring and base extraction done 3 times.
- 4 inch asphalt cores.
- 6 and 9 inch core barrels used for base extraction.

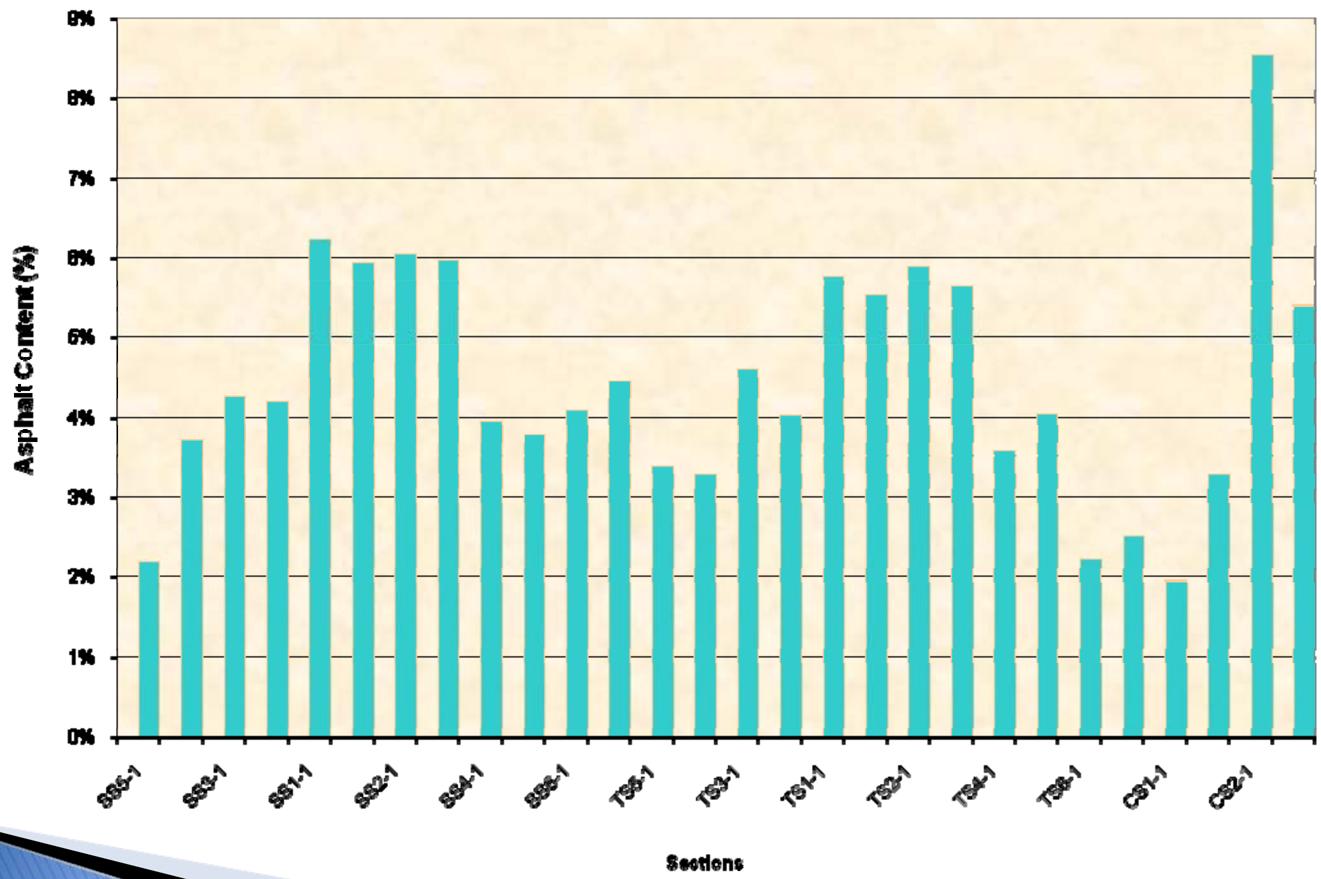
Sampling of Roadway Materials

- Gradations
  - Gradations were nearly the same throughout the sections.



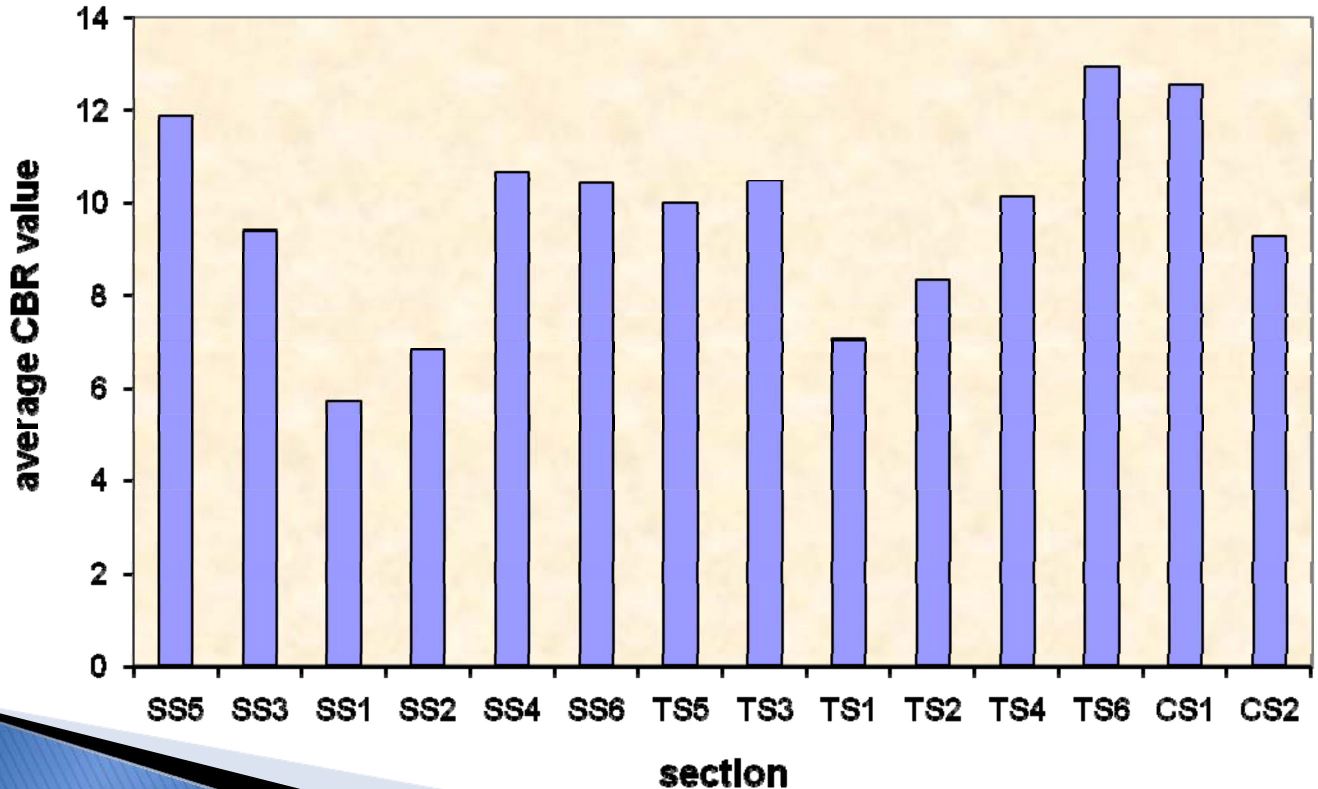
Sampling of Roadway Materials

- Asphalt Contents
  - AC% ranged from 1.95 to 8.56.



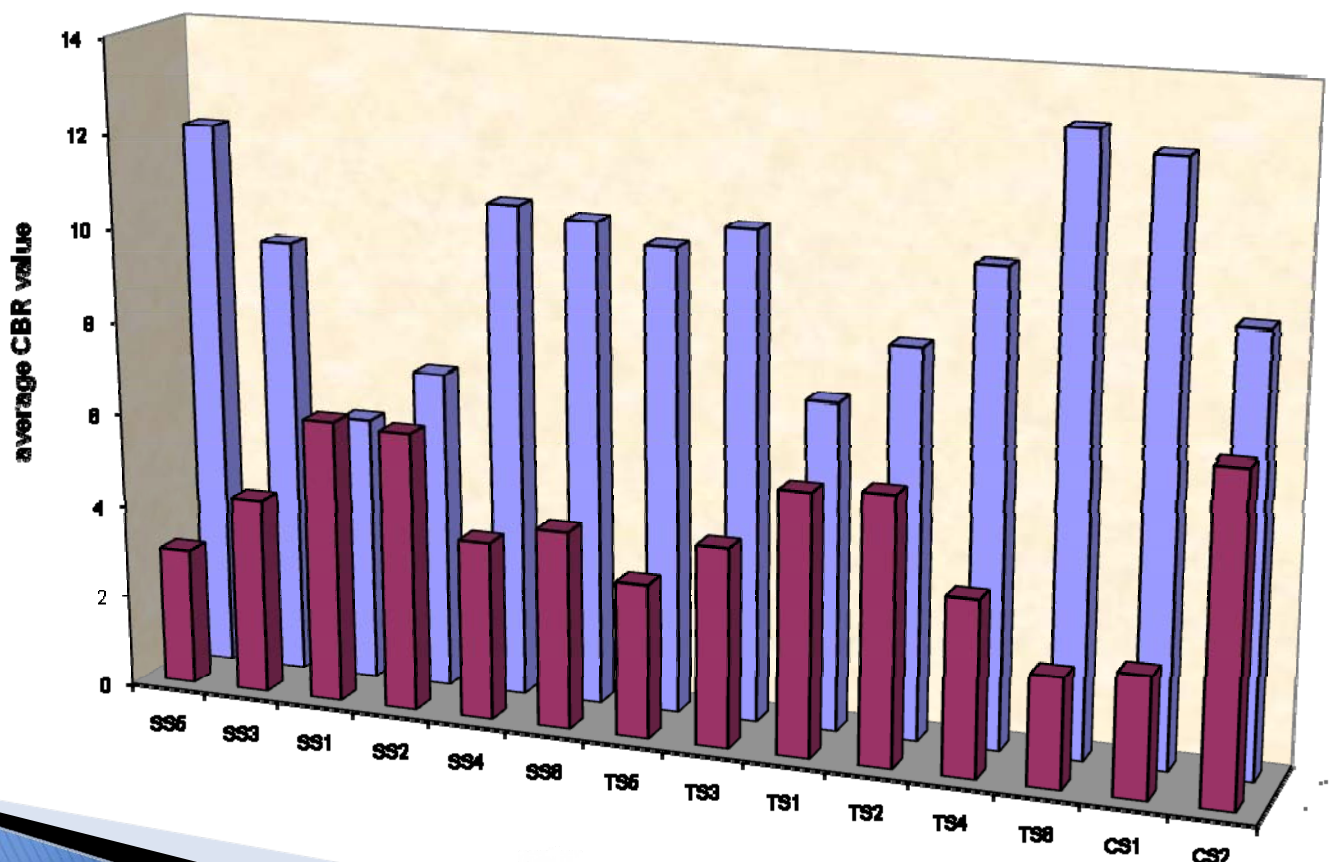
Sampling of Roadway Materials

- CBR Testing
  - Results: CBR values ranged from 5.3 to 12.1.



Sampling of Roadway Materials

- CBR Testing
  - Relation between CBR values and asphalt contents.



Falling Weight Deflectometer

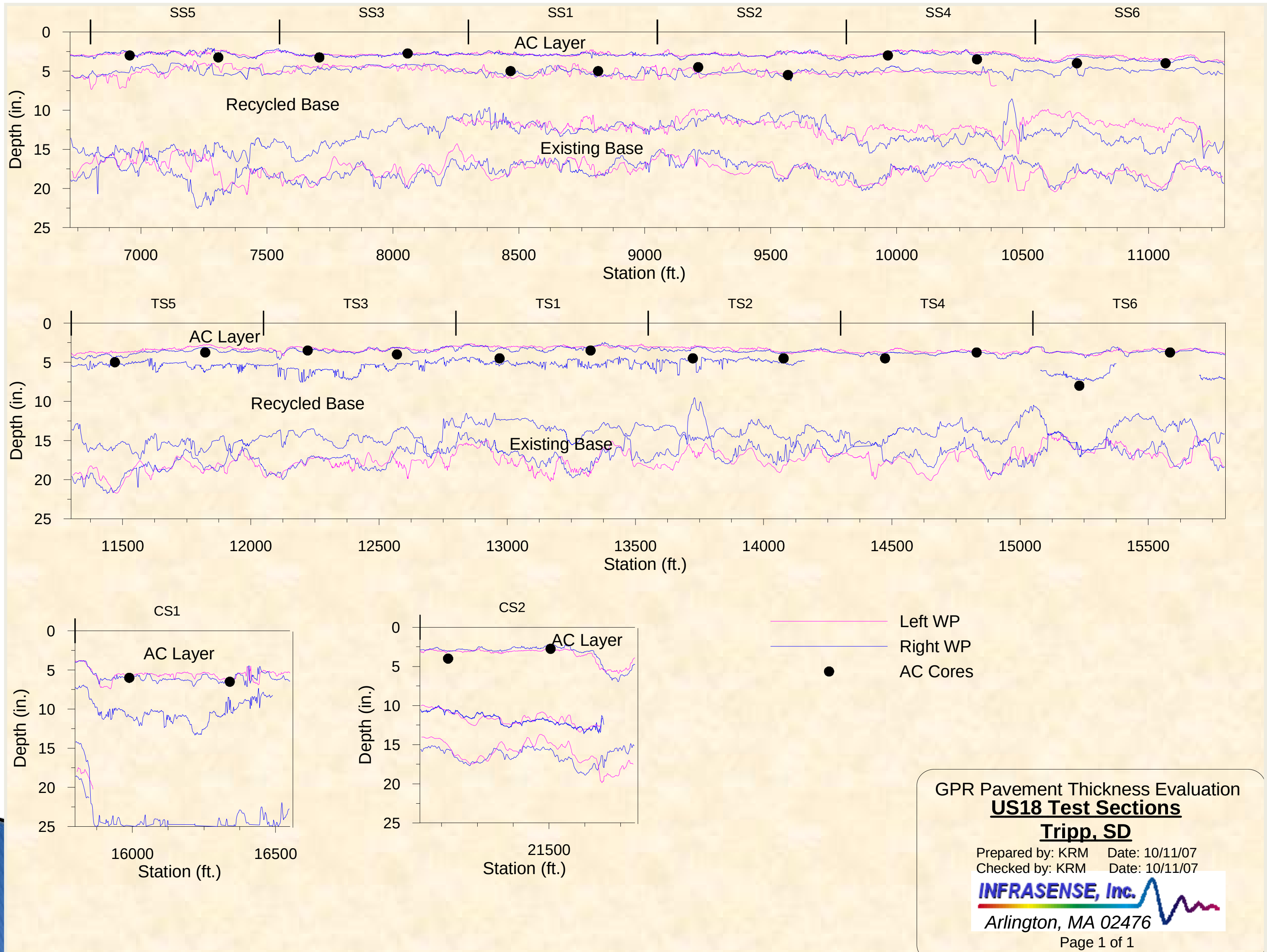
- FWD was conducted in April 2007.
- FWD data is combined with GPR data to estimate modulus values for the base and asphalt layers.

Ground Penetrating Radar (GPR)

- GPR was performed on the test sections in September 2007.
- Core locations and MRM's were noted when the data was collected.

Horn Antenna DMI

Ground Penetrating Radar (GPR)



Roadway Evaluation Van

- Data was collected in April 2007 with the DOT's roadway evaluation van.
  - Data collected included:
    - Profiles
    - Rut depths
    - Images

Visual Distress Identification Survey

- A Long Term Pavement Performance (LTPP) distress identification survey was performed in April 2007.
  - The LTPP distress identification manual was used.
    - Describes the various distresses and gives examples.
    - Explains how to record the distresses.

Visual Distress Identification Survey

- LTPP survey results.
  - Typical distresses


Fatigue Cracking Section SS2


Longitudinal and centerline cracking

Task 4

Task 4 – Development of FDR Mix Design Guide

- The objective of this task is to develop a mix design procedure for the various types of FDR.

- Each type of FDR has separate mix design:
  - Mechanically Stabilized

Chemically Stabilized

- Portland Cement
- Fly Ash

Bituminous Stabilized

- Asphalt Emulsion
- Asphalt Emulsion with 1% Lime
- Foamed Asphalt with 1% Portland Cement

Task 4 – Development of FDR Mix Design Guide

The base material mixtures will be proportioned with 75%, 50%, 25%, and 0% RAP material. The base material will consist of the following four combinations:

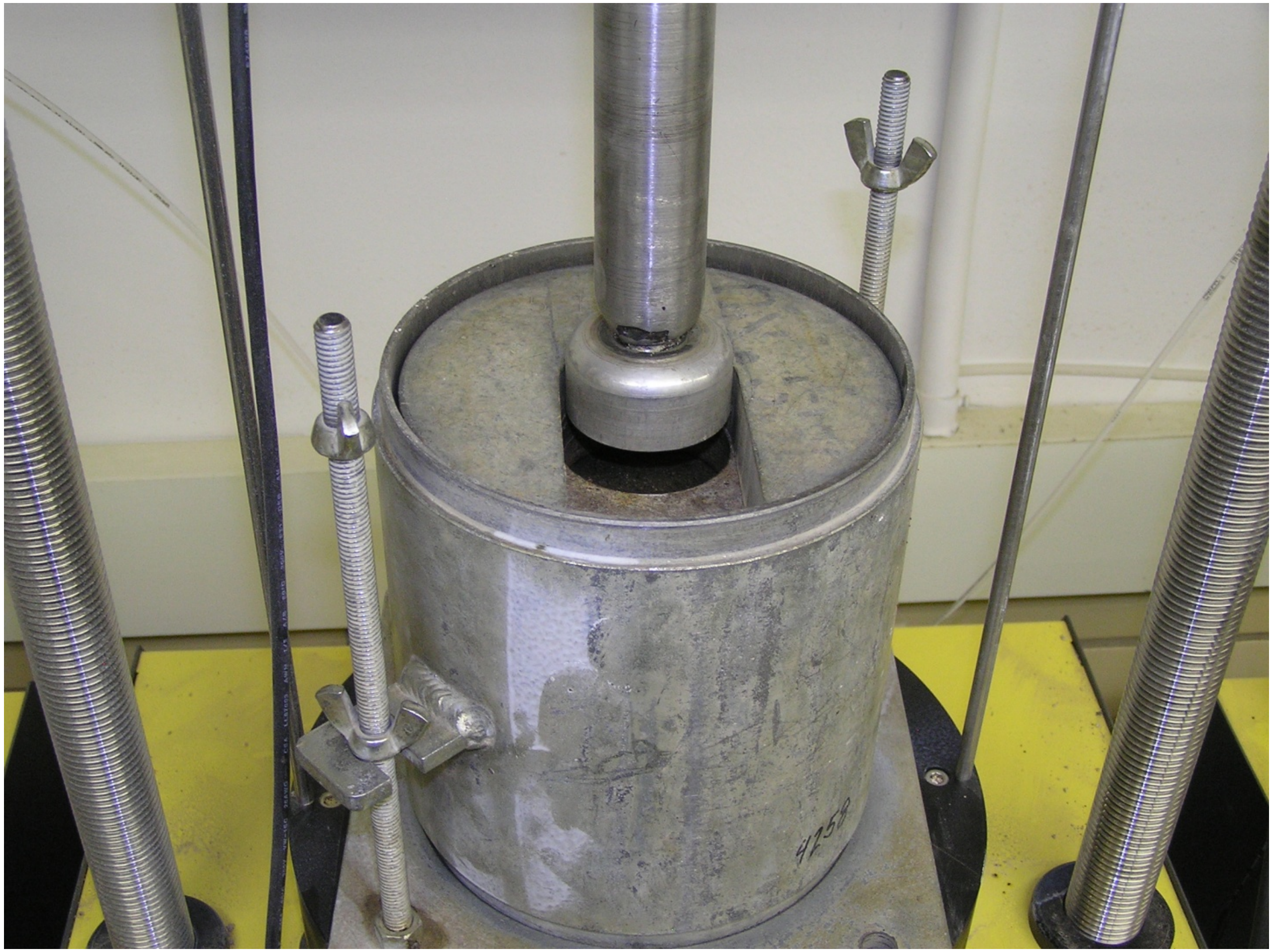
- Good quality material with clean gradation
- Good quality material with dirty gradation
- Poor quality material with clean gradation
- Poor quality material with dirty gradation

FDR Source	Gradation	FDR Type					
		Unstabilized	Stabilized with PC (3, 5, 7 %)	Stabilized with Fly Ash (10, 12, 15 %)	Stabilized with Asphalt Emulsion (3, 4.5, 6 %)	Stabilized with Asphalt Emulsion (3, 4.5, 6 %)+ Lime	Stabilized with Foamed Asphalt (2.5, 3, 3.5 %) + PC
Poor	Dirty	-Moisture-density curve -Mr and CBR	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Moisture-density curve (use results of unstabilized) - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning
	Clean	-Moisture-density curve -Mr and CBR	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Moisture-density curve (use results of unstabilized) - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning
Good	Dirty	-Moisture-density curve -Mr and CBR	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Moisture-density curve (use results of unstabilized) - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning
	Clean	-Moisture-density curve -Mr and CBR	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Moisture-density curve - Compressive strength -Moisture sensitivity	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning	-Superpave Gyratory - Moisture-density curve (use results of unstabilized) - Bulk density using Corelok - Maximum density using Corelok -Moisture conditioning

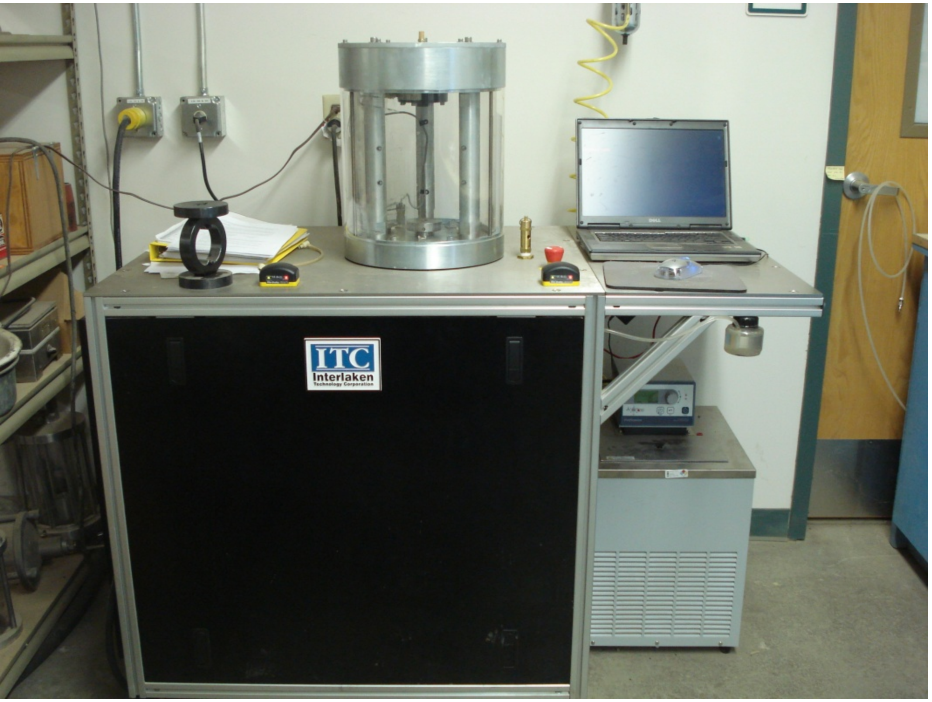
Testing Material

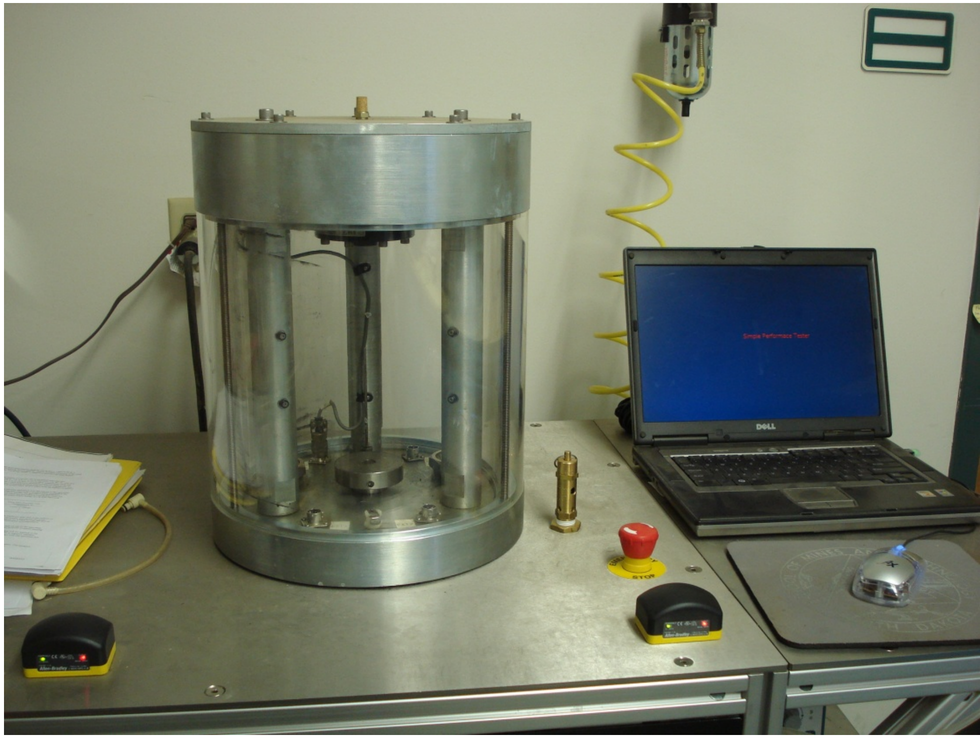
- Three levels of RAP for each combination: 25%, 50%, 75%.
- 5 levels of stabilizer (PC, Fly Ash, Emulsion, Emulsion + Lime, Foamed Asphalt + PC)
- Lime content for Emulsion + Lime is constant: 1.0 % Lime
- PC content for Foamed Asphalt + PC stabilizer: 1.0 % (if failed given conditions, use 2.0% PC)

California Bearing Ratio (CBR)

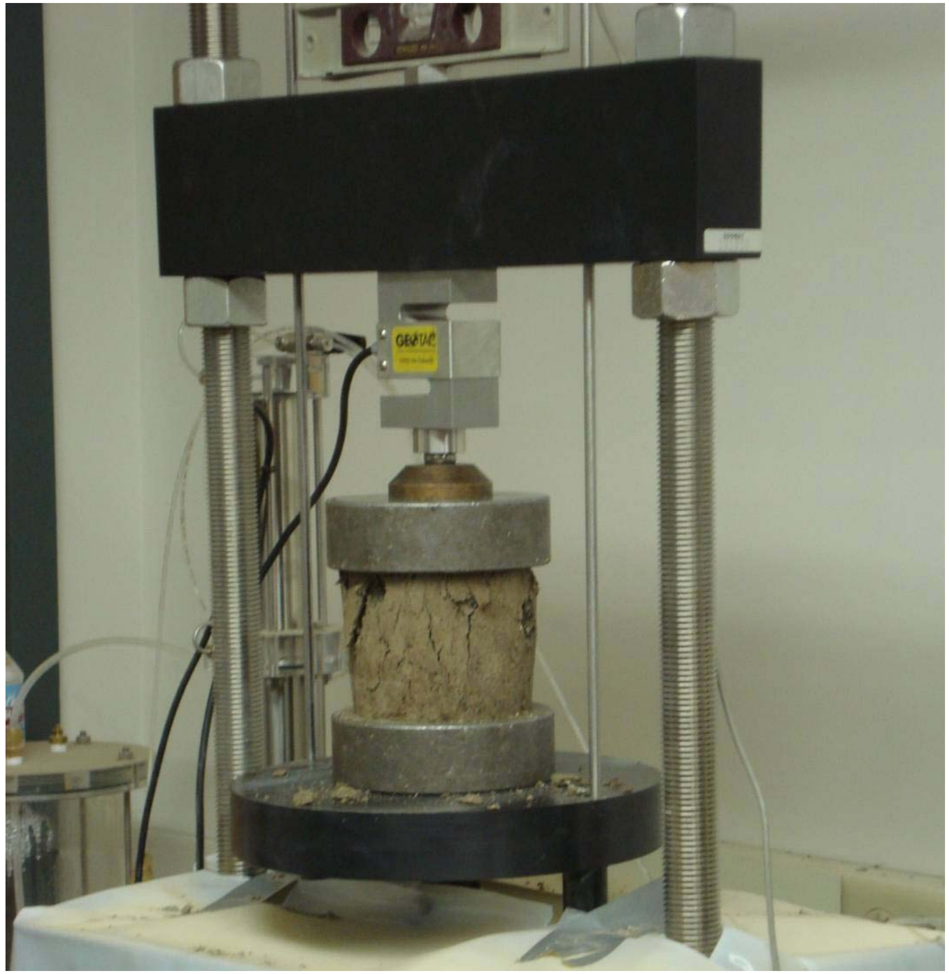


Simple Performance Tester (SPT)



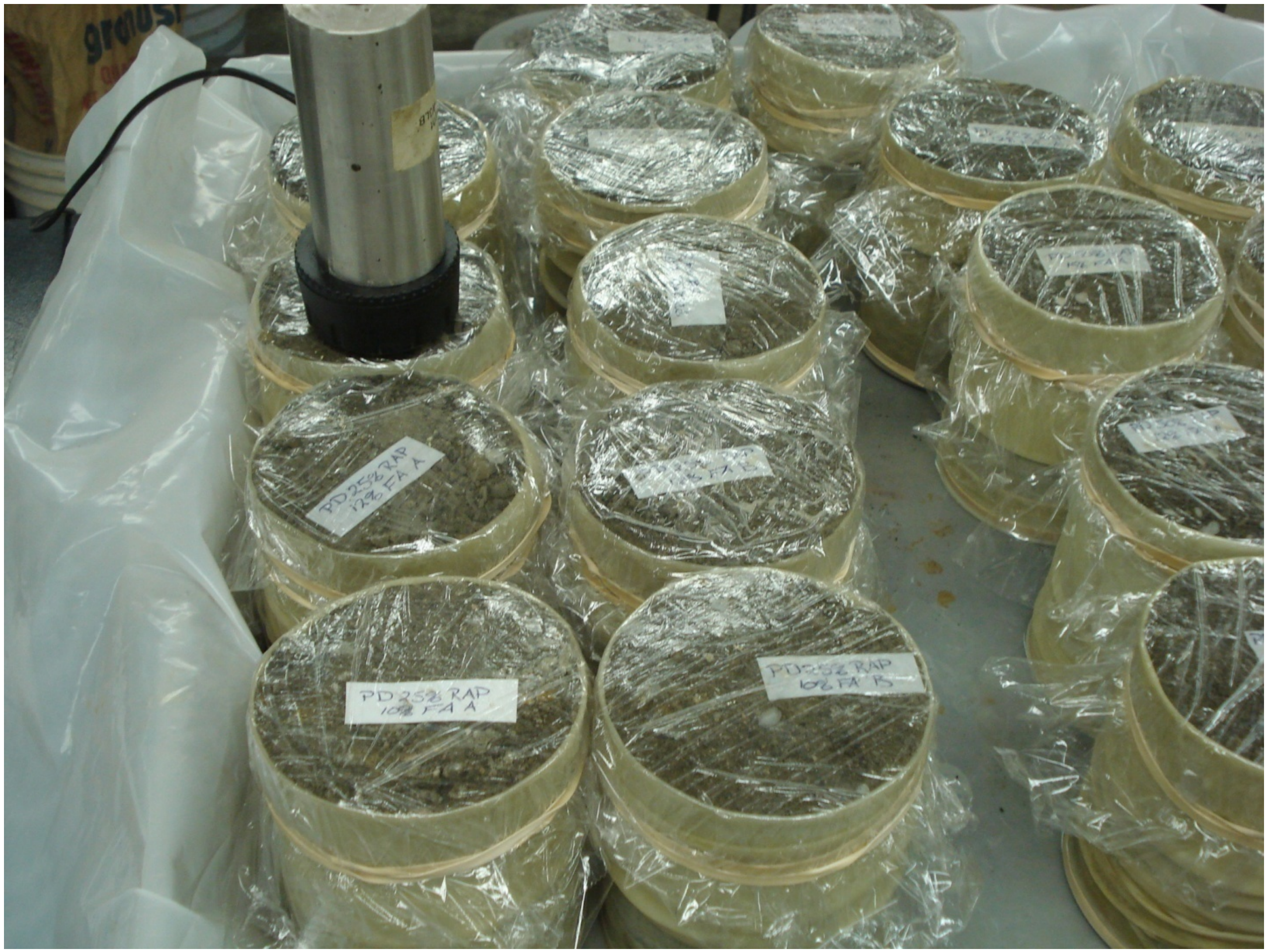


Unconfined Compressive Strength



Indirect Tensile Strength

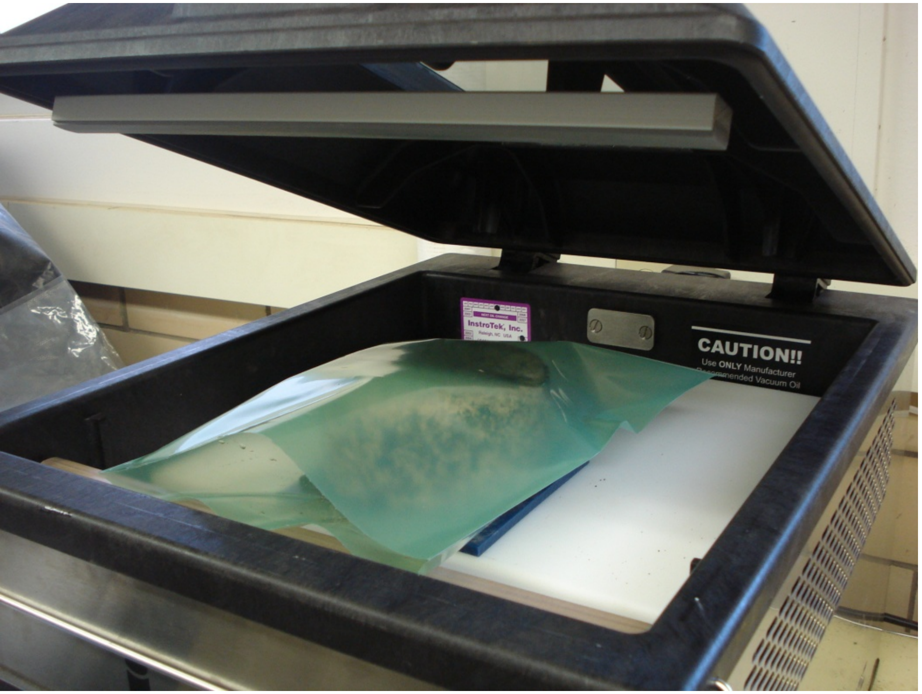
Moisture Sensitivity

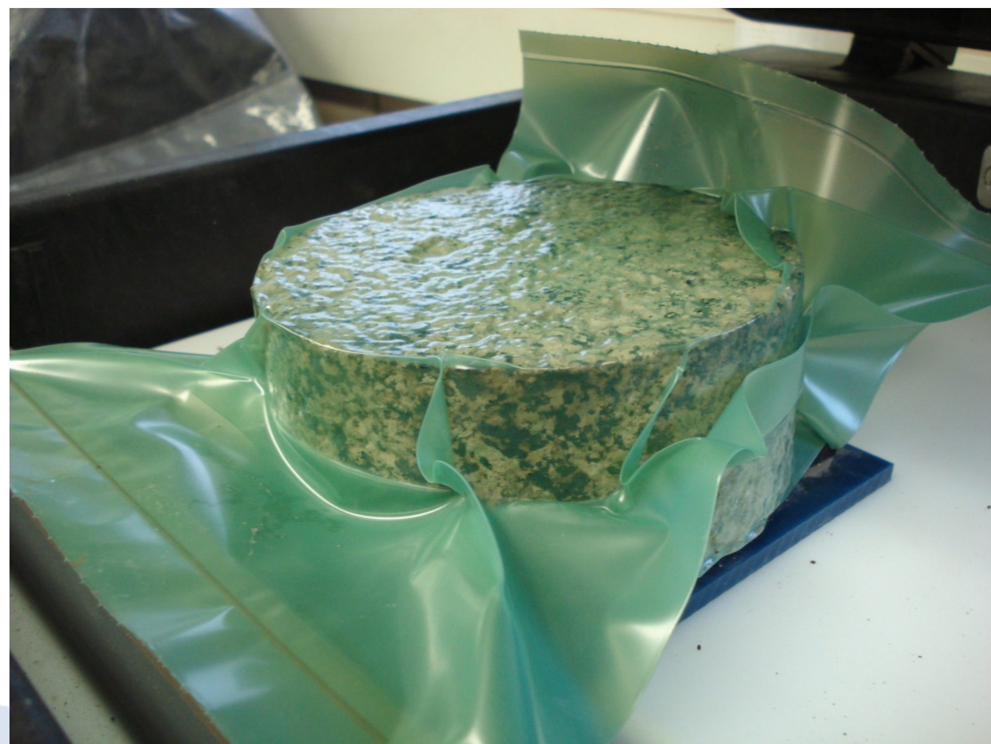


Foamed Asphalt

Gyratory Compactor

Corelok (Maximum and Bulk Specific Gravity)





Task 5

Task 5 – Development of Standard Laboratory Testing Method

- The objective of this task is to develop a laboratory testing procedure to address material properties needed to support practical pavement design. The focus will be on developing standard test methods to be used specifically for AASHTO related pavement designs.
- The FDR process produces a layer that will be modeled as a base course within the structure of a flexible pavement.

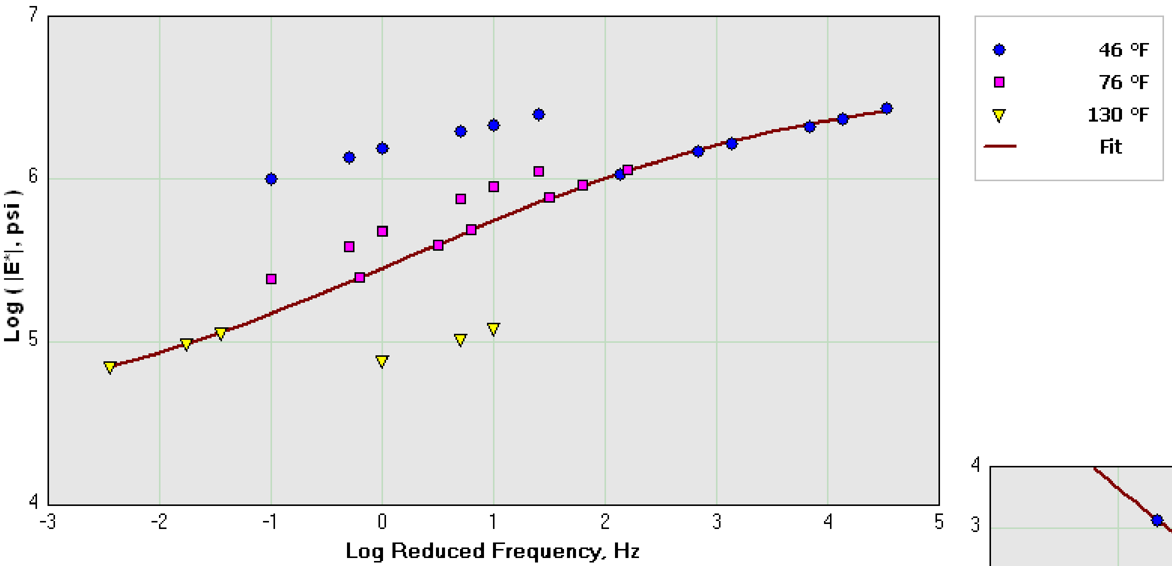
FDR Source	Gradation	FDR Type					
		Unstabilized	Stabilized with PC (Optimum %)	Stabilized with Fly Ash (Optimum %)	Stabilized with Asphalt Emulsion (Optimum %)	Stabilized with Asphalt Emulsion (Optimum %) + Lime	Stabilized with Foamed Asphalt (Optimum %) + PC
Poor	Dirty	- Resilient Modulus - CBR	-Compressive Strength -Modulus of Rupture	-Compressive Strength -Modulus of Rupture	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial
	Clean	- Resilient Modulus - CBR	-Compressive Strength -Modulus of Rupture	-Compressive Strength -Modulus of Rupture	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial
Good	Dirty	-Resilient Modulus - CBR	-Compressive Strength -Modulus of Rupture	-Compressive Strength Modulus of Rupture	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial
	Clean	-Resilient Modulus - CBR	-Compressive Strength -Modulus of Rupture	-Compressive Strength -Modulus of Rupture	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial	- E* Master Curve -Repeated Load Triaxial

Modulus of Rupture

Simple Performance Tester (SPT)

- Resilient Modulus
- Dynamic Modulus
- E* Master Curve
- Repeated Load Triaxial

E* Master Curve



AASHTO MEPDG Master Curve

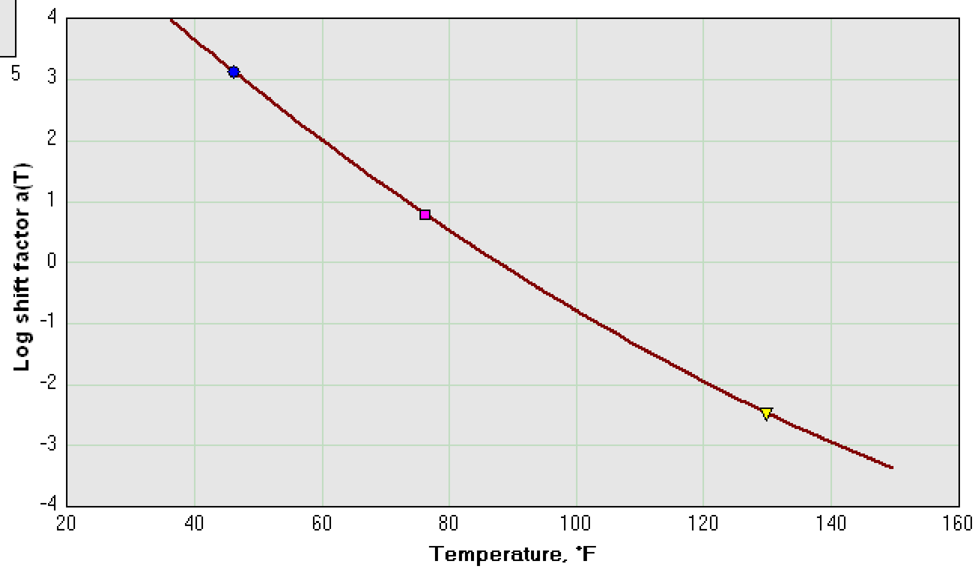
Sample ID: ion 0003

Reference Temperature = 88 ºF

$$\log E^* = \delta + \alpha[1 + \exp(\beta - \gamma \log t_r)]^{-1}$$

where $t_r = 1 \,/\, (Reduced\ frequency,\ Hz)$

$$\log a_T = b\ T^2 + c\ T + d$$



α	2.210962e+00
β	7.456269e-01
γ	5.284471e-01
δ	4.412635e+00
r^2	0.9997292

b	2.013474e-04
c	-1.022417e-01
d	7.425933e+00
r^2	1.0000000

NB. This is an empirical relation; E* is a function of Frequency, NOT of time.

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Tasks 6 and 7

Overview

- Basic Construction Specifications
- Test Sections
  - Material Used
  - Construction Process
  - Construction Results
  - Deviations From Plan Notes

Construction Specifications

Table of Test Section Location, Additives and Compaction According to Plans

Test Section	Construction Width	MRM	Begin Station	Process	Compaction
C1	Full Width	78.19+.086	770 + 00	Virgin	0.95
RAP1	Full Width	78.19+.280	762 + 50	25% RAP	0.95
RAP2	Full Width	78.19+.422	755 + 00	50% RAP	0.95
RAP3	Full Width	78.19+.564	747 + 50	75% RAP	0.95
FIB1	Full Width	78.19+.706	740+00	0.1% Fibers/Cement Base Course Salvage	0.95
C2	Full Width	79.00+.095	732 + 50	Virgin	0.95
CEM1	32'	79.00+.237	725 + 00	Cement	0.95
CEM2	32'	79.00+.379	717 + 50	Cement	95%/Microcracked
FA1	32'	79.00+.521	710 + 00	Fly Ash	0.95
FA2	32'	79.00+.663	702 + 50	Fly Ash	95%/Microcracked
C3	Full Width	79.00+.805	695 + 00	Normal Base	0.95
AE	32'	79.00+.947	687 + 50	Asphalt Emulsion	0.95
AEL	32'	80.00+.220	672 + 50	Asphalt	0.95
AF	32'	79.00+.504	657 + 50	Foamed Asphalt/PC	0.95

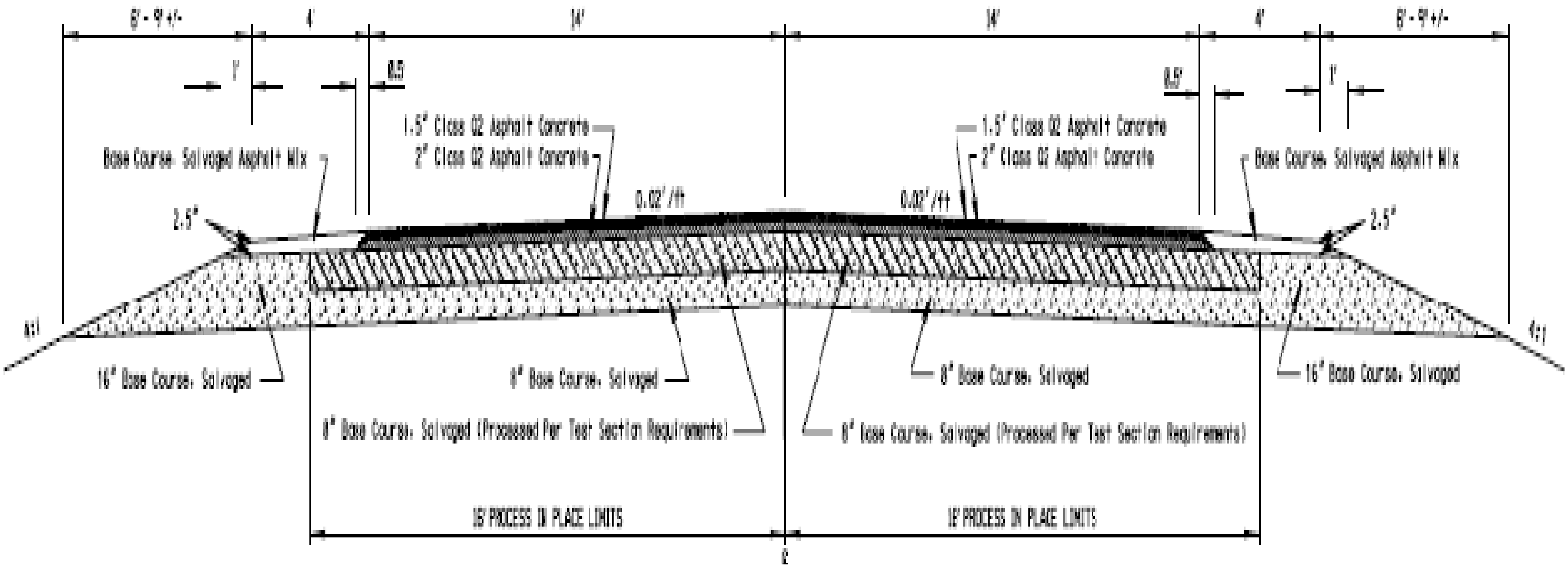
*FIB1 was excluded from construction

Construction Specifications

- Sections C1,C2,C3, RAP1,RAP2 and RAP3
  - Shall be constructed on an 8" unstabilized base section of the salvaged base course. The sections shall be 8" in thickness and shall be compacted according to the plan notes.
- Sections CEM1, CEM2, FA1,FA2, AE, AEL and AF
  - Shall be constructed within a 16" unstabilized base section of the salvaged base course. The upper 8" of the salvaged base course shall contain the stabilized material and shall be compacted according to the plan notes.

Typical Section

RESURFACING SECTION & PROCESS IN PLACE FOR RESEARCH TEST SECTIONS



Test Section Location

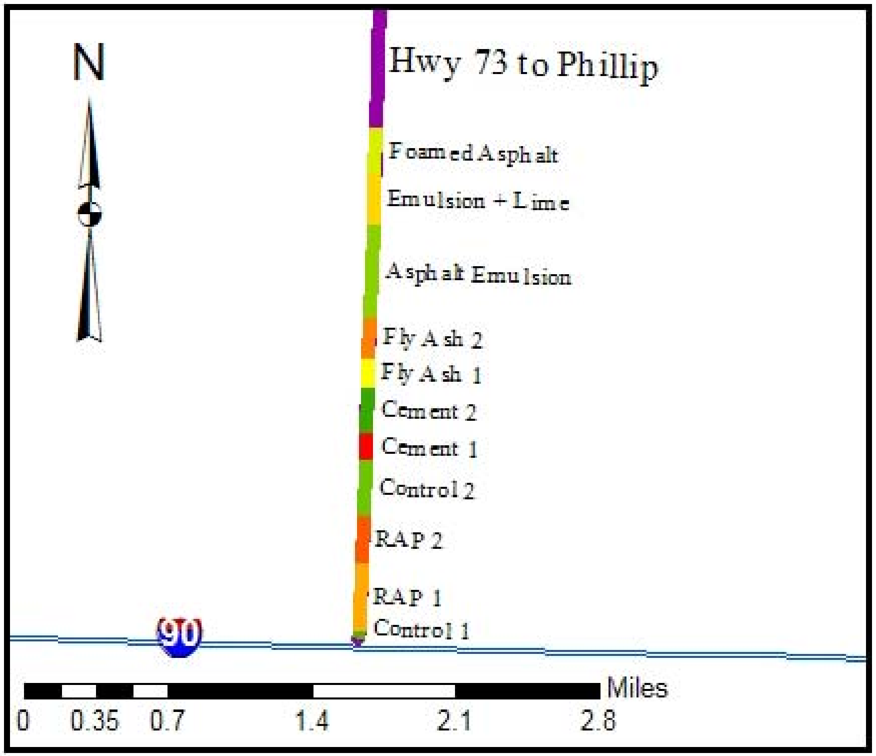


Figure A: Graphical Breakdown of Test Sections.

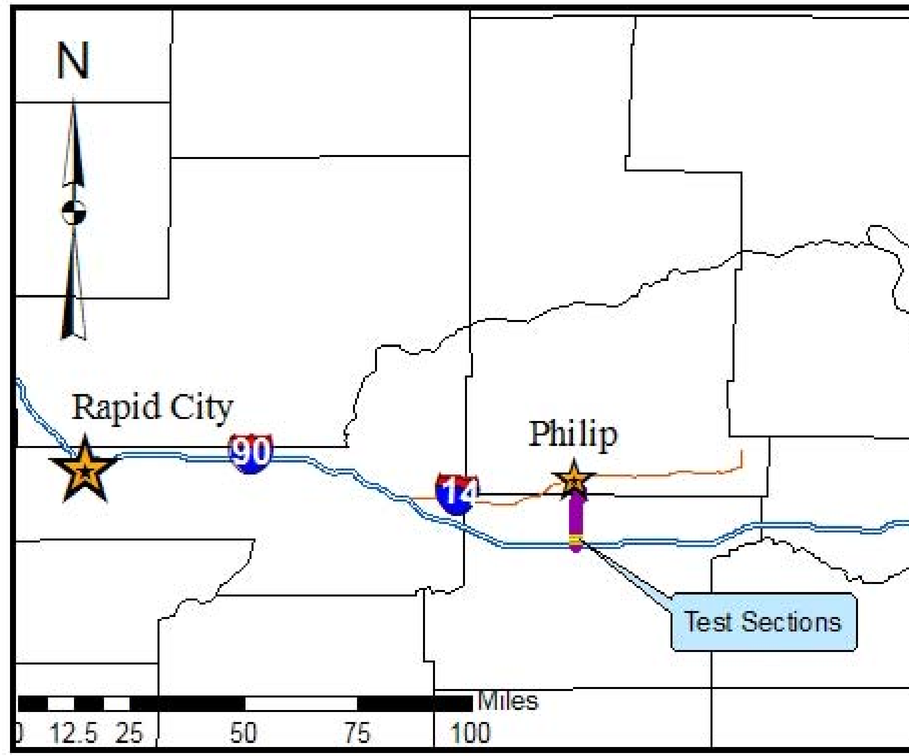


Figure B: Location of Test Section in Respect to Rapid City

RAP Sections

- Material Used
  - 25%, 50% and 75% RAP with virgin material.
- Construction Process
  1. Spray water over the surface.
  2. Place the processed RAP + Virgin material.
  3. Compact with pad foot roller.
  4. Shape the surface with a blade.
  5. Finish the section with a steel roller.

Note: All RAP sections were processed off-site.

CEM

- Material Used
  - Recycled material stabilized with 3% Cement.

- Construction Process

1. Spread cement (3%) on section with vane spreader.
2. Use FDR process to blend cement with upper 8” of RAP base course.
3. Compact with pad foot roller.
4. Shape with blade.
5. Smooth and shape with two rubber tire rollers.
6. Smooth and shape with a steel face roller.
7. Prime.
8. CEM 2 was microcracked using steel face roller with 3 passes after 48 hours.


Before


WARNING


DYNAPAC
NORTH
73


After

FA

- Material Used
  - Recycled material stabilized with 14% fly ash.

- Construction Process
  1. Spread fly ash (14%) on section with vane spreader.
  2. Use FDR process to blend fly ash with upper 8” of RAP base course.
  3. Compact with pad foot roller.
  4. Shape with blade.
  5. Smooth and shape with two rubber tire rollers.
  6. Smooth and shape with a steel face roller.
  7. Prime.
  8. FA 2 was microcracked using steel face roller with 3 passes after 48 hours.


Before


WARNING
THIS MACHINE MAY LUNGE BACKWARD WHICH COULD RESULT IN PERSONAL INJURY OR DEATH. STAY AT LEAST 25 FEET CLEAR OF
AREA BEHIND THE MACHINE.
TEREX
WARNING


DYNAPAC


After

AE

- Material Used
  - Recycled material stabilized with 3.5% emulsion.

- Construction Process
  1. Blend emulsion (3.5%) directly within reclaimer unit.
  2. Compact with pad foot roller directly behind reclaimer unit. Continue compaction with pad foot until light is visible between pads (“walk itself out”).
  3. Blade off nubs created by pad foot roller.
  4. Compact with two rubber tire rollers until compaction is achieved.
  5. Use blade and steel face roller, without vibration, to shape.


Before
WARNING
Industrial Builders, Inc.
GENERAL CONTRACTORS
TEREX
RS-800
231
KANE


DYNAPAC


After

AE with Lime

- Material Used
  - Recycled material stabilized with 3.4% emulsion and 1% dry lime.
- Construction Process

1. Spread a layer of dry lime (1%) using vane spreader.
2. Blend emulsion (3.4%) directly within reclaimer unit.
3. Compact with pad foot roller directly behind reclaimer unit. Continue compaction with pad foot until light is visible between pads ("walk itself out").
4. Blade off nubs created by pad foot roller.
5. Compact with two rubber tire rollers until compaction is achieved.
6. Use blade and steel face roller, without vibration, to shape.


Before
CA25


3-173
DYNAPAC


After

AF

- Material Used
  - Recycled material stabilized with 3% foamed asphalt and 2% Portland cement.

- Construction Process

1. Spread a layer of cement (1%) using vane spreader. Mill cement into base, lightly compact and blade. Allow to set for 3-4 hours.
2. Spread a layer of cement (1%) using vane spreader.
3. Blend foamed asphalt (3%) directly within foamed asphalt reclaimer unit.
4. Compact with pad foot roller directly behind reclaimer unit. Continue compaction until light is visible between pads.
5. Blade off nubs created by pad foot roller.
6. Compact with two rubber tire rollers.
7. Use blade and steel face roller, without vibration, to shape.


Before

BORDER STATES
US DOT-119768


DYNAPAC


After

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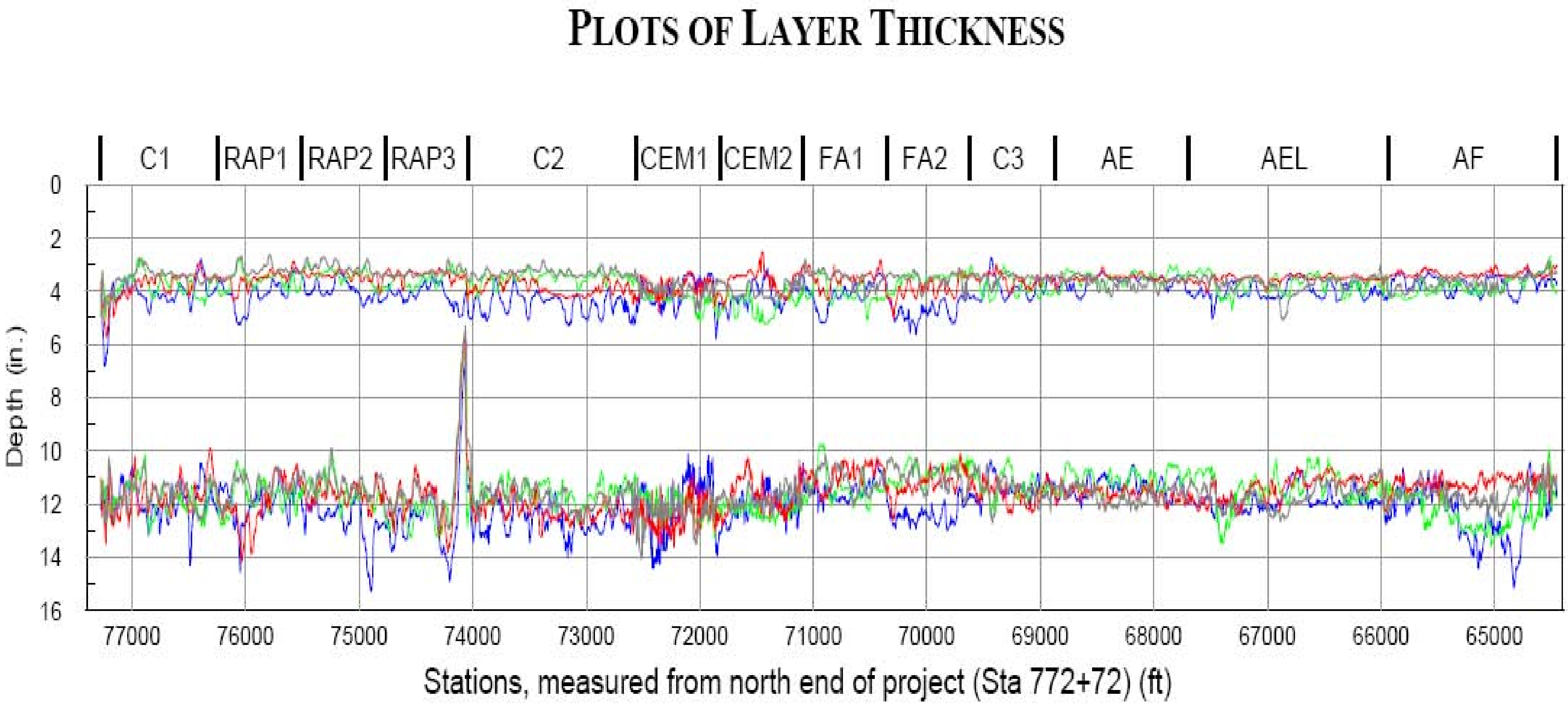
Task 8

Task 8 – Monitor Performance of Test Sections

- The objective of this task is to monitor the performance of the test sections over a period of two years:
  - Ground Penetrating Radar (GPR) in Summer 2009
  - Falling Weight Deflectometer (FWD) in Spring and Fall 2009 and 2010
  - Rutting and profile measurements in Spring and Fall 2009 and 2010
  - Periodic visual surveys.

Ground Penetrating Radar (GPR) Profile



Preliminary Performance of Test Sections

- All test sections are performing nominally with some cracking noted in the cement and fly ash sections.
    - Cement sections – Transverse cracks at ≈ 27 feet spacing in microcracked section and transverse cracks at ≈ 19 feet in non-microcracked section.
    - Fly ash sections – Transverse cracks at ≈ 125 feet spacing in non-microcracked section and only one crack was visible in the microcracked section.
    - No distress in other sections.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Thank you.

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