Design and Constructability of Emulsion-Stabilized Bases for Full-Depth Reclamation

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Developments in Foamed Asphalt and Asphalt Emulsion Stabilization
Sponsored by Committee: AFS90 - Chemical and Mechanical Stabilization

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DESIGN AND CONSTRUCTABILITY OF EMULSION-STABILIZED BASES FOR FULL-DEPTH RECLAMATION

ABSTRACT
Full-depth reclamation (FDR) of base courses with chemical-based stabilizers has been a common practice in many areas of Texas. Owing to its speed of operation and minimal lane closure period, asphalt emulsion has been recently used in a number of FDR projects in low volume roads as well. A few cases of premature failure of these stabilized bases primarily due to improper (or lack of) mix design or construction techniques led to a thorough evaluation and recommendations for an improved mix design and construction specification. The outcomes of the evaluation of construction-related, material-related and environmental-related parameters that significantly impact the performance of emulsion-treated base materials were used to propose laboratory test procedures for mix design and guidelines for the construction of bases with emulsion. The implications of the new specification were observed at several sites in Texas. The practical aspects of this study that are incorporated in a trial specification are discussed in this paper.

Keywords: base, full depth reclamation, emulsion, stabilization, construction.

INTRODUCTION
Rehabilitation of highway pavements, particularly, low volume roads through full-depth reclamation (FDR) is a cost-effective option that reduces the use of virgin base aggregates and eliminates the effort on disposal of the old aggregates. The process of FDR usually consists of pulverizing a predetermined amount of the existing unbound granular base and if desired asphalt layer, optionally stabilizing the material with additives, and compacting the new layer to a proper density. FDR can be used to treat a wide range of problems, particularly problems related to weak base courses. If designed and constructed properly, FDR is capable of rectifying rutting and fatigue cracking problems, deterioration of pavements due to maintenance patching and deterioration of ride quality caused by depressions and heaving.

Using chemical-based additives (e.g., cement or lime) to stabilize base courses during FDR has been a common practice. The strengths and weaknesses of these additives have been well documented and not repeated here. When asphalt emulsion is used as an additive, the residual asphalt in emulsion provides the base aggregate skeleton with distinct mechanical properties. The granular matrix in the emulsified base can provide similar internal friction as hot-mix asphalt (HMA) when compacted properly under the optimum water and emulsion contents. The dual stabilization, with blend of chemical-based additives and emulsion, can produce a base which has an optimum combination of strength, stiffness, moisture resistance and flexibility.

The major challenges of using asphalt emulsion alone or combined with chemical-based additives include determining the optimum mix design, establishing the test procedure for mix design and compacting and curing the mix sufficiently during construction. The main objectives of this paper are to share a laboratory test protocol to help in mix design and guidelines for the construction of bases with emulsion treatment. To achieve these objectives, a number of tasks were carried out. These tasks include:

• an information search focused on the current practices with regard to mix design and construction of emulsion bases.
• an in-depth investigation of the effects of emulsion content, the amount and type of chemical-based additives, and the pre-mixing water content on half-a dozen materials.
• a systematic parametric study to determine the factors that affect strength and modulus of emulsion-treated mixtures, and
• field studies on several construction projects to validate the findings and to provide recommendations and guidelines for construction.

This paper contains a summary of the findings and resulting practical recommendations. Detailed information on each topic can be found in Franco et al. (1).

BACKGROUND
Various mix design procedures have been proposed and implemented by different agencies for use in FDR. These procedures have the following items in common (2):

• Collection of road samples
• Material characterization of road samples
• Selection of stabilizing agent(s)
• Determination of total liquid content,
• Mixing, compaction, and curing of specimens, and
• Laboratory testing.

The collection of road samples is typically done with opening a trench at a random location at the site. The HMA layer is also sampled if the construction plans require combining it with the base. One concern with this process is that the sampled material may not be representative of the entire project site. A sampling plan to retrieve the materials thorough site investigation to ensure uniformity should be considered (3). The implication of pulverization of the in-place materials as part of the FDR should also be considered (4).

The main material characterization activities are the determination of the gradation and index properties (such as Atterberg limits and aggregate hardness) of the retrieved materials. These parameters are used to determine the appropriateness of emulsion or other additives for project at hand. If the gradation is not desirable, the addition of virgin materials or recycled asphalt pavement (RAP) to the mix can be considered to improve the strength of a mixture (5).

The type and amount of emulsion selected are extremely important. For bituminous stabilization, slow or medium set polymer modified emulsions are recommended (6). Adding small quantities (less than 2%) of cement to emulsion may accelerate the breaking of the emulsion (7). A cationic emulsion tends to entrain less air than anionic emulsion.

The optimum emulsion content is defined as the amount of emulsion to be added to a material to meet a minimum strength and/or modulus requirement. Several agencies use presumptive optimum emulsion contents depending on the regional factors and index properties of the raw materials (1). Additional chemical-based additives (typically 1% or 2%) can be added to the mix, if the emulsion alone would not provide adequate strength specified.

The mixing water and the water contained in the emulsion work together to aid in compaction of the specimen. The amount of mixing water is generally less than the optimum moisture content (OMC) of the raw material. The total liquid content (TLC), which is defined as the total amount of added water plus asphalt emulsion, has a significant effect on the strength and stiffness of emulsion-treated materials (8). Despite its importance, firm guidelines for selecting the amount of mixing water is not available. One prevalent practice is to add between 50% and 80% of the OMC based on the sand equivalency of the material (3).
Various tests are specified to quantify the mechanical properties of recycled materials. The method of sample preparation (typically Proctor or gyratory), curing method (e.g., room temperature vs. over-drying) and test method (e.g., unconfined compressive or indirect tensile strength) significantly impact the final proportioning of the mix.

Two factors that greatly affect the process are the ambient temperature and moisture condition of the surrounding area (4). Any moisture introduced to the mixture after initial compaction can have detrimental effects on the performance of the pavement (8). Any additive that is recommended for use in FDR must be evaluated in terms of its moisture susceptibility (8).

A lack of concrete guidelines for the construction of a reclaimed road with asphalt emulsion has led to large variations in the performance of such projects, even within the same region (3). Mallick et al. (3) provide a guideline for proper reclaiming, applying emulsion, mixing, grading and compacting. Currently, the nuclear density gauge (NDG) is the main tool used for quality control (QC) and assurance (QA) of the newly constructed emulsion bases. A number of on-site specimens have to be prepared and tested to calibrate the NDG readings. Alternative tools/methods of QC/QA are needed for emulsion-treated bases since the performance of these bases are only marginally correlated to the density (7).

**PRELIMINARY GUIDELINE FOR MIX DESIGN**
A schematic of the basic constituents of an emulsion-treated base is provided in Figure 1. The proportion of each constituent controls the engineering properties of a given mix. The ideal gradation of the material to be placed should be close to the specified gradation for a high quality virgin base (4). To adjust the gradation or if the new pavement section requires more material than is reclaimed, a source of add-rock (virgin high-quality base or RAP) is needed.

![Figure 1 – Constituents of an Emulsion Treated Base](image)

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Paper revised from original submittal.
The desirable moisture content for a high-quality and constructible untreated base is close to the OMC leading to a degree of saturation of about 80% to 90%. The degree of saturation, S, is obtained by determining the moisture content, \( \omega \), the dry unit weight, \( \gamma_d \), and the specific gravity of the solids, \( G_s \), from:

\[
S = \left( \frac{\gamma_d \omega}{G_s} \right) / \left( G_s \gamma_w - \gamma_d \right) \tag{1}
\]

where \( \gamma_w \) is the unit weight of water. Any loss in weight observed during traditional lab moisture content testing for untreated bases can be assumed to be due to moisture loss. Since the asphalt in the emulsion does not evaporate along with water during the drying process, its weight \( (W_{\text{asphalt}}) \) becomes part of the weight of solids. As such, the lab measured total liquid content (TLC\text{measured}) for emulsion-treated bases is calculated as:

\[
\text{TLC\text{measured}} = \frac{(W_{\text{water}} + W_{\text{water in emulsion}})}{(W_{\text{aggregates}} + W_{\text{asphalt}} + W_{\text{additives}})} \tag{2}
\]

which is lower than TLC\text{assumed} estimated from:

\[
\text{TLC\text{assumed}} = \frac{(W_{\text{water}} + W_{\text{water in emulsion}} + W_{\text{asphalt}})}{(W_{\text{aggregates}} + W_{\text{additives}})} \tag{3}
\]

The difference between the assumed and measured TLC has several implications in the mix design and construction quality control. The first implication is demonstrated in Figure 2a for a common base material in Texas where the mixing moisture content varied by 45%, 60%, and 75% of OMC and the emulsion content varied between 0% and 7%. For the mixture with mixing moisture content of 45% OMC, the TLC-density curve is flatter than the moisture-density curve obtained from the untreated base. This indicates that the density may not be sensitive enough to assess the quality of an emulsion-treated base. The TLC-density curves follow the patterns of the zero-air-void lines in standard compaction terminology for the specimens prepared with mixing moisture contents of 60% OMC and 75% OMC, indicating that these mixes are saturated. As such, for a given mixing moisture content, the emulsion content has to be limited to an upper limit. To ensure that the degree of saturation of the emulsion-treated mixes would not deviate significantly from a target value for constructability (S\text{target}, say 85%), the total liquid content has to be limited to TLC\text{max}. Eq. 1 can be rewritten as:

\[
\text{TLC\text{max}} = \left[ (\gamma_w / \gamma_d) - (1 / G_s) \right] S_{\text{target}} \tag{4}
\]

The maximum allowable emulsion content, EC\text{max}, for a given mixing moisture content, MMC can be determined from

\[
\text{EC\text{max}} = \text{TLC\text{max}} - \text{MMC} \tag{5}
\]

The example in Figure 2b shows that for a mixing water content of 60% OMC, the EC\text{max} is 5.2%, whereas for mixing water contents of 45% and 75% of OMC, the EC\text{max} values are 7.7% and 2.8%, respectively. This concept can be readily implemented in a simple excel worksheet.\(^1\)

\(^1\) We have developed one and will be glad to share with interested readers. See Emulsion Analysis Tool Manual in Appendix C of [http://ctis.utep.edu/publications/Reports/Report-0-5797-1_final.pdf](http://ctis.utep.edu/publications/Reports/Report-0-5797-1_final.pdf).
a) Impact of Total Liquid Content on Moisture Density Curve

b) Relationship between Maximum Emulsion Content and Mixing Water Content to Ensure Constructability

Figure 2 - Interaction among Mixing Moisture Content, Emulsion Content and Density for Typical Emulsion-Stabilized Mixes
The optimum emulsion content should be ultimately determined based on minimum strength and moisture susceptibility requirements (as discussed later). This is achieved by preparing specimens at different emulsion contents that meet the above criterion with full consideration that no emulsion (0% emulsion content) is always an option for some high-quality salvaged bases. If none of the trial mixes meet the strength and moisture susceptibility requirements specified, dual-stabilization (asphalt emulsion plus chemical-based additive) or chemical-based additive alone can be considered for mix design. Another reason for adding chemical-based additives is to minimize the use of the much more expensive emulsion.

**Performance Test Requirements**

Common performance tests required for mix design are included in Table 1. Even though Marshall Stability test is not uncommon, unconfined compressive strength (UCS) and/or indirect tensile strength (IDTS) and a retained strength after moisture conditioning are specified in the more recent specifications. The details about the sample preparation, curing and testing vastly vary among specifications. To provide concrete recommendations for the most representative and practical test protocols, a series of parametric studies was carried out on six representative materials sampled throughout Texas (see Ref 1). In these studies, the effects of a number of parameters that influence the strength parameters of the mixes were assessed. For each material, a preliminary mix design was carried out using the criteria reflected in a TxDOT special specification. Different factors were then varied from these baseline designs (one at a time) as discussed below.

The major strength requirements in TxDOT provisional specification are included in Table 1. Briefly, the UCS on 6 in. by 8 in. specimens was utilized as the primary strength parameter to estimate the optimum emulsion content (OEC). IDTS tests on 6 in. by 4.5 in. specimens prepared at the OEC were then carried out for further verification of the mixes. The logic behind this two-tier approach was that the UCS can be considered as a surrogate for rutting performance and the IDTS as a surrogate for cracking potential of the mix. TxDOT test protocols that are very similar to those established by ASTM were followed in this study. Unless otherwise noted, the specimens were cured for 2 days at 140°F before testing.

**Table 1 – Laboratory Performance Testing Methods in TxDOT Special Specification**
To verify that the mix is not moisture susceptible, the retained strength on duplicate specimens were prepared and were subjected to capillary moisture conditioning for ten days before testing. The ratio of the strengths after and before moisture conditioning is termed as retained strength.

A tube suction test (TST, as surrogate for moisture susceptibility) and two modulus tests were also specified without acceptance values. For the sake of brevity, the results from these tests are not included here but they can be reviewed in Ref (1). Basic observations were that:

• TST is not effective because of the interaction between the emulsion and mixing water and the low permeability of the specimens.
• To measure the resilient modulus as per AASHTO T-307 accurately, a test setup that is significantly more rigid than the setup used for unbound granular bases is needed.
• The free-free resonant column test (FFRC) is a good surrogate for measuring moduli.

All parametric studies summarized below were carried out on duplicate specimens prepared at the mixing water and optimum emulsion contents that were appropriate for a specific material. Again, for the sake of brevity, we will only provide the results that represent the typical patterns observed.

**Mixing Method:** The quality of a mix is significantly impacted by the method of mixing. Figure 3a shows a comparison of specimens prepared with a high-shear mixer (control) and a concrete mixer (which looked very similar to the hand-mixed specimens). The standard mixers used in preparing hot mix asphalt were not deemed feasible. The specimens prepared with the high-shear mixer were uniform while the specimens prepared with the concrete mixer and hand mixing were “spotty” because the fine aggregates absorbed most of the emulsion. The strength parameters from the specimens prepared with shear mixer are significantly greater than the specimens prepared with the other methods (Figure 3b). Even though not shown here, the high shear mixer also simulates the crushing of soft aggregates usually observed during pulverization.

<table>
<thead>
<tr>
<th>Property and Testing Protocol</th>
<th>Criteria</th>
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<tr>
<td>Unconfined Compressive Strength (UCS), Tex-117-E</td>
<td>150 psi min.</td>
</tr>
<tr>
<td>Indirect Tensile Strength (IDTS), Tex-226-F</td>
<td>50 psi min.</td>
</tr>
<tr>
<td>Retained Unconfined Compressive Strength, Tex-117-E</td>
<td>80% min.</td>
</tr>
<tr>
<td>Dielectric Constant, Tube Suction Test (TST), Tex-144-E</td>
<td>Report</td>
</tr>
<tr>
<td>Resilient Modulus (AASHTO T-307)</td>
<td>Report</td>
</tr>
<tr>
<td>Modulus, Free-free Resonant Column Test (Tex-149-E)</td>
<td>Report</td>
</tr>
</tbody>
</table>

a) Appearances of Specimens Mixed with High-Shear Mixer (left) and Concrete Mixer (right)
b) Variations in Strength with Mixing Method

**Figure 3 – Impact of Mixing Method on Strength Parameters**

<table>
<thead>
<tr>
<th>Mixing Method</th>
<th>UCS Dry</th>
<th>UCS Moisture Conditioned</th>
<th>IDTS</th>
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<tbody>
<tr>
<td>High Shear</td>
<td>237</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Hand</td>
<td>131</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Concrete Mixer</td>
<td>150</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>
Compaction Method: Another contributing factor to strength is the method of compaction. Three different compaction procedures, consisting of the Tex-113-E (similar to modified Proctor), and a Superpave gyratory compactor with 30 gyrations and 50 gyrations, were investigated. In general, specimens prepared with the gyratory compactor were more uniform than those prepared with the Proctor method. The densities of the UCS specimens prepared with the Proctor method were typically less than those prepared with the gyratory compactor, and the densities typically increased by increasing the number of gyrations. The densities were similar for the IDTS specimens independent of the compaction method. The differences in strength parameters among compaction methods are shown in Figure 4. The specimens prepared with the gyratory compactor are stronger than those prepared with the Proctor method. On the other hand, the specimens prepared with 50 gyrations are only marginally stronger than those with 30 gyrations. The concept of the compaction “locking point” was found to be relevant for emulsion bases. Depending upon the constituents, no appreciable density was gained passed 50 gyrations.

![Chart showing impact of compaction method on strength parameters]

Figure 4 – Impact of Compaction Method on Strength Parameters

Mixing Temperature: One of the steps in preparing specimens consists of placing the mixture of the base, water and emulsion in a 140°F oven for 30 minutes before compaction. The impact of this step on the final product was studied by placing the mix in a chamber set at 50°F, 70°F and 140°F for 30 minutes. The strength parameters for different mix temperatures cured for 48 hrs in the normal fashion are compared in Figure 5a. The differences between the strengths of specimens compacted at 140°F and 70°F were not very appreciable. The specimens compacted at 50°F were weaker. This trend indicates that 30-minute curing at room-temperature can simplify the day-to-day operation of the DOT labs without any sacrifice in final properties.

Curing Temperature and Time: The strength and stiffness development of emulsion-treated bases are highly dependent on curing temperature and time. One of the arbitrary aspects in the current mix design procedures is the use of a temperature of 140°F for curing the specimens before strength tests to reportedly simulate the long-term properties of these mixes. One of the benefits of the emulsion bases is to satisfy the desire of the highway agencies to open the road to traffic shortly after compaction. In most cases, the newly constructed bases cure at much lower temperatures than 140°F and for much shorter period of time before vehicles are allowed on them. Figure 5b shows the impact of curing temperature on strength parameters after 2 days of
Figure 5—Impacts of Mixing Temperature and Curing Duration and temperature on Strength Parameters
curing. Generally, the strength decreases as the temperature decreases and the indirect tensile strength seems to be impacted more by curing temperature. A compromise temperature of 104°F for climatic conditions of Texas seems reasonable.

To address the impact of curing time on strength parameters, specimens cured at 50°F and 104°F, which represent a cool and a hot ambient temperatures, were broken after two-day and ten-day curing without moisture conditioning. The impact of the curing time on strength development is evident in Figure 5c. The lesson learned from this experiment is that unless highway agencies are willing to delay the opening to traffic, the curing temperature during mix design should be set to match the regional environmental condition and the time of year when the construction will be carried out. This topic requires further study.

**Impact of Gradation:** Most specifications require that the aggregate in a base material comply with certain gradation, hardness, and index parameters. The percent passing No. 200 sieve and plasticity index seem to be the two controlling factors. FDR is routinely carried out through the pulverization process which can change the material gradation (4). Depending on the coarse aggregate content and hardness, the gravel content decreases while the fine sand and/or fines content increases after pulverization (4). The following three additional gradations were prepared from each mix:

1. Excess Sand (ES) assuming that coarse aggregates will be crushed to fine sand (passing No. 40 and retained on No. 200 sieves),
2. Excess Fine (EF) assuming that the coarser aggregates will be crushed to fines (passing No. 200 sieve), and
3. Excess Fine and Sand (ESF) assuming that the coarse aggregates will be crushed to produce both fines and sand.

The four gradations for a typical material are shown in Figure 6a. The UCS and IDTS of the specimens after two days of dry curing and the UCS after moisture conditioning are shown in Figure 6b. The addition of the excess sand or excess fine improved the UCS but adversely impacted the IDTS. This study indicates that the design should be carried out on a gradation that considers the change in gradation during pulverization following the guidelines provided by Garibay et al. (4).

**Selection of Primary Performance Test:** After performing an entire matrix of testing using both the UCS and IDTS, it was observed that the IDT test results are more sensitive to the amount of emulsion. Also, the strain at failure of the mixes with emulsion tested under IDT increased significantly as compared to mixes without emulsion. Since aggregate bases cannot hold tension, such increase in strain may contribute to reducing the cracking of the pavement. As such, the IDTS as opposed to the UCS is proposed as the main strength criteria for mix design. Using IDT as the first line of testing will also require less material.

Based on the parametric study, the following sample preparation and curing are proposed:

- Use a high-shear mixer to mix the aggregates, water and emulsion. Limit the mixing period to 60 seconds to minimize the excessive aggregate crushing during mixing.
- Allow the loose mix to equilibrate for 30 minutes at room temperature.
- Utilize a gyratory compactor to prepare the specimens with 30 to 50 gyrations. Based on our field comparison study 30 gyrations is more representative of the field performance.
- Cure the specimens in 104°F oven for 48 hours before testing at room temperature.
Moisture Susceptibility Testing: The retained strengths based on UCS were greater than the retained strengths based on IDTS for almost all mixes. This is partly because of partial penetration of moisture within the 8-in.-high UCS specimens during moisture conditioning. However, the moisture could penetrate throughout or through a significant portion of the 4.5-in.-high IDT specimens. As such, the retained IDTS is proposed as the main criterion for moisture susceptibility.

FIELD CASE STUDIES
The study also involved four FDR projects of base courses treated with asphalt emulsion to verify the effectiveness of stabilization and observe construction practices. For each project, the
research activities included material collection, observation of the construction practices, laboratory tests on the collected materials and in-situ field modulus tests on top of the newly-constructed base (see Ref 1). However, only the results from lab strength tests are represented here due to the space limitation. Table 2 provides a brief description of the emulsion-treated base courses in these projects.

The pulverized materials were sampled at several locations at each project site before the emulsion and other additives were added. The materials collected at each location from each project site were tested in the laboratory. Reasonably large variations in the intermediate sieves of the gradation curves were observed. A coefficient of variation (COV) of 15 to 20% for the sand content of the sampled materials was not atypical.

<table>
<thead>
<tr>
<th>Project</th>
<th>Location Area</th>
<th>Base Thickness</th>
<th>Emulsion Base Content</th>
<th>Granular Base</th>
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<tbody>
<tr>
<td>1</td>
<td>San Antonio</td>
<td>6 in.</td>
<td>67%</td>
<td>33%</td>
</tr>
<tr>
<td>2</td>
<td>San Antonio</td>
<td>6 in.</td>
<td>33%</td>
<td>67%*</td>
</tr>
<tr>
<td>3</td>
<td>Amarillo</td>
<td>10 in.</td>
<td>20%</td>
<td>80%</td>
</tr>
<tr>
<td>4</td>
<td>Dallas</td>
<td>10 in.</td>
<td>60%**</td>
<td>40%</td>
</tr>
</tbody>
</table>

*: 33.5% existing RAP plus 33.5% additional RAP
**: 27% existing base plus 33% crushed concrete

Table 2 – Description of Emulsion-Treated Base Courses in Four TxDOT Projects

Figure 7 summarizes the UCS and IDTS results obtained at each site. Each error bar in the figure denotes ±1 standard deviation. The strength COVs varied from about 17% to 27%, purely due to change in gradation. On average only Project 2 met the strength requirements of 150 psi for UCS and 50 psi for IDTS. Also shown in Figure 7 are the seismic moduli measured on the lab specimens 48 hrs after compaction cured at 104°F and those measured in situ after construction. The in situ moduli were measured with a nondestructive device called portable seismic property analyzer (PSPA) as discussed in Ref (1). The COV from the field moduli were similar to those observed from the strength tests. Field moduli gradually increased in Projects 1 and 2 which were closed to traffic for three days. Project 4 could not be tested past 24 hours because the road was opened to traffic. Overall, the average field moduli after 48 hrs were about 60% of the corresponding lab values. These general observations confirm the findings from the parametric studies above that the ambient temperature and gradation impacts the strength and stiffness of the mixes.

OBSERVATIONS AND RECOMMENDATIONS

The end goal of this project was to develop a laboratory test protocol for selecting the appropriate combination and dosage of additives and to draft a guideline for the construction of emulsion bases. As part of this study, several different materials were sampled and subjected to various forms of testing in order to document the effects of several parameters on their engineering properties. Construction activities at four sites were also documented. The recommendations on all aspects of emulsion base materials by activities (from the beginning of a project to completion) are as follows.
a) Statistics of UCS and IDTS of Materials from Construction Projects

b) Moduli Measured in Field and Laboratory

Figure 7 – Results from Laboratory-Field Studies
(Project 3 could only be tested after 48 hrs because test device was not available at 24 hrs and road was opened to traffic after 48-hr tests, Project 4 could not be tested after 24 hrs because it was opened to traffic)
Material Retrieval for Mix Design: Under the current practice, the material retrieval from the site is carried out by randomly selecting a location within the project limit and digging a test pit. Substantial variability in the base material was documented in the field (1). More upfront investment in site evaluation is recommended even though this activity would increase the initial budget of the project by a small fraction. To capture the variability of the site, a survey with an FWD and GPR before material retrieval is recommended. The FWD data should be utilized to assess the strength of the subgrade to ensure that it can carry the traffic load after the FDR. The GPR can provide information about the changes in the layer properties and thicknesses and the intrusion of moisture in the pavement structure. If the lack of budget preclude pre-construction field investigation, borings should be placed at regular intervals (say every 0.1 mile), so that the variability of the base and hot mix can be established.

Mix Design: The mix design procedure recommended is as follows.

- Determine the OMC and MDD of the blended material without emulsion
- Determine the mixing moisture content and maximum allowable emulsion content as discussed above.
- Prepare and test at least four sets of IDTS specimens at nominal emulsion contents of zero (no emulsion), 1/3, 2/3 and 1 times maximum allowable emulsion content.
- Determine the optimum emulsion content as the minimum amount of emulsion added to the material to meet a 50 psi IDTS. If this IDTS cannot be achieved,
  - Repeat the process with a lower mixing moisture content to allow for higher emulsion content, or
  - Prepare and test additional IDT specimens with 1% to 2% chemical-base additives and the emulsion content which achieved the highest strength.
- Verify the adequacy of the compressive strength and measure the modulus of the mix with the free-free resonant column device by preparing a set of 6 in. by 8 in. specimens with the amounts of emulsion and chemical-based additive (if applicable) determined from IDT tests.
  - Ensure the mix design yields a minimum UCS of 150 psi.
  - Report the modulus measured on the specimen (a minimum value of seismic modulus of 500 ksi is desirable).
- Verify the adequacy in terms of moisture susceptibility by preparing an additional set of IDT specimens with the amounts of emulsion and chemical-based additive (if applicable) determined from IDT tests. Perform IDT tests on the specimen after initial 48-hr curing and eight-day capillary moisture conditioning. Ensure the moisture conditioned mix yields a minimum IDTS of 80% of the IDTS obtained without moisture conditioning, or 50 psi

Construction Practices: Based on the field observation of the projects in this study, the following recommendations are made.

- Hot Mix/Surface Treatment: When hot mix/surface treatment are pulverized into bases, ensure that the large size pieces are minimal. For thicker hot mix asphalt layers, the material may be milled separately, sorted and then be added to the base similar to add rock.
- Add Rock: The mixing of the add rock and in place materials should be monitored to ensure that they are mixed uniformly. In the cases when the road is widened, it is of utmost importance that the add rock and in place materials are thoroughly mixed and spread
uniformly throughout the width of the new roadbed. Dissimilar materials used for the existing road and the widened portion negatively impact the performance.

- **Addition of Additives:** The sequence of adding the water, chemical-based additives and emulsion was reasonable in all our projects. The uniform distribution of the additives and water should be carefully observed.

- **Compaction Activity:** The current methods of compaction seem to be adequate for FDR projects observed provided all the required rollers are used. The amount of water in the mix has a significant impact on the final product. Since the variation in density with moisture content is rather small for emulsion bases, the moisture content before compaction should be of great concern. Allowing the compaction when the moisture content is not within 1% of the design moisture content (especially wet of optimum), would have negative impact on the strength of the final product.

- **Quality Management:** The current specification for quality management of the stabilized layers is primarily based on the adequate density and moisture content before and/or after compaction. The moisture content before compaction is typically not enforced rigorously. If the NDG is used, the importance of calibrating it for a particular base and stabilizer should be emphasized. Achieving the density, without controlling the moisture content, may not ensure a high quality material. Therefore, it is desirable to supplement the acceptance based on the density requirements with some alternative means of quality control such as nondestructive modulus-based field tests.

- **Opening to Traffic:** In most projects the opening of the road to traffic after pulverization and compaction is dictated by the need to minimize the traffic disruption to the motoring public. Since a number of factors, including the ambient temperature, impact the rate of increase in strength/stiffness of the finished material, a more objective way of deciding on the opening of the roads under construction is needed. The opening should be established by setting a minimum limit for the strength/stiffness before traffic is allowed. This is especially critical for late season constructions.

**REFERENCES**


