Response and Performance of Flexible Pavement Test Sections with Stabilized Full Depth Reclamation Base at MnROAD

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ABSTRACT

Three test sections were constructed in 2008 on Interstate 94 at the MnROAD test facility to study pavement performance with stabilized full depth reclamation base using engineered emulsion. Each section used a different emulsion content due to the inherent differences in the sections.

Pavement testing, including rut and crack measurements, was performed, along with falling weight deflectometer tests. The three sections had slight increases in rutting from April 2009 to July 2009 but leveled off by September 2009. This was likely due to material consolidation, which is commonly observed for most asphalt pavements immediately after opening to traffic. The amount of rutting is still low, with most of rutting less than 0.15 inches. No cracking has been observed. FWD testing showed the least average deflection occurred in cell 3, but cell 4 was the stiffest material, based on the Area index.

Laboratory testing characterized the mechanical properties of the three mixtures. The testing results showed that the mixture used in cell 3 has the highest dynamic modulus, slightly greater than cell 4 at most frequencies. Cell 3 also has the best fatigue life, which indicates that this mixture type is probably an optimal design in terms of material strength and performance. Ultimate performance, however, will be determined from field results, dependent on materials and design of all layers and construction quality. The sections were designed for 3.5 million ESALs in five years, and it must be pointed out that the sections are still in early stage of the study and performing well.
INTRODUCTION

Full depth reclamation (FDR) using chemical, bituminous, and mechanical stabilizing methods has been increasingly used by states and local agencies to increase the strength of the base and as an alternative to reconstruction. Full depth reclamation is typically used on low to medium volume roads, with few agencies using the process on high-traffic pavements.

A majority of agencies are using FDR and plan on continuing the use of the process, as determined in a survey by South Dakota School of Mines and Technology (1). Furthermore, South Dakota DOT is conducting a comprehensive research project to produce a design guide for construction of FDR using mechanical, chemical, and bituminous stabilization methods. This on-going study consists of laboratory work and a field test section.

Georgia DOT’s experience with cement in FDR showed that in-situ deflections were reduced compared to the control that was not stabilized and just overlaid, and had a cost reduction of 42 percent compared to conventional methods (2).

The Texas Transportation Institute (TTI) performed an evaluation of laboratory mix design and field performance of asphalt emulsion and cement stabilized Full-depth Reclamation projects in Texas (3). They pointed out that cement treatment provides a strong base material but is prone to environmental cracking. Emulsions by themselves have advantages, like improved moisture resistance. However, for some aggregates and emulsions, the early strengths are low and traffic has to be kept off the section for an extended period, which is unacceptable in many reclamation projects. By combining treatments and materials on some roads, it was hoped that a flexible, strong, waterproof, and durable base could be created with good early strength gain.

The city of Las Vegas, Nevada used asphalt emulsion in an FDR process on a busy city street that needed reconstruction (4). Typical reconstruction time for the length treated would normally have been 120 days, but the city reduced the time to 40 days using FDR. Cost savings to the city were 30 percent compared to reconstruction.

The FDR process includes pulverizing the flexible pavement section and a portion of the underlying base. Stabilizing agents are added during the crushing and blending process to increase overall pavement stiffness. During the FDR process, typically the first grinding pass pulverizes the bituminous pavement and can be completed to a variable depth. Stabilizing agents are added during the second mixing pass, which needs to occur at a uniform depth to correctly proportion the material mix.

The Transportation Engineering and Road Research Alliance (TERRA) and Road Science, LLC (formerly SemMaterials, LP) formed a partnership to demonstrate and test the concept of full depth reclamation as pavement base material with engineered emulsion at the MnROAD interstate facility in three sections. Each section was composed of different combinations of aggregate base and asphalt concrete. Falling weight deflectometer (FWD) testing has been conducted on the cells to study pavement responses. Also, performance measurements, such as rutting and cracking, have been measured since opening to traffic in February 2009.

The purpose of this cooperative research is to 1) study how the emulsion-stabilized FDR in the different sections affects pavement performance in an accelerated loading scenario and 2) compare advanced laboratory tests to field performance. This paper presents one-year performance test results of the test cells along with FDR mix design, pavement structural methods, and mechanistic material properties.

PROJECT PLANNING

The Minnesota Road Research (MnROAD) project is located about 45 miles northwest of Minneapolis/St. Paul near Otsego, Minnesota on and adjacent to Interstate 94. It consists of a mainline transition roadway to carry live interstate traffic and a low volume closed loop road for controlled loading research. This research project was conducted on the interstate segment. The FDR process was performed on three sections (cells) and the adjacent outside shoulder on Cells 2, 3 and 4. MnROAD personnel have the ability to close the interstate segment of the research section from time to time to take measurements such as rutting, crack surveys, falling weight deflectometer deflections, and other tests. A thorough pavement design and analysis was performed and is discussed below (5). Pavement performance will be monitored for expectations from design.
Pavement Design

Traffic

The design level of traffic for this experiment was 3,500,000 ESAL for a cross-section to provide adequate service until reaching a terminal present serviceability index (PSI) of 2.5. This ESAL level is expected to occur in a time period of approximately five years.

Climate

According to the LTPPBIND software (6), the expected extreme air temperatures range from -31.7 to 32.4°C (-25.1 to 90.3°F). Based on climate alone, the recommended asphalt binder performance grade (PG), using 98 percent reliability, is PG 58-34. However, with the potential for heavy trucks, a polymer-modified PG 64-34 was recommended for the upper hot mix asphalt (HMA) layers to minimize the potential for rutting.

The average annual precipitation is approximately 27.4 inches in this area; drainage is critical with the medium to high frost susceptibility of the soil materials on the project.

Soils and Existing Pavement Sections

The materials used in the layer components of MnRoad have been measured and well documented as part of the ongoing research project. The existing layer thicknesses and properties are summarized for Cells 2, 3, 4, and adjacent shoulder in Table 1. These pavement sections were in service since the completion of construction in September 1993 until FDR construction in 2008. The surface of Cells 2 and 4 were also treated with a microsurfacing in 2003.

TABLE 1 Pavement Sections Before Construction

<table>
<thead>
<tr>
<th>Cell 2</th>
<th>Cell 3</th>
<th>Cell 4</th>
<th>Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 inch microsurface</td>
<td>6 inches HMA</td>
<td>0.5 inch microsurface</td>
<td>2 inches HMA</td>
</tr>
<tr>
<td>6 inches HMA</td>
<td></td>
<td>9 inches HMA</td>
<td></td>
</tr>
<tr>
<td>4” Class 6 base</td>
<td>4” Class 5 base</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28” Class 4 base</td>
<td>33” Class 3 base</td>
<td>Clay</td>
<td>7” aggregate base (Cell 4)</td>
</tr>
<tr>
<td>Clay</td>
<td>Clay</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The subgrade soil is a sandy lean clay, classified as CL-OH (Unified) or A-6; A-7-5 (AASHTO), with a plasticity index (PI) of 10 to 20. Based on laboratory testing, the material has a soil resistance value (R-value) of approximately 12, which correlates to a resilient modulus (Mr) of 7,800 psi, using the correlation [Mr = 1155 + (555 x R)].

Cells 2 and 3 have 4 inches of aggregate base and a substantial thickness of granular (graded sand) subbase, assumed to be placed for freeze-thaw mitigation. Cell 4 has a thicker layer of asphalt concrete (AC), paved directly on top of the subgrade.

Soil Stabilization

On Cell 4, with no existing base and subbase material, various types of stabilization were considered to minimize the amount of required new material and to directly address the low strength of the existing soil. There were too many fines in this native soil to attempt asphalt emulsion stabilization. Three other calcium-based additives were considered technically feasible for this type of soil with a PI of 10 to 20: Type C fly ash, hydrated lime, and cement. Type C fly ash is the least expensive material per ton, but typically requires the highest dosage. Cement is the most expensive material per ton, but typically requires the least dosage. Hydrated lime typically lies between these two dry application extremes in terms of dosage and cost and can be applied dry or in slurry form (usually made from Quicklime on site). Many factors were evaluated in addition to cost, such as contractor experience, equipment availability, and proximity to the source of material. Based on all of these factors and the goal to create a stable but not too stiff layer (to avoid shrinkage cracking), Type C fly ash was selected for stabilizing the soil in Cell 4.
Pavement Design Methods

The *1993 AASHTO Guide for Design of Pavement Structures* (7) was used to design the sections. The following input values were used: initial pavement serviceability index of 4.2, terminal pavement serviceability index of 2.5, overall standard deviation of 0.49, and a design reliability of 95 percent. Design ESALs were 3,500,000 or greater. This design method is limited by layer coefficient material inputs, 80 psi tire contact pressures, and an out-dated 1960s vintage performance prediction regression equation that usually is not adjusted for new or different materials such as polymer-modified asphalt concrete (PMAC) or emulsified asphalt mixtures.

Numerous pavement sections were evaluated with the KENLAYER (8) elastic layer analysis (ELA) software to check the design thickness obtained from the AASHTO method. For the ELA, individual layer material properties (modulus and Poisson’s ratio) were conservatively estimated for each of four seasons, to incorporate the effects of temperature gradient (AC). In addition, a more realistic heavy truck tire contact pressure (100 psi) was used to evaluate the impact of the ESAL, rather than the 80 psi used in the 1993 AASHTO Guide. An ELA analysis (KENLAYER) was used to evaluate critical responses to load (strain) at critical depths, such as horizontal tensile strain at the bottom of the AC (related to fatigue cracking) and vertical compressive strain at the top of the subgrade soil (related to base failure deformation or rutting). Software analyses showed that the resulting life using the input from the AASHTO design analysis was five years or greater, which is the estimated time to reach 3,500,000 ESAL.

For this project, a ¾ inch layer of ultra-thin bonded wearing course (UTBWC) over 2 inches of PMAC and the FDR layer was recommended. The UTBWC, which is a gap-graded mixture placed on a heavy spray of polymer-modified tack coat through a spray paver, provides structural benefit greater than or equal to PMAC, in addition to a durable highly textured surfacing. For Cell 4, the HMA surface layer was placed through a spray paver.

The specific design cross-sections recommended for the mainline of each cell, and the structural coefficient values used for each material in the AASHTO analysis, are contained in Table 2. Figure 1 shows the current pavement condition.

<table>
<thead>
<tr>
<th>TABLE 2 Pavement Sections for Construction Determined from Design</th>
<th>Cell 2</th>
<th>Cell 3</th>
<th>Cell 4</th>
<th>Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75 inch UTBWC (0.45)</td>
<td>0.75 inch UTBWC (0.45)</td>
<td>1 inch bonded HMA (0.45)</td>
<td>Micro surfacing</td>
<td></td>
</tr>
<tr>
<td>2 inches HMA (0.4)</td>
<td>2 inches HMA (0.4)</td>
<td>2 inches HMA (0.4)</td>
<td>4 inches EE FDR (50/50 blend)</td>
<td></td>
</tr>
<tr>
<td>6 inches EE FDR (0.25)</td>
<td>6 inches EE FDR (0.25)</td>
<td>8 inches EE FDR (0.25)</td>
<td>Aggregate base</td>
<td></td>
</tr>
<tr>
<td>6 inches untreated base (0.1)</td>
<td>6 inches untreated base (0.1)</td>
<td>9 inches Class C fly-ash treated clay</td>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td>26” aggregate base</td>
<td>35” aggregate base</td>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mix Design

A total of four blends were prepared by proportioning the materials as they existed and were to be reclaimed, as determined by the pavement design. Cell 2 pre-pulverization (no emulsion addition) was performed at 12 inches to uniformly blend the materials and break up the asphalt concrete. This resulted in a blend of 50 percent asphalt concrete and 50 percent aggregate base. Cell 3 had an 8 inch pre-pulverization resulted in a 75 percent blend of asphalt concrete and 25 percent of Class 5 aggregate base. Cell 4 pre-pulverization incorporated as little clay as possible in this material, and this material was essentially 100 percent asphalt concrete. The shoulder was the fourth blend with pre-pulverization performed at 4 inches, and this material was a proportion of 50 percent asphalt concrete and 50 percent aggregate base.

Gradations after washing were performed according to ASTM C 117 and C 136. The particle size distributions of these blends are shown in Figure 2. These blends treated the crushed reclaimed asphalt pavement (RAP) as a black rock in the particle size distribution. Sand equivalent (SE) values were determined on the blends using ASTM D 2419. The SE of Cell 2 was 46, 59 for Cell 3, greater than 80 for Cell 4, and 29 for the shoulder.
The asphalt emulsion was formulated specifically for the FDR materials and was cationic. The emulsion was composed of 65 percent asphalt and 35 percent water. The penetration of the residue of the emulsion used for mix design was 111 dmm (ASTM D 5).

Design emulsion contents were determined from indirect tensile strength (ITS, ASTM D 4867), water-conditioned ITS, resilient modulus (ASTM D 4123), and thermal cracking (AASHTO T-322). The recommended emulsion content for Cell 2 was 4.0 percent; for Cell 3, it was 3.0 percent; for Cell 4, it was 0.5 percent. The emulsion content was increased to 0.75% prior to the start of the project for Cell 4. The recommended emulsion content for the shoulder was 4.5 percent. Emulsion content is determined by dry aggregate weight. Details of the mix design method and testing criteria can be found in Finberg et al. (4).

CONSTRUCTION

Pre-pulverization and emulsion injection occurred with a Wirtgen 2500S. The full depth bituminous section in cell 4 was rehabilitated by removing and stockpiling eight of the nine inches of the in place HMA pavement. The remaining one inch was pulverized with eight inches of the clay subgrade. This mixture was then modified with fly ash to neutralize and stabilize the subgrade. The eight inches of HMA was then returned to be placed as a base layer and treated with asphalt emulsion. Design emulsion content was 0.5 percent and was increased to 0.75 percent for improved cohesiveness.

A conventional paver was used to place 2 inches of level 4 Superpave in cells 2, 3, and 4. An innovative spray paver was then used to place a ¾-inch ultra thin bonded wearing course (UTBWC) surface treatment in cells 2 and 3 as well as a 1-inch top lift of HMA in cell 4. The spray paver uniformly applied a high quality tack coat immediately in front of the mix, which eliminated any construction traffic crossing the tack material.

ONE-YEAR PERFORMANCE

The three test sections opened to traffic on I-94 in February of 2009. Since then, the sections experienced approximately 810,000 ESALs by the end of October 2009.

Rutting and Cracking

Periodic pavement distress measurements including rutting and cracking have been made since the completion of the construction. The cracking measurements were made visually, while the rutting measurements were taken using an Automated Laser Profile System (ALPS) (Figure 3).
The three sections have performed well with no cracks observed, and a small amount of rutting has been measured. Figures 4 to 6 show the rutting progression since the sections opened to traffic.

FIGURE 4 ALPS Rutting Data for Cell 2.
The measurements show that the three sections all had a biggest increase in rutting from April to July of 2009, while rutting has not increased from July to September of 2009. The increase from April to July 2009 could be due to the material consolidation, which has been observed for almost every asphalt pavement immediately after the pavement open to traffic. Also, it is observed from the measurements that overall the rutting level is still low with most of rutting less than 0.15 inches although the rutting reached 0.3 inches on one particular location of cell3 and cell4. It must be pointed out that the three sections have already received about 24% of their designed life.

**Falling Weight Deflectometer**

Falling weight deflectometer (FWD) testing was performed on April 13 and 14, 2009 with Dynatest equipment. Testing was performed in the driving lane in the right wheel path, a total of 118 drops for each section. Pavement surface temperatures at the time of testing ranged from 50.2 to 52.4 °F (10.1 to 11.3 °C). The center-plate deflection ($D_0$) was normalized to a 9000-pound load and a temperature of 68 °F, as shown in Figure 7.

The Area factor (9), adjusted for a temperature of 68 °F, was calculated and is shown in Figure 8. It was calculated from the deflection sensors as follows:
Area = $6/D_0 x (D_0 + 2D_{12} + 2D_{24} + D_{36})$

where

Area = deflection basin area in inches

$D_i$ = surface deflection at radial distance (inches) i

A minimum Area value is 11.8 and a maximum is 36 inches.

The deflection and Area values on this interstate section are considered fair, considering the design life is five years.
FOLLOW-UP LABORATORY TESTING

Reclaimed aggregate base samples (before emulsion addition) along with emulsion samples were collected during construction. The samples were prepared in the laboratory by proportionally blending the collected materials as they existed and were reclaimed during the construction. Dynamic modulus and beam fatigue testing were conducted in laboratory on the three sets of stabilized reclamation materials.

Dynamic Modulus Testing

Dynamic modulus testing of laboratory prepared samples was determined using an Interlaken Testing machine in the MnDOT Maplewood Laboratory and a Cox and Sons 7500 machine in the Road Science laboratory. The testing systems are servo-hydraulic, computer-controlled and closed-loop systems, and specimens are enclosed in an environmental chamber. Three Linear Variable Differential Transducers (LVDTs) were used to measure specimen deformation.

The dynamic modulus test was performed in accordance to the AASHTO TP62. The test was conducted under six loading frequencies (0.1, 0.5, 1, 5, 10, and 25 Hz) and five different temperatures (10, 14, 40, 70,100 and 130 °F). The average air voids, and the difference from mix design, was determined as follows – Cell 2 had 10.3 percent voids (+0.1%), Cell 3 had 8.3 percent voids (-1.0%), and Cell 4 had 12.0 percent voids (+1.2%). Two (MnDOT) or three (Road Science) specimens of each mixture from cells 2, 3 and 4 were tested (See Figure 9). Figure 10 shows a best-fit curve of the average results of the master curve of the MnDOT specimens and an average of the Road Science (RS) specimens; it shows reasonable agreement between the two labs. It illustrates that cell 3 and cell 4 have similar modulus values, while cell 2 has lowest modulus.

FIGURE 9 Dynamic Modulus Specimens (from left to right – Cell 2, Cell 3, and Cell 4).
Beam Fatigue Testing

Fatigue testing of beams cut from slabs made in the laboratory was conducted according to ASTM D 7460 at a temperature of 59°F (15°C) and a frequency of 10 Hz. Fatigue life curves are shown in Figure 11, where failure was the average of the normalized modulus method (defined in ASTM D 7460) and the dissipated energy method (defined in AASHTO T-321). The average air voids of the beams, and the difference from mix design, was determined as follows – cell 2 had 10.1 percent voids (-0.1%) and cell 3 had 12.6 percent voids (+3.3%). The air voids for cell 4 beam fatigue specimens were very high compared to design voids, so the data could not be used. Cell 3 performed better than cell 2 in spite of having higher than design voids.
SUMMARY AND CONCLUSIONS

Three test sections were constructed in 2008 on Interstate 94 at the MnROAD test facility to study pavement performance with emulsion-stabilized full depth reclamation bases. Each section used different emulsion contents, pre-determined from mix designs, due to the inherent differences in the materials of the sections. Cell 2 consisted of grinding the existing HMA with the underlying granular base (50:50) and injecting new asphalt emulsion (4.0%) into the top six inches. On cell 3, the HMA was ground with two inches of the underlying granular base (75:25) and injected with new asphalt emulsion (3.0%) in the top six inches. The full depth bituminous section in cell 4 was rehabilitated by removing and stockpiling eight of the nine inches of the in place HMA pavement. The remaining one inch was ground with eight inches of the clay subgrade. This mixture was then modified with fly ash to neutralize and stabilize the subgrade. The pulverized HMA was then returned (100%RAP) to be placed as a base layer and treated with asphalt emulsion (0.75%).

Pavement testing, including rutting and cracking, has been performed since the sections opened to traffic in February 2009. The sections received approximately 810,000 ESALs by October 2010. The measurements show that the three sections all had the biggest increase in rutting from April 2009 to July 2009, while rutting did not increase from July to September 2009. The increase from April to July 2009 could be due to the material consolidation, which is commonly observed for most asphalt pavements immediately after opening to traffic. The amount of rutting is still low, with most of rutting less than 0.15 inches. No cracking has been observed. FWD testing showed the least average deflection occurred in cell 3, but cell 4 was the stiffest material, based on the Area index.

Laboratory testing characterized mechanical properties of the three stabilized mixtures. The testing results showed that the mixture used in cell 3 has the highest dynamic modulus, slightly greater than cell 4 at most frequencies. Cell 3 also has the best fatigue life, which indicates that this mixture type is probably an optimal design in terms of material strength and performance.

Ultimate performance, however, will be determined from field results, dependent on materials and design of all layers and construction quality. The sections were designed for 3.5 million ESALs in five years, and it must be pointed out that the sections are still in early stage of the study and performing well. Long term monitoring of pavement performance is needed.

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