Optimum Use of Local Material for Roadway Base and Subbase

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ABSTRACT
Base materials that meet specifications are getting more difficult to get in many regions of the United States. As a result, higher quality materials have to be hauled long distances. This act would significantly increase the costs associated with roadway construction and subsequent maintenance and rehabilitation. Low quality or out-of-specification materials are usually available from local sources. If through appropriate treatment of the materials or/and structural design, the optimum use of local materials can be permitted, the construction can be accelerated and significant monetary benefits can be realized. Under many current specifications, a material can be considered low-quality for a variety of reasons such as inadequate gradation, inadequate plasticity, and inadequate strength. In many cases, the local base supplies miss the specifications by small margins. Since the criteria set in most of current specifications are experienced-based, some of the criteria used to classify a base material may be less significant than others. This paper presents a test protocol for the use of low quality flexible base materials based on the test results of materials from eight local pits in Texas to document how a low-quality material can be used on low-volume roads and still get a quality foundation layer.
INTRODUCTION
The performance of flexible pavements depends on many factors such as structural adequacy of the pavements, properties of materials used, traffic loading, climatic conditions and construction practices. Previous research has found that much of the distress experienced in flexible pavements can be traced to the problems encountered in base materials (1). Normally, the use of high-quality base materials is required for pavement construction and rehabilitation to comply with the standard specifications. However, the reserves of high-quality materials are diminishing in some regions and the long-distance hauled-in materials would result in high transportation costs. This situation has required the use of local sources of base materials in pavement construction.

Local materials may be out-of-specification with respect to the standard specifications for roadway base/subbase. Under many current standard specifications, a base material can be considered out-of-specification for a variety of reasons (inadequate gradation, inadequate plasticity, inadequate strength etc.). In many cases, local base supplies miss these specifications by a small margin. Since the criteria set in the current specifications are experienced-based, some of the parameters used to classify base materials may be less significant than others. With appropriate treatment or structural design, many of these out-of-specification materials can perform adequately for low-volume roads (2, 3, 4). These materials should be capable of providing low-cost base and subbase in roads that are subjected to low traffic levels but high axle loads (5). Studies conducted by the UK Department for International Development (DFID) and others have shown that, with appropriate design, the use of local materials can play a crucial role in terms of cost saving, pavement performance, resource management and environment protection (4, 5, 6).

Based on the evaluation results of marginal or out-of-specification materials from eight local pits in Texas, this paper presents a test protocol and guideline for the optimum use of low quality flexible base materials in low volume roads. The standard specification for flexible base materials utilized in Texas is Item 247 of Texas Department of Transportation (TxDOT).

NON-STANDARD/OUT-OF-SPECIFICATION MATERIALS
Base material not wholly in accordance with the specification but can be used successfully either in special conditions, or because of climatic characteristics, or recent progress in road techniques or after having been subject to a particular treatment is defined as non-standard and nontraditional material (4). Base materials that miss the standard specifications by a small margin are the marginal materials. Besides those manufactured, these materials can be grouped within a four tier system (7):

- Group I - Hard Rocks: usually comprising materials that require crushing and processing but retaining properties that result in the material does not fully meeting the requirements of a crushed stone base.
- Group II - Weak rocks: materials derived from weakly cemented, poorly consolidated or partially weathered parent deposits.
- Group III - Natural Gravels: transported and residual soils and gravels not meeting the minimum material standards for natural gravel base.
- Group IV - Duricrusts: indurated or partially indurated soils not meeting the minimum material standards for natural gravel base.
Currently, in Texas, any base material that does not meet the requirements of TxDOT Item 247 is considered out-of-specification. The criteria set in this specification for Grade 1 base materials are reflected in Table 1.

Grade 1 base materials are the primary materials for base course performing as a structural layer in a pavement structure. The material provides a more uniform gradation given more control on the particle distribution. Also, Grade 1 provides more cohesive strength properties, given a higher zero psi lateral strength requirement. This offers more stability to the material in the presence of minimal lateral support or overburden, such as roads with narrow pavements or thin surfaces. Grade 1 requirements also contain more stringent plasticity property specifications and less allowable fines (material passing No. 40 sieve), that can result in base material with less moisture susceptibility and less variable mechanical properties (strength), as compared with other grade materials (8).

EVALUATION METHOD AND TESTING
A survey was conducted to understand the extent of the use of local base materials and to identify the TxDOT districts that could benefit from the outcome of this study. For this, a questionnaire was prepared and sent out to all 25 districts in Texas. Based on the responses, those districts that had ample supply of high-quality base and those that did not have any suitable base source at all were eliminated. For example, no sites from the east or south Texas were included because these districts primarily relied on imported materials, and they did not seem to have a source of local materials. Based on the interaction with TxDOT districts, nine materials from eight different pits in five districts (Abilene, Brownwood, El Paso, Lubbock and San Angelo) were collected. The evaluation method, the first proposed step was to characterize the materials from local pits to determine the reasons for these materials being considered low quality or out-of-specification. TxDOT Item 247 for Grade 1 base materials was considered as the target. The materials that failed to meet those requirements were either treated with calcium-based additives (mainly cement and lime) and/or their gradations were modified to improve their quality.

Laboratory Tests on Raw Materials
The following laboratory tests were performed to assess the suitability of using these raw (untreated) base materials.

- Index Property Tests - gradation, liquid limit (LL) and plasticity index (PI)
- Triaxial Compression Tests (at lateral pressures of 0, 5, 10 and 15 psi)

Table 1 summarizes the results obtained from these tests and compares them with the requirements in TxDOT Item 247 for a Grade 1 base. Each number in the parentheses in the table represents that the material is out-of-specification for a particular requirement. From the table, it can be concluded that:

- El Paso material passed all the requirements for a Grade 1 base and was used as a baseline material to help in developing appropriate test protocol and guideline.
• Abilene (Black Lease) material passed all the requirements for a Grade 1 base except for gradation which was just slightly out-of-limit for No. 40 sieve.
• Materials from Abilene (Old Bobby Noble), Lubbock (Caddell), Brownwood (Prater “Medium” and “Good”, and Vulcan) and San Angelo (Lumpkin) were out-of-specification.

Based on the amount of out-of-specification and in consideration with difference in sampling at the local pits and errors in specimen preparation and testing, we considered the materials from Black Lease of Abilene District and Turner of San Angelo District as Grade 1 base materials.

Remedial Measures
To ensure that the materials classified as out-of-specification can be improved to meet the requirements for a Grade 1 base, chemical treatment and gradation modification measures were adopted. For chemical treatment, 1% of calcium-based additive(s) (lime and/or cement) was used in order to improve the quality of base materials. The preliminary motivation of using such a small amount of additive was to see if a low quality base material (out-of-specification) after such treatment can be used as an economical quality foundation layer. In addition, El Paso base material was treated with three different additives (lime, cement and fly ash) to help in developing guidelines and protocols. For gradation modification, fines content (material passing No. 200 sieve) was adjusted if they failed to meet 5% and 10% range, which as per Gandara et al. (11) is optimal for a quality base material in Texas.

Based on the laboratory test results, the following remedial measures were adopted for the low quality base materials:
• Chemical treatment for Lubbock (Caddell), Brownwood (Prater “Medium” and Vulcan) materials,
• Gradation modification for San Angelo (Lumpkin) material, and
• Both chemical treatment and gradation modification for Abilene (Old Bobby Noble) and Brownwood (Prater “Good”) materials.

TxDOT Item 247 does not contain performance-based or mechanistic-based criteria to evaluate the base materials. As such, besides the tests required in Item 247, the following laboratory tests were also employed:
• Repeated Load Triaxial Test for resilient modulus and permanent deformation (AASHTO T-307 and NCHRP 1-29)
• Free-Free Resonant Column Test for Young’s or seismic modulus (9)
• Tube Suction Test for moisture susceptibility of materials in terms of retained unconfined compressive strength and retained seismic modulus (10)

The retained strength is defined as a ratio of the unconfined compressive strength after 10 days of moisture conditioning to the unconfined compressive strength after 24 hours of curing in room temperature. The same definition is also applicable to the retained modulus. The recommended value for the two parameters is greater than 80%. (10).
### Table 1 - Evaluation of the Results Based on Item 247 for Grade 1 Base

<table>
<thead>
<tr>
<th>TXDOT District</th>
<th>El Paso (ELP)</th>
<th>Lubbock (LBB)</th>
<th>Abilene (ABL)</th>
<th>Brownwood (BWD)</th>
<th>San Angelo (SJT)</th>
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<tbody>
<tr>
<td><strong>Pit</strong></td>
<td>Cemex</td>
<td>Caddell</td>
<td>Black Lease</td>
<td>Old Bobby Noble</td>
<td>Prater &quot;Medium&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Prater &quot;Good&quot;</td>
<td>Vulcan</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lumpkin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Turner</td>
</tr>
<tr>
<td><strong>Material Type</strong></td>
<td>Limestone</td>
<td>Rhyolite</td>
<td>Limestone</td>
<td>Limestone</td>
<td>Limestone</td>
</tr>
<tr>
<td>Requirements for Grade 1 Base</td>
<td></td>
<td>Tuff</td>
<td>Limestone</td>
<td>Limestone</td>
<td>Limestone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gradation Sieve Size (% cumulative retained)</th>
<th>El Paso</th>
<th>Lubbock</th>
<th>Abilene</th>
<th>Brownwood</th>
<th>San Angelo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-¾ in. (0%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7/8 in. (10%-35%)</td>
<td>23</td>
<td>21</td>
<td>19</td>
<td>24</td>
<td>(7)</td>
</tr>
<tr>
<td>3/8 in. (30%-50%)</td>
<td>40</td>
<td>(51)</td>
<td>46</td>
<td>50</td>
<td>31</td>
</tr>
<tr>
<td>No. 4 (45%-65%)</td>
<td>55</td>
<td>(66)</td>
<td>62</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>No. 40 (70%-85%)</td>
<td>78</td>
<td>(88)</td>
<td>(88)</td>
<td>(90)</td>
<td>(69)</td>
</tr>
<tr>
<td>No. 200</td>
<td>95</td>
<td>99</td>
<td>96</td>
<td>99</td>
<td>81</td>
</tr>
</tbody>
</table>

| Liquid limit, max. 35%                       | 27      | 34      | 18      | 16        | 29         |
| Plasticity index, max. 10                     | 8       | (20)    | 6       | 7         | (11)       |
| Classification*, 1.0                          | 1.0     | (2.5)   | 1.0     | (3.6)     | (2.6)      |
| Min. compressive strength                     |         |         |         |           |            |
| Lateral pressure at 0 psi: 45 psi             | 62      | 46      | 54      | (34)      | (32)       |
| Lateral pressure at 15 psi: 175 psi           | 230     | 198     | 255     | (130)     | (133)      |

*Classification as per Test Procedure Tex 117-E, which depends on shear stress and normal stress.
Laboratory Tests on Gradation-Modified/Chemical-Treated Materials

The minimum required or recommended unconfined compressive strength (UCS) values are 300 psi for cement-treated base materials (10) and 150 psi for either lime-treated or fly ash-treated base materials (see Tex 121-E and Tex 127-E procedures) in Texas. As expected, a small dosage of additives (1%) would not fulfill these stabilization requirements (> 2% additives) as shown in Figure 1. For economical reasons, the goal of adding 1% of calcium-based additives was to just strengthen the material to meet the Item 247 requirements for a Grade 1 base so that such treatment could be applied on a low-volume roadway and still get a quality foundation layer.

Based on the results obtained from the laboratory tests (see Table 2), the following findings and observations were made:

- Except for Brownwood materials, the PI of treated material showed lower values than those obtained from untreated materials. The variation of LL between treated and untreated materials depended upon the type of material.
- For all the cement-treated base materials (with 1% cement) and most of the lime-treated base materials (with 1% lime), the compressive strength values at zero psi lateral pressure and 15 psi lateral pressure met the Item 247 minimum requirements of 45 psi and 175 psi, respectively. For most materials under this study, the change in gradation did not significantly improve their quality.
- A resilient modulus of 40 ksi was arbitrarily considered as a baseline value for delineating low quality and good quality base materials. Most of the raw materials did not reach the resilient modulus of 40 ksi. For cement-treated and lime-treated materials, the resilient modulus of 40 ksi was readily achieved. For most materials, the resilient modulus of cement-treated base was higher than the ones obtained from lime-treated base materials (see Figure 2).

![Figure 1 - Unconfined Compressive Strength of Different Materials](image-url)
### Table 2 - Laboratory Results before and after Chemical Treatment or Gradation Modification

<table>
<thead>
<tr>
<th>District</th>
<th>Material Source</th>
<th>Material Type</th>
<th>Atterberg Limits</th>
<th>Constituent*, %</th>
<th>Triaxial Compression (Tex 117-E)</th>
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<td></td>
<td></td>
<td></td>
<td>LL</td>
<td>PI</td>
<td>Gravel</td>
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<tr>
<td>ABL</td>
<td>Old Bobby</td>
<td>Raw</td>
<td>16</td>
<td>7</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Noble</td>
<td>1% Cement</td>
<td>20</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>New Gradation</td>
<td>Same as for Raw</td>
<td>65</td>
<td>30</td>
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<tr>
<td>BWD</td>
<td>Prater “Medium”</td>
<td>Raw</td>
<td>20</td>
<td>5</td>
<td>55</td>
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<tr>
<td></td>
<td>Prater “Medium”</td>
<td>1% Lime</td>
<td>29</td>
<td>8</td>
<td></td>
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<tr>
<td></td>
<td>Prater “Medium”</td>
<td>1% Cement</td>
<td>29</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prater “Good”</td>
<td>Raw</td>
<td>26</td>
<td>9</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Prater “Good”</td>
<td>1% Cement</td>
<td>24</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prater “Good”</td>
<td>New Gradation</td>
<td>Same as for Raw</td>
<td>53</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raw</td>
<td>15</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1% Cement</td>
<td>17</td>
<td>4</td>
<td></td>
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<tr>
<td>ELP</td>
<td>Cemex</td>
<td>Raw</td>
<td>27</td>
<td>8</td>
<td>55</td>
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<tr>
<td></td>
<td>Cemex</td>
<td>1% Lime</td>
<td>12</td>
<td>2</td>
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<td>13</td>
<td>3</td>
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<td>Cemex</td>
<td>1% Fly Ash</td>
<td>12</td>
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<tr>
<td>LBB</td>
<td>Caddell</td>
<td>Raw</td>
<td>34</td>
<td>20</td>
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<td></td>
<td>Caddell</td>
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<td>27</td>
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<td>SJT</td>
<td>Lumpkin</td>
<td>Raw</td>
<td>29</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Lumpkin</td>
<td>New Gradation</td>
<td>Same as for Raw</td>
<td>55</td>
<td>40</td>
</tr>
</tbody>
</table>

* (1) Requirement for gravel should be between 45% and 65% as per Item 247
(2) Requirement for fines content should be between 5% and 10% as per Project Report Tex 0-4348
Figure 2 - Representative Resilient Modulus at OMC of Different Materials before and after Treatment/Gradation Modification

- On Tube Suction Test, most of the chemical-treated and gradation-modified materials passed the requirement of 80% for retained strength and retained modulus (see Figure 3). However, the two retained parameters largely depended upon the type of material. For most of the materials treated with 1% cement or 1% lime, the dielectric constants did not show significant changes as compared with those obtained from raw materials.

Performance Evaluation with Small-Scale Test

Since actual field testing is expensive and the level of control in placing the section is hard to achieve in the field, it is necessary to have a method that can verify the outcomes from standard laboratory tests and link these outcomes to those from field tests. A small-scale lab testing system as shown in Figure 4 is an alternative to obtain realistic performance results for comparison. This system is easier to control the quality of subgrade, and to vary the moisture content from the as-built or as-compacted condition in the laboratory than in the field.

The small-scale testing system has been used to evaluate the performance of a number of bases under different moisture conditions to verify their performance (12). In that study, it was demonstrated that the results from field sections could be reasonably well simulated with this system. The results from different experiments could be compared to demonstrate the effectiveness of the remediation proposed based on lab testing on each local base material under different environmental conditions.

Three different moisture conditions were considered to simulate different environmental conditions: 1) both base and subgrade at optimum moisture content, 2) base at optimum moisture content and subgrade saturated, and 3) both base and subgrade saturated. The moisture condition
or the saturation level of base and subgrade was monitored using resistivity probes placed in the middle of each layer. These moisture conditions were expected to cover the best and most severe conditions for a flexible pavement.

![Figure 3 - Retained Strength and Retained Modulus before and after Treatment/Gradation Modification](image-url)
Modulus and permanent deformation tests were performed on each small-scale specimen 1) three days after construction, 2) after saturation of the subgrade and 3) after saturation of both base and subgrade. The modulus tests were carried out with a Portable Seismic Pavement Analyzer (PSPA) (8) and a Dynamic Cone Penetrometer (DCP) as shown in Figure 4. The permanent deformation test was carried out with a 220-kip MTS system. In the permanent deformation test, the load was applied and the resulting displacement was monitored, digitized, and saved for further analysis.

The results on Lubbock material from Caddell Pit and Abilene material from Old Bobby Noble Pit are discussed here. Four specimens for each material were prepared for small-scale testing. The base layers in two specimens did not contain additives while other two were treated with 1% lime for Lubbock material and with 1% cement for Abilene materials. Two of the specimens were constructed using a clay subgrade and the other two using a sandy subgrade. The results from modulus tests on the base layer of each small-scale specimen indicated that the bases treated with 1% lime or 1% cement were significantly stiffer than in its virgin state, which was consistent with the results obtained from the traditional laboratory tests.

As an example, the load-deflection curves from the three moisture conditions for specimens of Lubbock base material are presented in Figure 5. Assuming that 100 mils of deformation
Figure 5 - Load Deflection Curves from Small Scale Test
correspond to failure, under the optimum moisture condition, the base treated with 1% lime carried substantially more load as compared to the base without treatment. This pattern was also observed for the other two moisture conditions. The permanent deformation or resilient deformation (rutting) after 200 cycles of loading was substantially less for the base treated either with 1% lime or with 1% cement under the optimum condition. Under the subgrade-saturated condition, the specimens on sandy subgrade performed better. Again, the resilient deformations were less for the treated bases. When both, base and subgrade, became moist, the resilient deformations were much higher than the optimum condition for all cases. However, for the lime-treated samples, the resilient deformations were less than 100 mils. Based on this experience, the treatment of low-quality base materials with a small amount of additive will provide a better-performing pavement foundation.

Structural Analysis
Since the major structural distress in low-volume roads is rutting (13), this type of distress was emphasized in this study. Also the equivalent thicknesses of a two-layer base system, one with a high-quality base material and the other one with a low-quality base material, were determined for the feasibility of using lower-quality local base materials as a subbase.

In most classical structural design programs (such as TxDOT FPS19 or AASHTO 1993), the designed thicknesses of pavement layers are directly or indirectly estimated based on the criterion that the stresses at the interfaces between the surface layer and base, and between the base and subgrade are low enough so that the cracking of the surface layer and rutting of the subgrade will not be an issue. For a given traffic condition, the thicker the layers overlying the base, the thicker the base layer and the stiffer the subgrade are, the lower the critical stresses and strains will be. With these design algorithms, replacing a good quality base with a thicker low-quality base can control the rutting of subgrade. The classical design programs neglect the rutting of the base layer. For a given thickness of surface layer, a low-quality base may rut, even though subgrade may not. This is very critical for low-volume roads where the surface layer is quite thin, or only the surface-treatment is applied.

A software package, VESYS5W (14), was used to model the rutting of each individual layer in a flexible pavement with the number of truck passes. The parameters of interest in this program are the permanent deformation parameters $\alpha$ (the rate of increase in permanent deformation with the number of load applications) and $\mu$ (permanent deformation after one cycle) (15). Other parameters influencing the rutting of pavement structure are the moduli of the base and subgrade.

Determination of Equivalent Layer Thickness
The main principle of structural equivalency is that the flexible pavements constructed with low-quality base materials should experience the same amount of fatigue cracking and rutting when the pavement is constructed with the high-quality base materials. As the first step, the thickness of base layer using FPS19 design program for the flexible pavements constructed with high-quality base materials was determined for each district. The resilient moduli obtained from lab tests was used for this purpose. This step was necessary to ensure that the design pavement is within current TxDOT guidelines. The layer-by-layer and total rut depths of these pavements were then determined using VESYS5W. As the total rut depths in pavements using the high-quality bases were determined, equivalent base thicknesses for low-quality base were obtained with the following criteria:
• If the rut depth with a high-quality base was greater than 0.5 in., the thickness of the low-quality base was adjusted until the rut depth became close to that of high-quality material.
• If the rut depth with the high-quality base was less than 0.5 in., the thickness of the low-quality base layer was adjusted until the rut depth became close to 0.5 in.

The minimum layer thickness required for each material used in this study was subjected to a low-volume traffic load (ADT = 250) over a design life of 20 years. Two different types of subgrade with the moduli of 20 ksi and 10 ksi were considered to document their impact on base thickness. These analyses were based on the assumption that the pavement structure was only covered by a surface-treatment, which is the case for the majority of low volume roads in Texas.

Figure 6 depicts the base thicknesses for the high quality and treated bases. The thickness required for a high quality base increased as the modulus of subgrade decreased. For example, the thickness required for El Paso base increased from 12.5 in. to 14.5 in. as the modulus of subgrade decreased from 20 ksi to 10 ksi. As reflected in Figure 6, the rut depths are rather small for all cases.

Figure 7 shows the similar information as Figure 6 but with the corresponding low quality base materials. For practical reasons the thickness of the base was limited to 18 in. In this case the total rut depths of pavement were significantly higher than those in Figure 6. Most of the additional rutting was contributed to the rutting of base. Based on the results, the following conclusions were made:

• With an increase in high-quality base thickness, the subgrade rut depth decreased substantially while the base rut depth increased marginally. Hence, an increase in base thickness would result in a decrease in the total rutting of pavement structure.
• In the case of low-quality base, the rutting of subgrade decreased with an increase in base thickness. However, base itself rutted substantially, resulting in a significant increase in rut depths with an increase in base thickness. As such, increasing the thickness of low-quality base to provide an additional protection to subgrade seemed not prudent.

Utilization of Subbase Layer
One practical way to utilize the lower quality local materials is to use them as a subbase. For simplicity in the analysis, it was assumed that the base course consisted of a 6-in. thick high quality (HQ) layer over a 6-in. thick low quality (LQ) layer and that the moduli were 100 ksi for the high quality layer and 30 ksi for the low quality layer. The influences of permanent deformation parameters $\alpha$ and $\mu$ on the rutting of the combined base and subbase course are shown in Figure 8. The use of low quality material as subbase does not result in a significant rutting increase in the entire base course as compared with the rutting for the base course built only with a high quality material. This statement is almost independent of the subgrade modulus. Generally speaking, as long as the top 6 in. to 8 in. of base is of high quality and rut resistant, the remainder of the base thickness is only necessary to control the rutting of subgrade and can be
Figure 6 - Base Thickness and Total Rutting of High-Quality/Treated Materials
Figure 7– Equivalent Base Layer Thickness, Base Thickness from FPS 19 and Total Rutting of Low Quality Base
Figure 8 - Comparison of Variations in Rutting with Parameters Alpha and Mu for One-Layer Base and Two-Layer Base

potentially of the lower quality. Even though these results are not verified, a number of cases in TxDOT database of successful pavements points to the same conclusions

TEST AND EVALUATION PROTOCOL
The requirements for Grade 1 base materials by TxDOT Item 247 are the basis of evaluating and using local pit materials for roadway base and subbase. The flow chart of activities is shown in Figure 9 and detailed step by step in the following paragraphs.

If the gradation is slightly or partially out of limits, particularly, for smaller than No. 40 sieve, the modification of gradation is an option. Also if more than 15% of the material passing No. 200, the modification of gradation may be considered.

The LL should be less than 35 and the PI should be less than 10. If LL or PI or both are out of the limits, the use of chemical treatment is recommended.
Figure 9 - Flow Chart of Test and Evaluation Protocols

The retained unconfined compressive strength should be greater than 80%. If the retained strength is less than 80%, chemical treatment is recommended.

Dielectric constant measurement is recommended for secondary assessing the moisture susceptibility of untreated material through. If dielectric constant is greater than 16, chemical treatment is recommended, depending upon the strength values. Depending on the availability of the equipment, these tests should be carried out in-house or should be performed by a commercial laboratory. These values are required for structural analysis. The additional cost associated with this task is justified to ensure that the local base will
not experience excessive permanent deformation. A representative resilient modulus higher
than 40 ksi is recommended. The modulus test can be performed with a free-free resonant
column (FFRC) device, depending on the availability of the equipment. A seismic modulus of at
least 80 ksi is proposed at this time.

The permanent deformation should be conducted similar to NCHRP 1-29 protocol. The primary
reason for conducting permanent deformation tests is to obtain parameters needed for assessing
the rutting of the base. As such it is difficult to set acceptable limits. Usually, permanent
deformation in excess of 2% may be considered excessive without structural analysis.

The two main factors considered are the percentage of material passing the No. 200 sieve and the
Plasticity Index (PI). If the PI is greater than 10 by a large margin, the use of lime is
recommended. For economical reasons, the percentage of additive should not exceed 2% by dry
weight of the material being tested. Since the amount of additives used is low, the strength
parameters of the treated materials shall be evaluated as a flexible base material. If the treated
material does not satisfy the strength requirements for a flexible base, the use of greater amount
of additives can be considered, if deemed economical. In that case, the material should be
considered as a stabilized material and the percentage of the additives should be determined
based on the appropriate protocols for stabilized materials.

Based on the result of sieve analysis, the gradation of the material should be changed so that it
would conform to the Grade 1 requirements of Item 247. If the percent passing No. 200 is
substantially more than 12%, consider reducing the fine content of the mix. The viability of the
new gradation should be evaluated as recommended above.

The thickness requirements for the base course should be evaluated to ensure that the base layer
is stable in terms of rutting as discussed above.

CONCLUSIONS
Based on this study, the following conclusions can be drawn:

• Permanent deformation of the base layer in a pavement with thin surfacing controls the
  amount of rutting that the pavement experiences.
• Current pavement design algorithms (e.g.: FPS19 or AASHTO 2003) should be used with
care for the base courses of lower quality materials. These algorithms tend to provide
base thicknesses that may exaggerate the rutting of bases. More advanced analysis is
recommended to ensure the stability of low quality bases.
• The use of low quality materials as subbase seems feasible and advantageous. The top 6
  in. to 8 in. of the base layer in a low-volume road with thin surfacing seems to contribute
  the most to rutting. As such, for a base course thicker than 12 in., the use of low quality
  material as subbase, especially for strong subgrades, is recommended.

1 Representative modulus is estimated at a confining pressure and a deviatoric stress representative of the middle of
the base layer due to an 18-kip equivalent single axle load. The typical values of the confining pressure and
deviatoric stress of 5 psi and 15 psi, are recommended for a typical base.
The quality of most low quality materials can be significantly improved by treating them with a small amount of calcium-based additives (1% to 2%). In this study, for all cement-treated base materials (1% cement) and most of the lime-treated base materials (1% lime), both unconfined and confined strengths met the minimum requirements in TxDOT Item 247.

For most materials, adjustment in gradation did not significantly improve their quality.

Most of the untreated materials did not achieve adequate modulus. The resilient modulus of treated materials was significantly higher.

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