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# IN-SITU EVALUATION AND LABORATORY TESTING OF ASPHALT CONCRETE FULL-DEPTH RECLAMATION

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***ABSTRACT***

***Rehabilitating an old pavement by pulverizing and stabilizing the existing pavement is a process referred to as Full Depth Reclamation (FDR). The stabilized layer becomes either the base or sub-base of the new pavement structure. This process has been used widely for over 20 years in Texas to strengthen and widen structurally inadequate pavement sections. However, there is little success incorporating more than 50 percent recycled asphalt pavement (RAP) material in typical FDR design, so approaches to dealing with thick localized HMA layers must be developed. This study focuses on implementation of test protocol on successful FDR practice, in-situ evaluation of existing asphalt pavement (FM 1887), and determination of optimum mix design of a 50/50 combination of RAP and flexible base materials. In order to accomplish the objective of study, characterization of existing asphalt pavement structure and laboratory mix design test were conducted on the basis of FDR practice protocol. The evaluation of the in-service performance of current flexible pavement section was carried out using ground penetrating radar (GPR), dynamic cone penetrometer (DCP), and coring of asphalt concrete sample for the selected field test sections. To assess the performance characteristics of FDR in base-course mix design, the determination of optimum moisture content, triaxial compression test, capillary suction test, seismic property test, and unconfined compressive strength test were conducted. The in-situ pavement analysis results indicate that the current pavement distresses are related primarily to the stripped gravel layer, but secondary problems are caused by high plasticity index (PI) soils and edge drying, causing longitudinal cracks and roughness. To rehabilitate this road, FDR could be considered. Laboratory testing to select the optimal type and amount of stabilizer indicates that the suggested mix design would be a 50/50 blend of existing base and recycled asphalt pavement (RAP) materials containing 3% cement which satisfied the necessary strength and moisture susceptibility requirement.***

***KEYWORDS:** Full Depth Reclamation, High Plasticity Index Soil, Ground Penetrating Radar, Recycled Asphalt Pavement, Cement Stabilization*

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**Original Article**

## 1. INTRODUCTION

Rehabilitating an old pavement by pulverizing and stabilizing the existing pavement is a process referred to as Full Depth Reclamation (FDR). Basically, the existing pavement layers are milled, stabilized with lime, cement, fly ash, asphalt, or combination of such materials and compacted as a new base or subbase layer of the new pavement structure. This process shows great potential as an economical rehabilitation alternative that provides deep structural benefit, conserves highway construction raw materials, and quickly returns the section to service [ARRA 2001]. This process has been used widely for over 20 years in Texas to strengthen and widen structurally inadequate pavement sections. For example, the Bryan and Lubbock district constructed their first few projects on low volume roadways in the early 1990s [Scullion et al. 2012]. Their initial experiences were positive and both districts have now recycled closed to 1000 miles of low volume roadways. Although the FDR process is widely used in several districts in Texas, others are just getting started. Moreover, there is little success incorporating more than 50 percent recycled asphalt pavement (RAP) material in typical FDR design. Therefore, approaches to dealing with thick localized HMA layers and the FDR techniques and interpretation guidelines to select the optimum rehabilitation strategy for a flexible pavement must be developed. This study presents implementation of test protocol on successful FDR practice as recommendations for those districts wishing to embark on FDR programs.

## 2. RESEARCH OBJECTIVES, SCOPES, AND METHODS

An objective of this study is focused on implementation of test protocol on successful FDR practice, in-situ evaluation of existing asphalt pavement (FM 1887 roadway), and determination of optimum mix design of FDR. This goal was initiated by both characterization of existing pavement structure and laboratory mix design test as illustrated in Figure 1. The evaluation of the in-service performance of current pavement section such as structure of pavement and HMA condition was carried out using ground penetrating radar (GPR), dynamic cone penetrometer (DCP), and coring of asphalt concrete sample for the selected field test sections.

To assess the performance characteristics of FDR in base-course mix design, the laboratory testing protocol included the determination of optimum moisture content, triaxial compression test for unbound materials, the evaluation of the moisture susceptibility using the capillary suction test, seismic properties, and unconfined compressive strengths for the fabricated specimens as per Texas Department of Transportation (TxDOT) guideline for base-course sample evaluation.

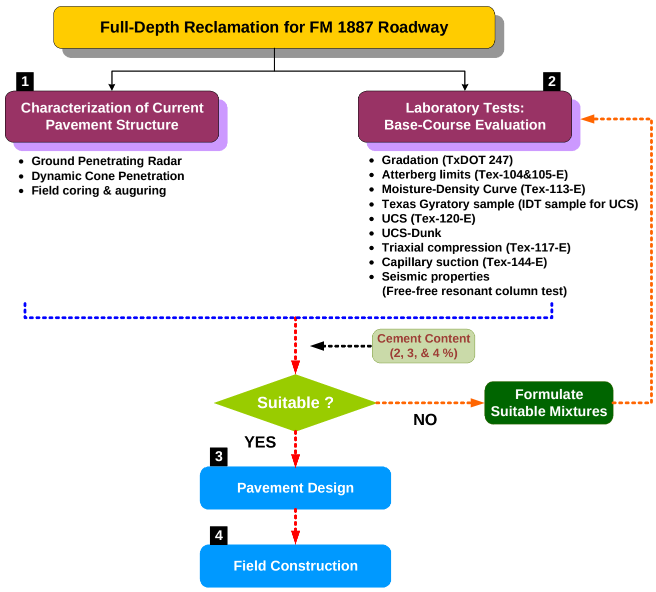



**Figure 1: Diagram of FM 1887 FDR project Scope and Experimental Program**

## 3. CHARACTERIZATION OF EXISTING PAVEMENT STRUCTURE

### 3.1 Visual Survey on Pavement Condition

Figure 2-(a) and 2-(b) show the visual survey on FM 1887 pavement conditions for both south bound (SB) and north bound (NB) lanes, respectively. The primary distress is longitudinal cracking and edge faulting for the two lane

section of FM 1887. In fact, the existing surface layer was placed in 2004 and substantial maintenance has been applied to this highway in the past 10 years. It consisted of an underseal and approximately 2 inches of HMA. The current condition of the roadway is only fair with many areas being patched, multiple surface seals and extensive crack sealing has been placed. Although the 2004 treatment consisted on an underseal and thin overlay, it did not perform well. There is nothing wrong with the last overlay and underseal, as described the cause of the problem are related to the poor quality of the lower HMA layers.

### 3.2 Characterization of Pavement Structure

Ground penetration radar (GPR) was used to assess the pavement structure such as base layer thickness and layer interface condition. Figure 3 presents typical GPR data and a typical core from FM 1887 which is about 1 mile of pavement from 5.5 to 6.5 miles north of Monaville. The surface is the solid red line and the depth scale is on the right of the figure. The upper plot is color coded GPR data. The most significant feature is the strong blue reflection at some depth below the surface. The core was taken at the location marked. This core shows severe moisture damage. The only good part of the HMA layer is the top 2 inches, the deeper in the HMA the worse the condition. Stripping of this severity is common in many gravel hot mixes made with uncrushed river gravel which were placed typically before the use of anti-stripping agents and before the crushed face requirement. It is very common in many areas in East Texas.

**(a). Typical Condition of FM 1887 (SB)** **(b) Typical Condition of FM 1887 (NB)**

**Figure 2: Typical Pavement Conditions of FM 1887**

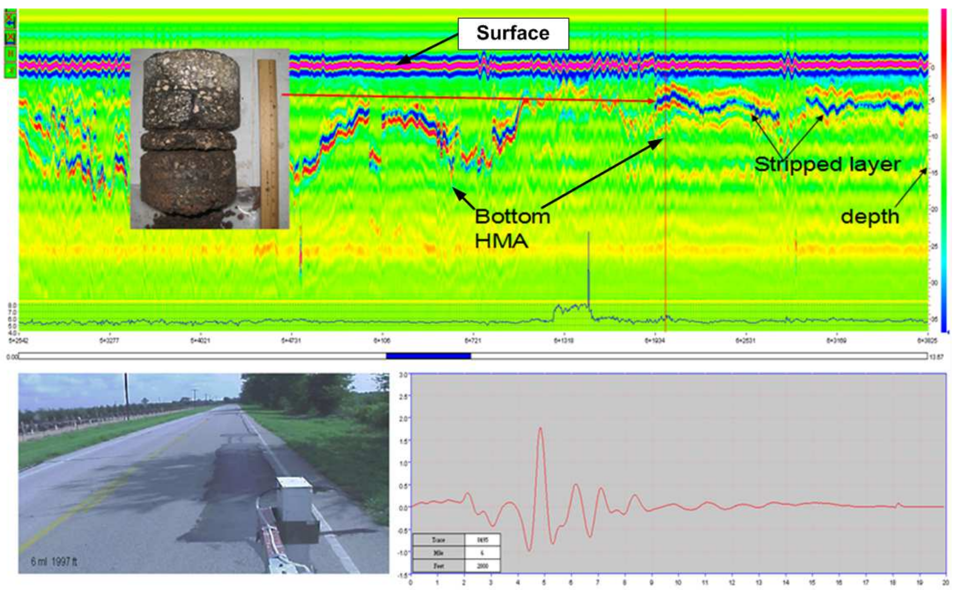



**Figure 3: GPR Data and Core Sample (NB Direction) of FM 1887**

### 3.3 Verification of Pavement Structure and Sampling of Material

The existing pavement structure characterized by GPR was further verified using dynamic cone penetrometer (DCP) profiles and core sample analysis. As shown in Figure 4, five core locations were selected for validation of the pavement structure and for collecting materials for laboratory testing. These locations were in the northbound direction from Monaville.

Basically, the structure of this roadway consists of the 9 to 15 inches of HMA and the 5 to 10 inches of base. The thickness of HMA is reasonable, but some lower layers are severely stripped (See core samples in Sections 1 and 3) as previously stated. The deterioration of HMA occurred at different depths.

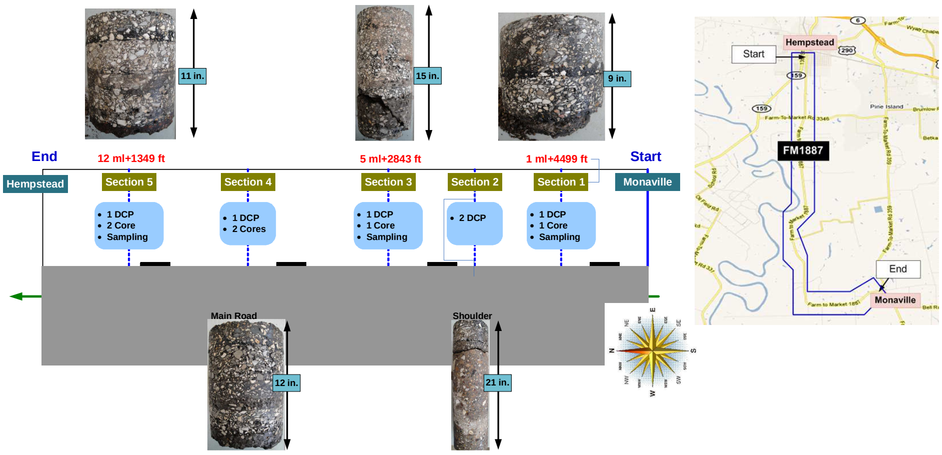



**Figure 4: Asphalt Concrete Core Samples and Material Sampling Locations of FM 1887**

Dynamic Cone Penetration (DCP) profiles were collected at each section and presented in Figure 5. The DCP data indicate that both base and subgrade appear to be quite poor. In general, typical elastic modulus (E) for an unbounded aggregate base ranges from 15 to 45 ksi, while that for stabilized flexible base modulus is 60 to 120 ksi. The E for base at section 2 is 7.8 ksi and is quite low. This low E could result from a wet subgrade condition which contributes to degradation of the modulus for base by weakening the bonding between materials' particles.

Base and subgrade samples at each site were collected and Atterberg limits of these samples were determined (Table 1). As expected, soil samples in locations 1, 2, and 3 have higher plasticity index than that of locations 1 and 2. This supports the results of visual survey and GPR causing longitudinal cracks and roughness of pavement surface.

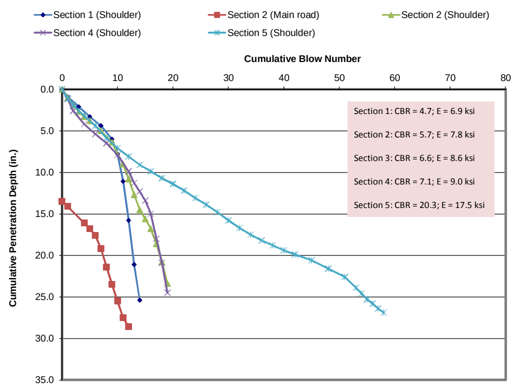



**Figure 5: Dynamic Cone Penetration (DCP) Profiles on FM 1887**

**Table 1: Atterberg Limits of Base and Soil Samples on FM 1887**

| Location | Pavement Structure | Liquid Limit (LL) | Plastic Limit (PL) | Plasticity Index (PI) |
|---|---|---|---|---|
| Section 1 | Base | - | - | - |
| | Subgrade (soil) | 31.3 | 13.4 | 17.9 |
| Section 2 | Base | 13.7 | 9.0 | 4.7 |
| | Subgrade (soil) | 53.4 | 20.4 | 33.0 |
| Section 3 | Base* | 12.6 | 11.4 | 1.2 |
| | Subgrade (soil) | 49.4 | 19.7 | 29.7 |
| Section 4 | Base | 13.3 | 9.9 | 3.4 |
| | Subgrade (soil) | 27.8 | 12.4 | 15.4 |
| Section 5 | Base | 11.2 | 8.1 | 3.1 |
| | Subgrade (soil) | 10.4 | 8.9 | 1.4 |
| *Materials were mixed with base materials in locations 1 and 3 and exposed to dry condition. Then, PI was determined. | | | | |

## 4. LABORATORY TESTS: FDR MIX DESIGN OF BASE-COURSE EVALUATION

To select the optimum FDR base-course mix design, specimens are prepared in accordance with Texas Department of Transportation (TxDOT) guidelines. The determination of the optimal FDR mix design includes consideration of what percentage reclaimed asphalt pavement (RAP) to allow, what pretreatments are required, and what level of stabilizer to use. The laboratory testing protocol includes the determination of gradation, Atterberg limits, optimum moisture content, unconfined compressive strength, evaluation of the moisture susceptibility using the tube suction test (TST), and seismic properties. These engineering properties are obtained from laboratory tests using 6-in. by 8-in. specimens. Traditionally, approximately 300 lb of materials are required to complete a single set of laboratory evaluations for FDR mix design. For example, the following design criteria for cement designs are often used. Similar criteria are available for the other commonly used stabilizers (lime and asphalt).

- **Unconfined Compressive Strength (UCS) after Seven-Day Moist-Curing:** Cement-stabilized: ≥175 psi (minimum)
- **Retained UCS after TST:** ≥100% seven-day UCS

### 4.1 Aggregate Gradation and Triaxial Compressive Strength of Unbound Aggregates

As shown in Figure 4, recycled asphalt pavement (RAP) materials and existing base materials were collected from three different locations, namely Sections 1, 3, and 5. Gradation analysis was conducted. While the existing base material belonged to Grade 3, the RAP material was affiliated to Grade 1 specified by TxDOT Item 247. A 50/50 combination of RAP and flexible base materials were selected and its gradation analysis was virtually categorized to Grade 2. Thus, the blend of 50% flexible base and 50% RAP materials was selected to a FDR base mixture.

The triaxial testing, Tex-117-E test method, "Triaxial Compression for Disturbed Soils and Base Materials," was used to characterize whether the blend materials possess any cohesion and required confinement. The specimens were subjected to a constant confining pressure, $\sigma_3$, and then loaded under an increasing axial stress, $\sigma_1$, until failure. The minimum requirements of the trixaxial compression test for Grade 2 material defined in TxDOT Item 247 are $\sigma_1$ = 35 (min.) at $\sigma_3$ = 0 psi and $\sigma_1$ = 175 (min.) at $\sigma_3$ = 15 psi, respectively.

The results of triaxial compression test of the 50/50 blend of flexible base and RAP materials are shown in Figure

6. At the zero confinement pressure, the axial compressive strength of blend material reached 22.8 psi whereas axial strength at the 15-psi confinement reached 87.9 psi. These results failed the requirements of a Grade 2 aggregate as per TxDOT Item 247 [TxDOT 2004]. Therefore, this blend material seems to require stabilizer in order to achieve enough strength as base-course material.

To achieve early strength development and good durability for moisture susceptibility, cement was chosen as a stabilizer. Its replacement level was decided to 2%, 3%, and 4% for a FDR base mix design evaluation. The maximum dry density and optimum moisture content of mixture treated with 3% cement were 129.5 lbs/ft$^3$ and 7.8%, respectively. Moisture contents were adjusted for each of the remaining cement contents (2 and 4%) at 1/4 % moisture per 1% cement.

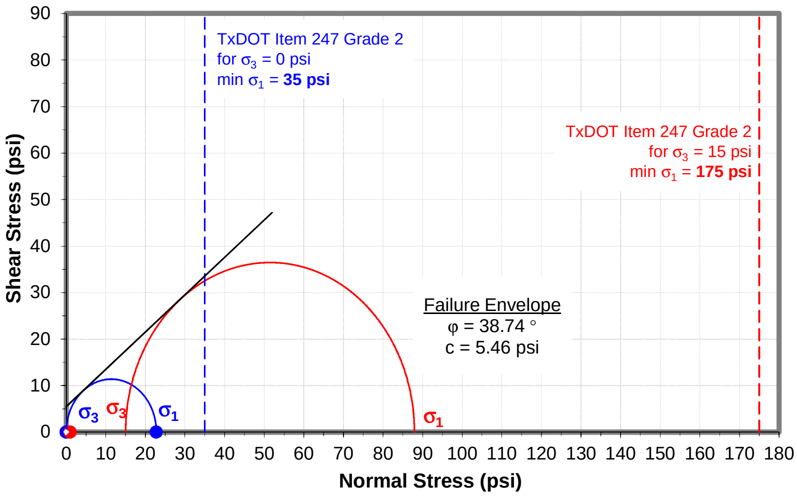
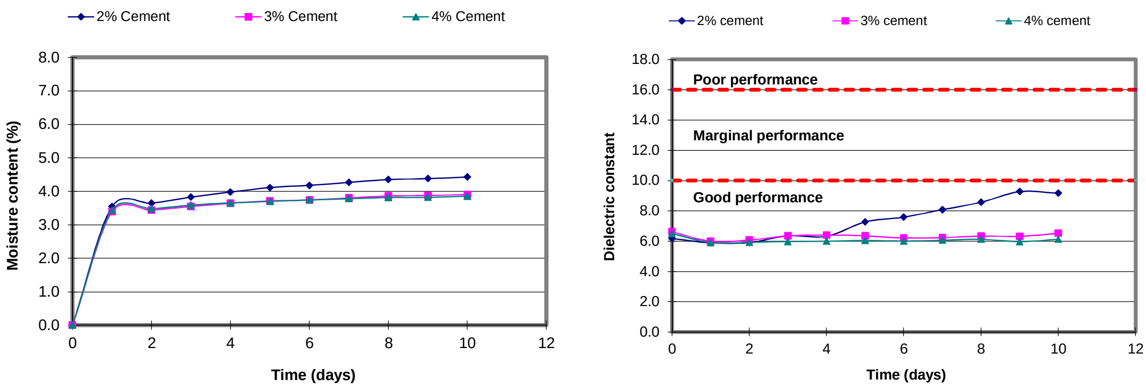



**Figure 6: Triaxial Compression of the 50/50 Blend Materials**

### 4.2 Tube Suction Test (Capillary Suction Test) and Unconfined Compressive Strength

Tube suction test (TST) called capillary suction test was conducted for assessing the moisture susceptibility of base material when exposed to prolonged capillary soak conditions. The specimens with final dielectric values less than 10 are expected to provide a good field performance, while those with the dielectric values above 16 are expected to provide a poor field performance as base materials. Specimens having final dielectric constant values between 10 and 16 are expected to be marginally moisture susceptible.

As presented in Figure 7-(a) and 7-(b), for all mixtures, dielectric value (DV) increased as absorbed moisture content (MC) increases. All mixtures have low moisture susceptibility with the corresponding good DV below 10. Increasing cement content improved the moisture susceptibility resistance of FDR mixture.




**(a). Moisture Content Changes Over Time** **(b) Dielectric Value Development Over Time**

**Figure 7: Tube Suction Test Results**

Figure 8 shows the comparison of UCS before and after TST. The wet strengths are always substantially higher than the dry strength. The high UCS values of the all mixtures after TST may be attributed to the continuation of hydration of cement. The relative retained strength values of all cement-stabilized mixtures exceeded the threshold value of 80% recommended by TxDOT.

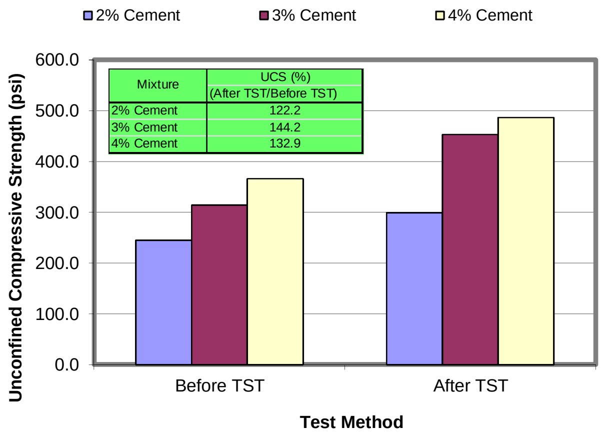



**Figure 8: Retained Unconfined Compressive Strength before and after TST**

### 4.3 Seismic Modulus

Figure 9 presents seismic modulus (SM) development of each cement-treated mixture during curing. The SM of the cement-stabilized mixtures increases over time and with increment of cement content. Currently, there is no magic SM number to determine a good base-course material at a certain age, but typical values of SM for cement-stabilized base material range from 1, 000 psi to 5,000 ksi at 7 days. Therefore, the MS for cement-treated FDR mixtures for FM 1887 roadway seem to be good enough for base course application.

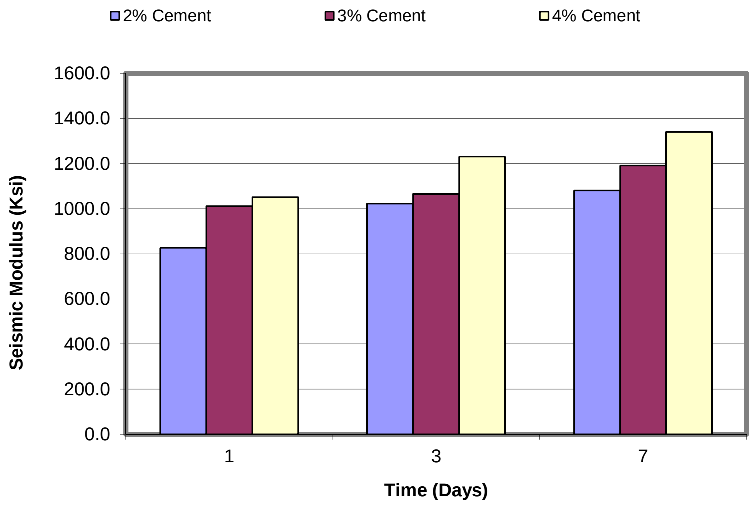



**Figure 9: Seismic Modulus Development over Time for Different Mixtures**

Based on the criteria previously stated, the suggested mix design would be 50/50 blend of existing base and RAP materials containing 3% cement which satisfied the necessary strength and moisture susceptibility requirement.

## 5. CONCLUSIONS

The vast majority of the full depth reclamation (FDR) projects in the districts are performing well when good pavement testing and existing Texas Department of Transportation (TxDOT) design protocols are used. FDR can be highly cost-effective if executed properly. However, lack of guidance in the overall design and construction process, including formulating a mixture design for the reclaimed materials, controlling the construction process, and performing quality assurance of the in-place product often lead to construction delays and poor performance of pavement. Especially, designing and constructing FDR project incorporating more than 50 percent recycled asphalt pavement (RAP) material in typical FDR design are challenging because there are little data available.

This study evaluated Farm-to market (FM) 1887 road from the center of Hempstead to the intersection with FM 359 in Monaville for a total distance of over 13.5 miles as a good candidate for FDR project. In addition, laboratory mix design test were conducted to find the optimal FDR mix design. Test results shows that the primary distress on FM 1887 pavement is the stripped gravel layer. Furthermore, the secondary problem is extensive longitudinal cracking and roughness with some edge faulting. This may be attributed to a lack of edge support with steep side slope, wet and dry shrinkage caused by trees close to the sides of the roadway, and highly plastic soils.

Laboratory test results indicate that the suggested mix design would be 50/50 blend of existing base and RAP materials containing 3% cement which satisfied the necessary strength and moisture susceptibility requirement. For FDR construction of typical sections, some of the existing 4” HMA from the surface should be removed first, and then the remaining HMA and base should be mixed together to achieve 50/50 blends. These blend materials should be treated with 3 percent cement to a depth of 8 inches.

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