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

DTFH61-06-C-00038
(October 2006 – July 2012)

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Western States Regional In-Place Recycling Conference
Ontario, CA
Sep., 11-13, 2012

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. It conserves natural resources and is cost effective.

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

  - 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 utilizing advanced test methods.

Project Technical Panel

- Randy Battey, Mississippi DOT
- Joe Feller, SDDOT
- Gary Goff, FHWA ND Division
- David Gress, Univ. of New Hampshire
- Gregory Halsted (ARRA)
- Brett Hestdalen, FHWA SD Division
- Lee Gallivan, FHWA
- 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, Colas, Inc. (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

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

Task 1
Literature Review

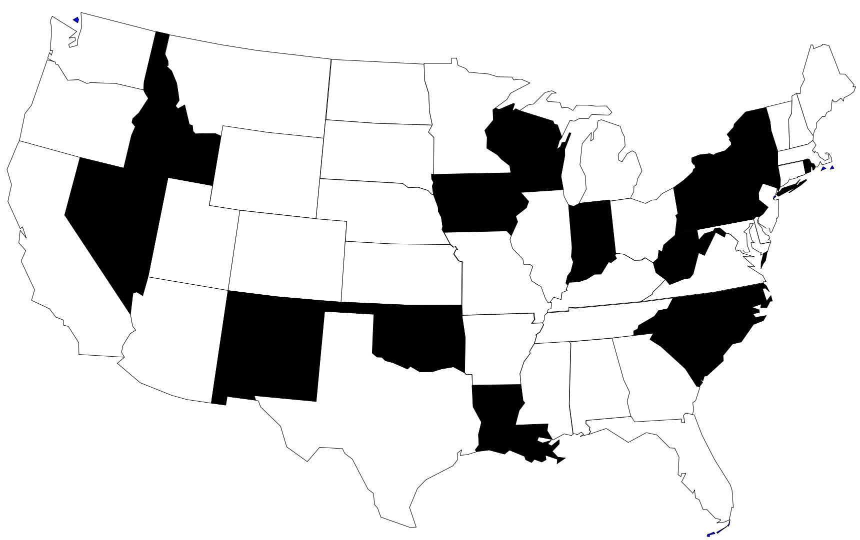
- Included in this task are summaries of literature reviews on: (1) the history, economics, construction equipment, and specifications associated with FDR; (2) field testing methods; (3) laboratory testing procedures; and (4) additives.

Task 2

Document State Specifications and Construction Experiences

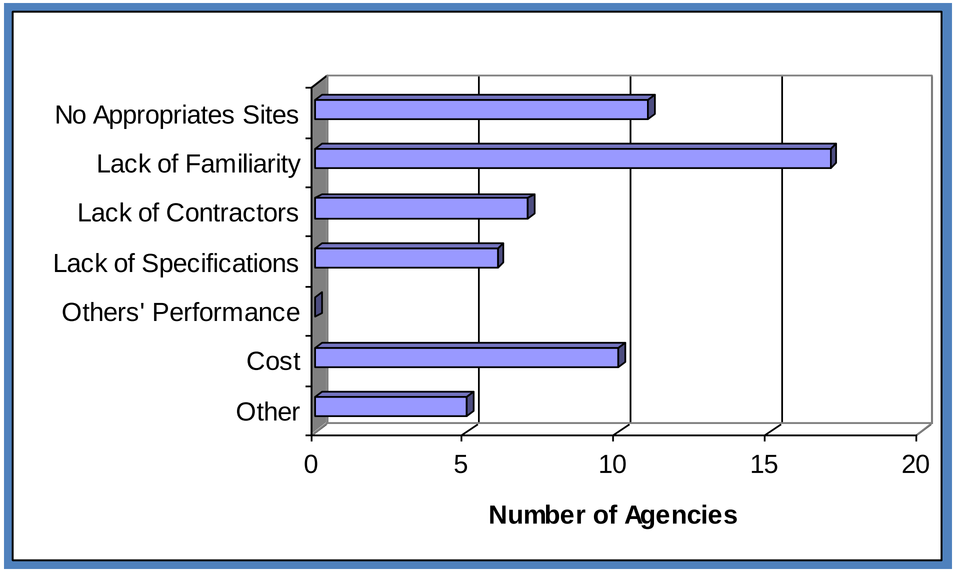
Survey Results

- 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.)



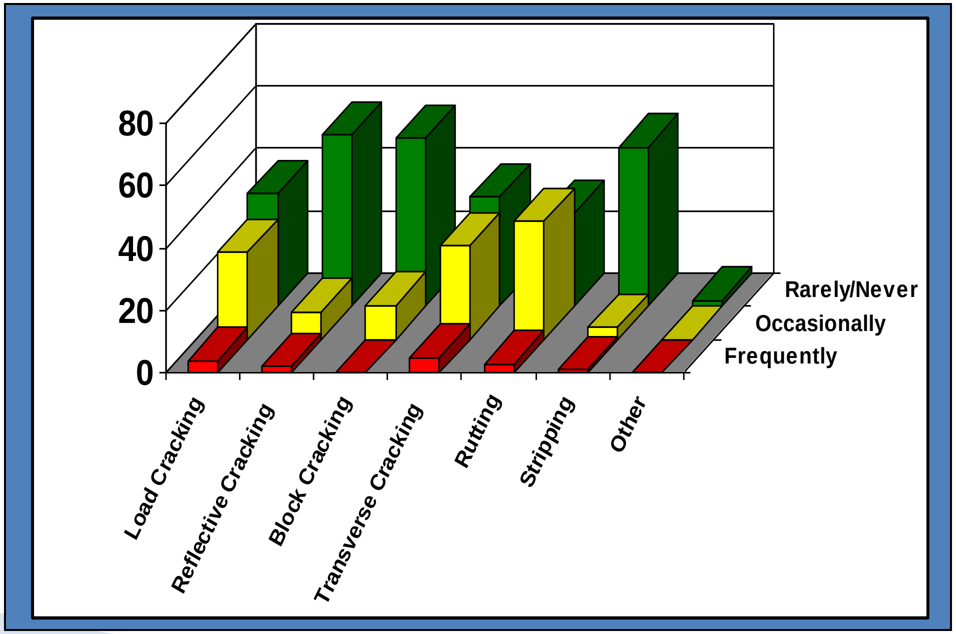
Survey Results

- 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:



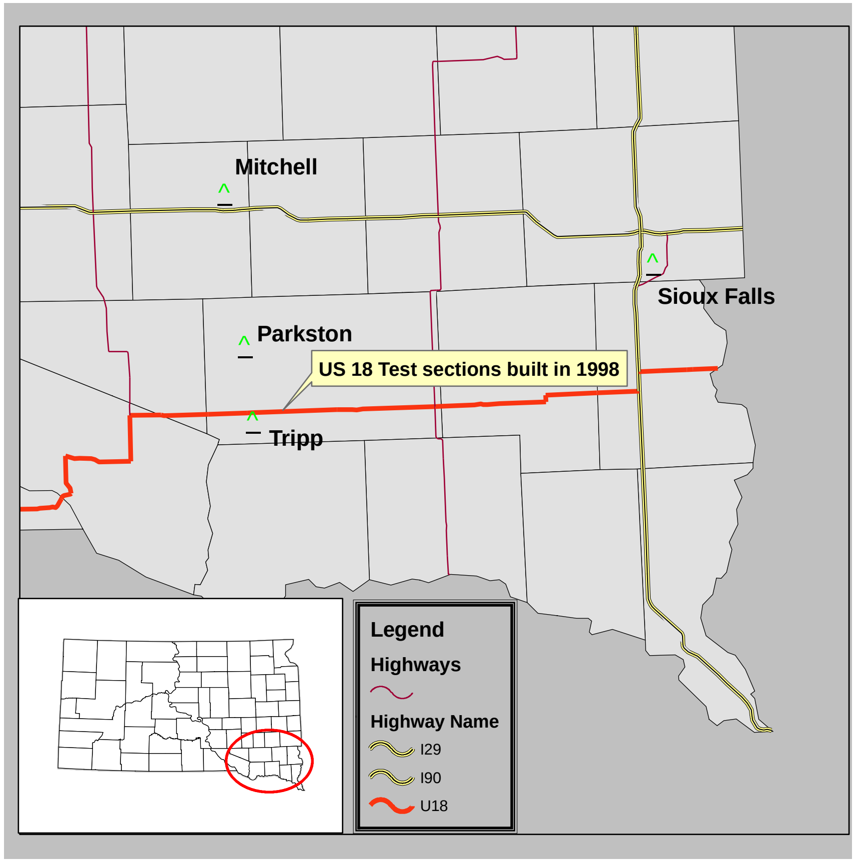
Survey Results

- 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



Task 3
Condition Survey of Existing Test Sections

Condition Survey of US Highway 18



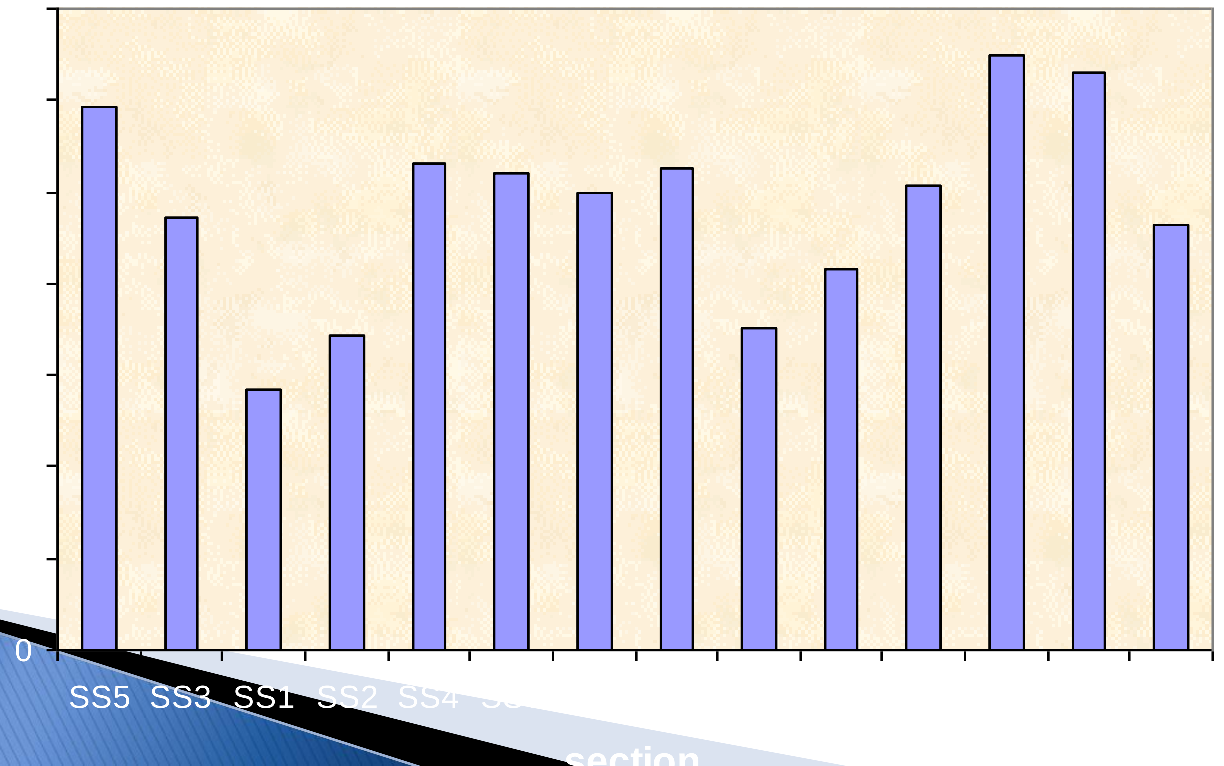
- Location: south east corner of SD and begins 1 mile east of Tripp.
- Extends 3 miles east.

US 18 Test Sections

- 12 test sections were constructed in 1997.
- 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.

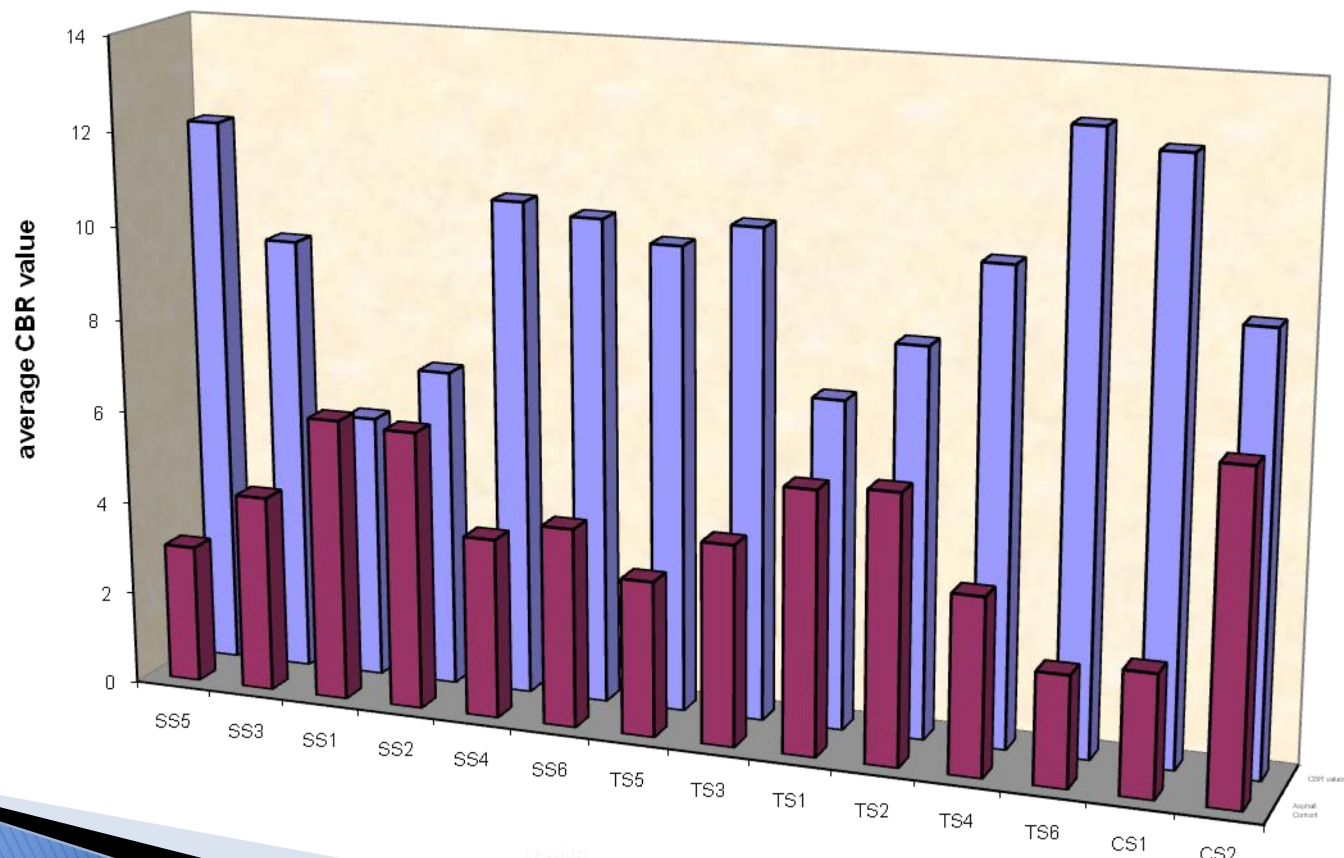
Sampling of Roadway Materials

- 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.



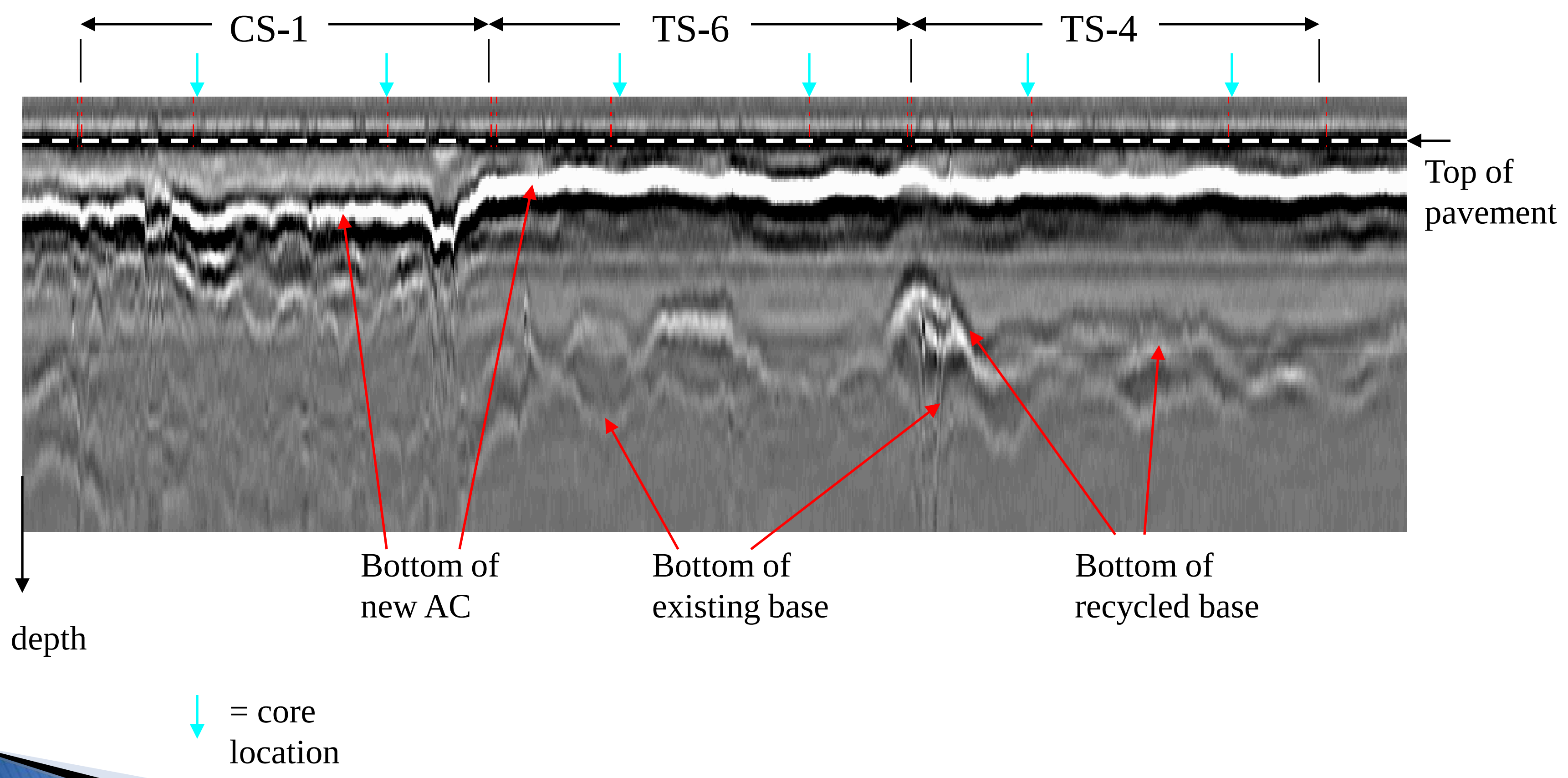
Falling Weight Deflectometer

- 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.

Sample of GPR Data Collected



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

- Long Term Pavement Performance (LTPP) survey results.
  - Typical distresses

Fatigue Cracking Section SS2

Longitudinal and centerline cracking

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

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

Composition of FDR

- Good Clean (GC) – Good source crushed aggregate with less than 10% of the material passing the #200 US standard sieve.
- Good Dirty (GD) – Good source crushed aggregate with 14.7% passing the #200 US standard sieve.
- Poor Clean (PC) – Poor source rounded aggregate with less than 10% of the material passing the #200 US standard sieve.
- Poor Dirty (PD) – Poor source rounded aggregate with 14.7% passing the #200 US standard sieve.
- RAP: 0, 25, 50, and 75%

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
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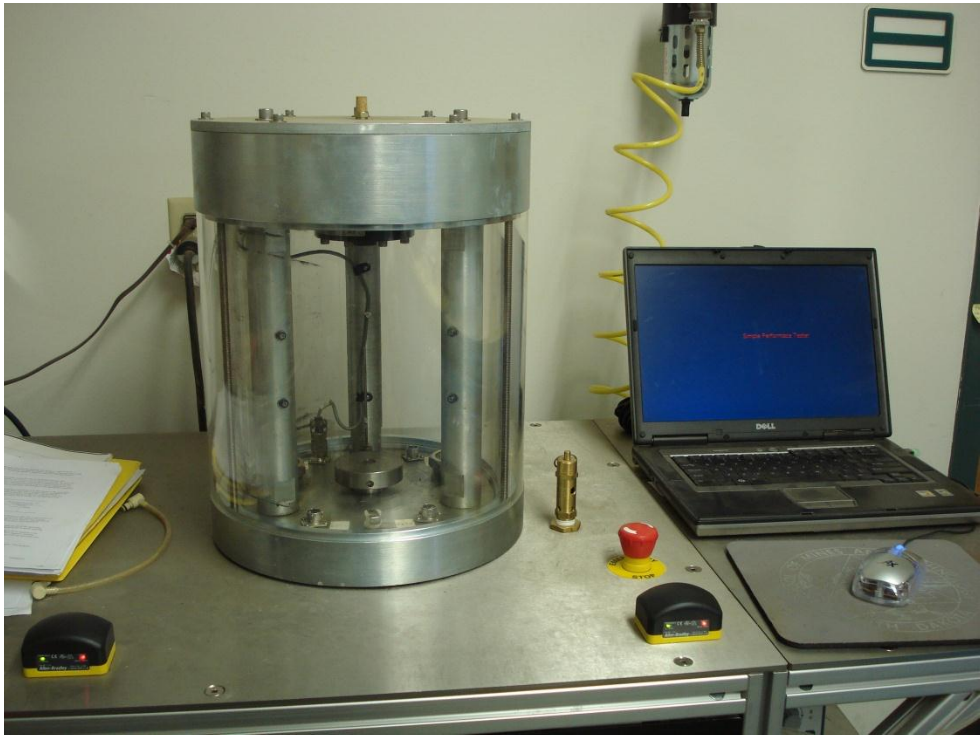
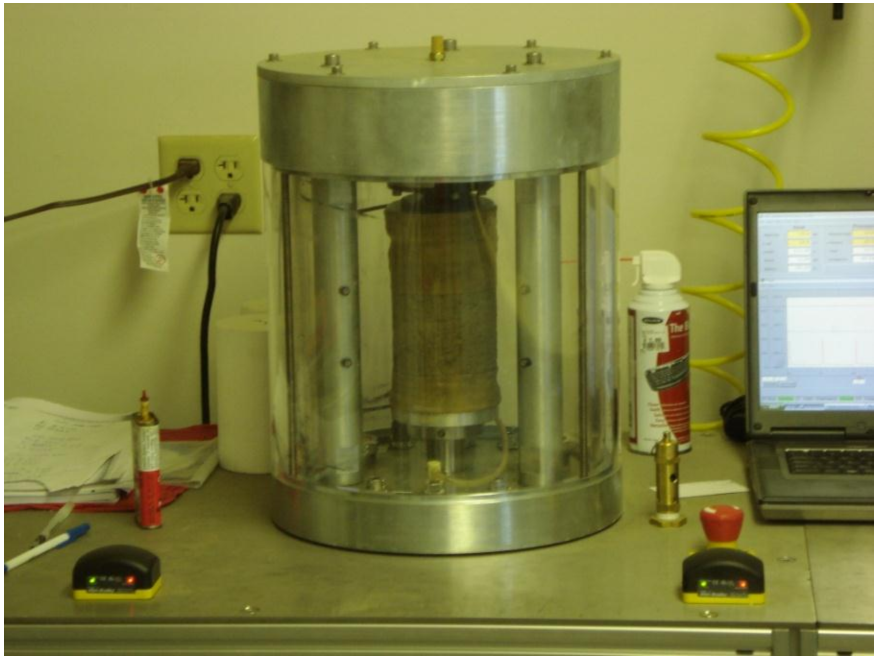
Simple Performance Tester (SPT)

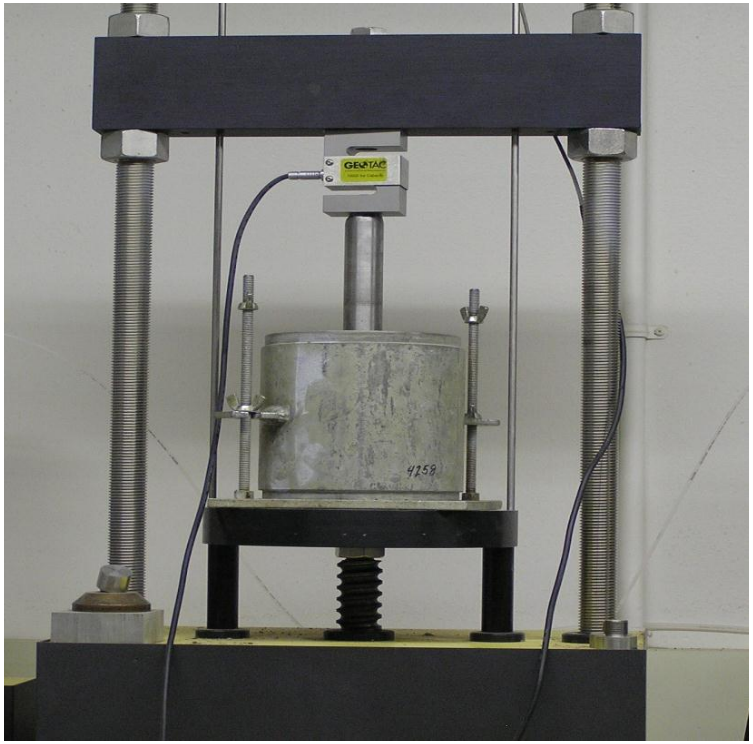


Gyratory Compactor

Testing of Mechanically Stabilized FDR Mixes



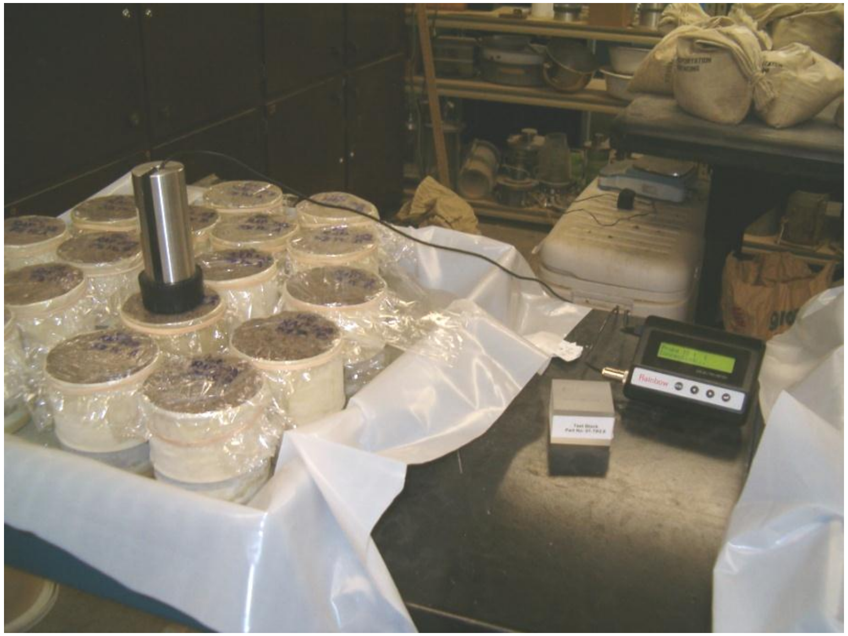
Resilient Modulus Testing



California Bearing Ratio (CBR) Testing

Testing of Portland Cement/Fly Ash Stabilized FDR Mixes

Unconfined Compression Testing



Tube Suction Testing

Testing of Portland Cement/Fly Ash Stabilized FDR Mixes

Moisture Sensitivity Testing with Wire Brush Method

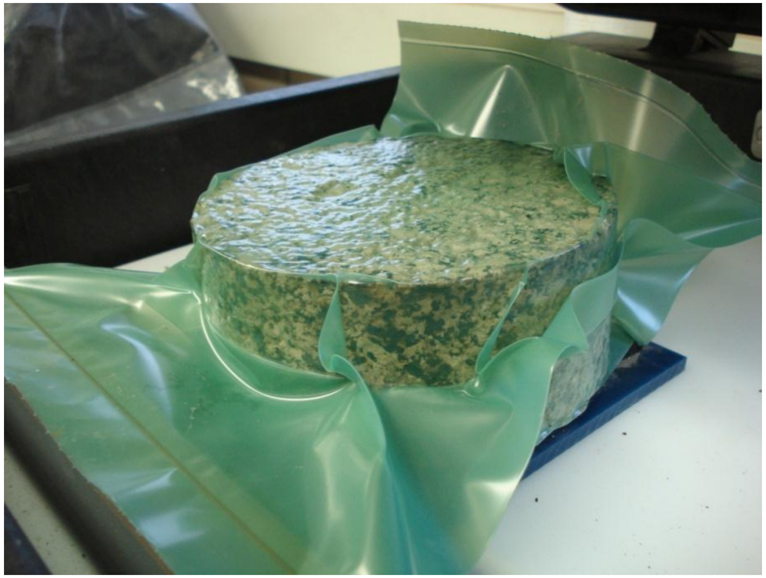
Tested Samples

Testing of Asphalt Emulsion/ Foamed Asphalt FDR Mixes

SuperPave Gyratory Compactor

Foamed Asphalt Lab

Testing of Asphalt Emulsion/ Foamed Asphalt FDR Mixes



CoreLok Device

Indirect Tensile Strength (ITS) Testing

Task 5

Development of Standard Laboratory Testing Method

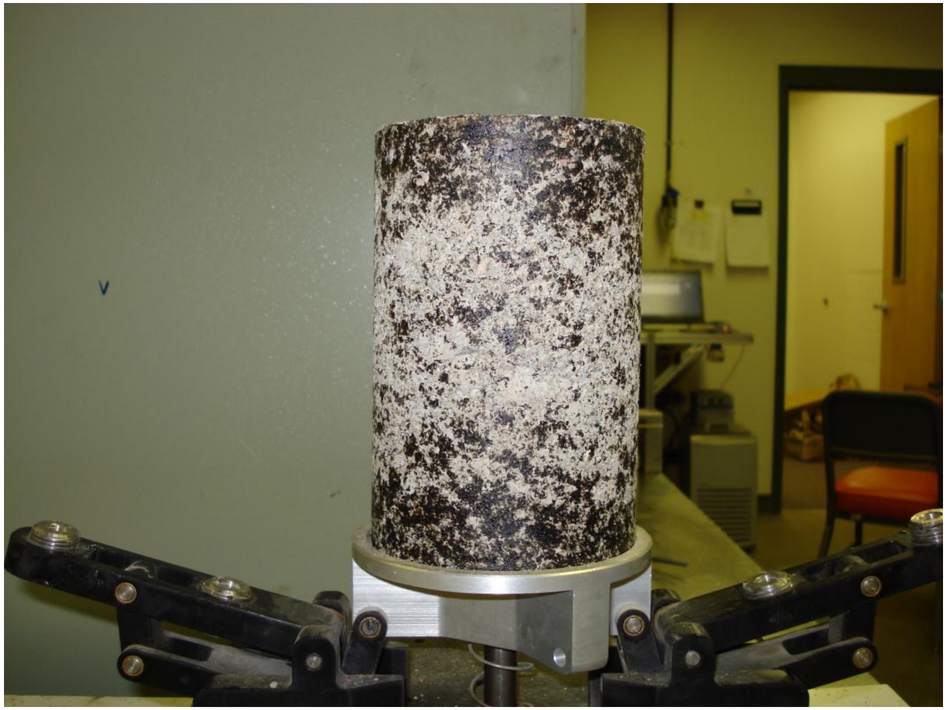
- The objective of this task is to develop a laboratory testing procedure to address material properties needed to support practical pavement design. The focus will be on developing standard test methods to be used specifically for AASHTO related pavement designs.
- The FDR process produces a layer that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

Simple Performance Tester (SPT)

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

Testing of Asphalt Emulsion/ Foamed Asphalt FDR Mixes



Foamed Asphalt Specimen:
Poor Dirty Gradation with 75% RAP.

CoreLok for specific gravity determination.

Modulus of Rupture

Tasks 6 and 7

Field Procedures and Construction Details

Test Section Location

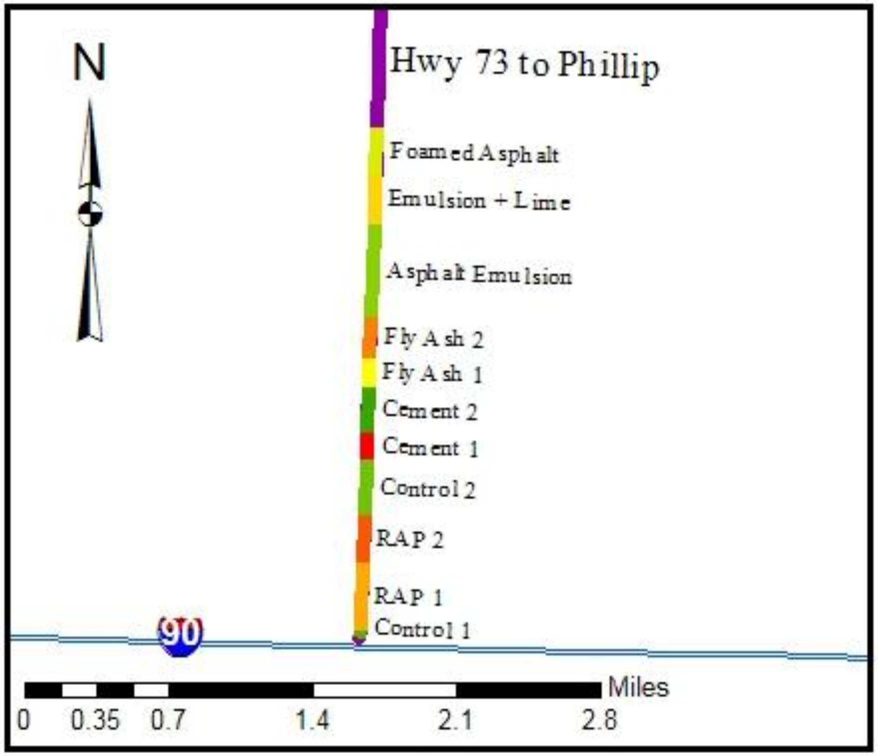


Figure A: Graphical Breakdown of Test Sections.

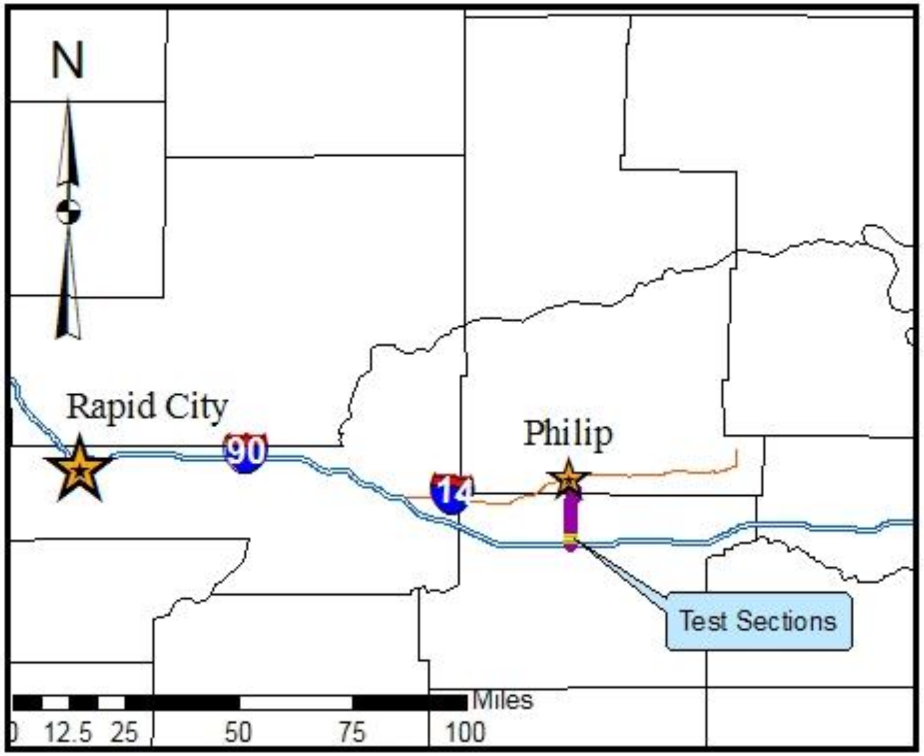


Figure B: Location of Test Section in Respect to Rapid City

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


Before


WARNING

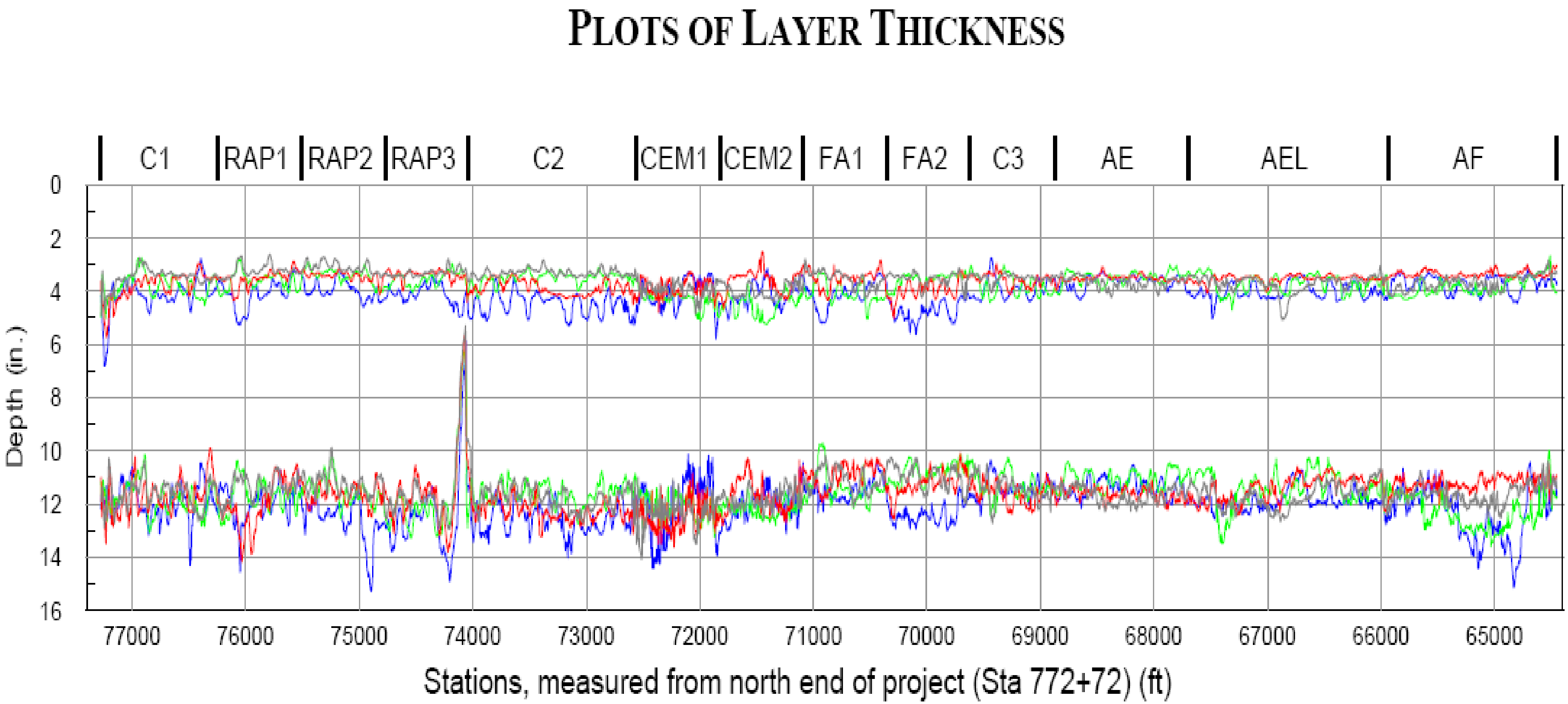

After

Task 8
Monitoring of Construction 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)
  - Falling Weight Deflectometer (FWD)
  - Rutting and profile measurements
  - Dynamic Cone penetrometer (DCP)
  - Unconfined Compression Tests (UC)
  - Dynamic Modulus Tests (M_R)
  - Periodic visual surveys

Ground Penetrating Radar (GPR) Profile

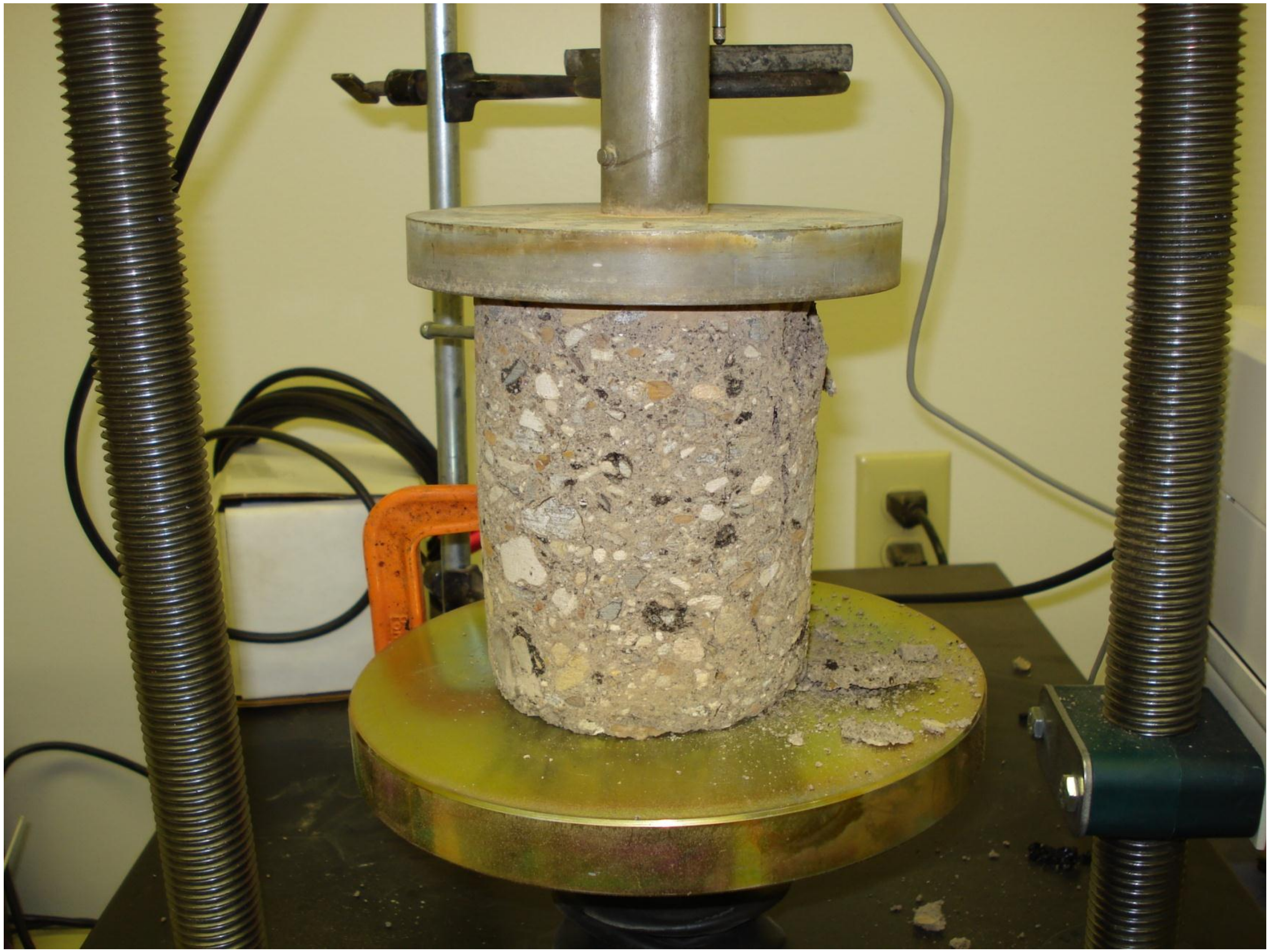


Falling Weight Deflectometer (FWD)

Dynamic Cone Penetrometer (DCP)

Coring of Base Material

Unconfined Compression Testing



Preliminary Performance of Test Sections

- Cement sections – Transverse cracks at ≈ 27 feet spacing in microcracked section and transverse cracks at ≈ 19 feet in non-microcracked section (majority of cracks within two years).

- Fly ash sections – Transverse cracks at ≈ 125 feet spacing in non-microcracked section and only one crack was visible in the microcracked section (majority of cracks during the first year).

- Microcracking of the cement and fly ash test sections did appear to reduce the amount of transverse cracking.

- Performance of the FDR test sections constructed with 25 percent, 50 percent, and 75 percent RAP, along with the test sections consisting of emulsion and emulsion with lime was very similar to the control sections, i.e., very little rutting and generally no transverse or longitudinal cracking was observed during the monitoring period.

- FDR test sections with cement and foamed asphalt had the lowest short term performance (most likely because these test sections were very stiff as observed in the DCP testing and FWD resilient modulus back-calculation).


12/06/2008


12/06/2008

Task 9
Establishment of Laboratory Testing and Design procedures

- The objective of this task is to develop a set of standard laboratory testing and design procedures for FDR based on the results of all subsequent tasks.

- Primary areas of interest were stabilization methodology, optimum moisture, optimum design, and the mix design criteria.

- Stabilization method
  - Un-stabilized by adding virgin aggregates
  - Chemically stabilized by adding PC or fly ash
  - Asphalt stabilized by adding asphalt emulsion or foamed asphalt
- Optimum moisture content
  - Moisture density curve following AASHTO T 180

- Optimum design meeting the recommended design criteria

  - Resilient modulus for un-stabilized FDR
  - Unconfined compressive strength and moisture sensitivity properties using Tube Suction Test for chemically stabilized FDR
  - Tensile strength and moisture sensitivity properties for asphalt stabilized FDR

- Mix design criteria
  - FDR stabilized with PC or fly ash
    - Dry unconfined compressive strength: 200 – 400 psi (1.4 – 2.8 MPa)
    - Tube Suction Test, 14 days dielectric constant: max. 9
  - FDR stabilized with asphalt emulsion or foamed asphalt
    - Dry tensile strength at 77°F (25°C), minimum: 30 psi (0.21 MPa)
    - Tensile strength ratio at 77°F (25°C), minimum: 70 percent

A draft AASHTO Standard Provision has been prepared and submitted to the AASHTO Subcommittee on Materials. This standard includes step by step methods for mix design including mix design process, compaction, air content, moisture sensitivity, and tolerance criteria.

Complete final reports can be downloaded from our website

http://fdr.sdsmt.edu

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