Strategies to Improve and Preserve Flexible Pavement at Intersections:
Information Search

Technical Memorandum 0-5566-1

Conducted for
Texas Department of Transportation
P.O. Box 5080
Austin, Texas 78763

January 2009
Strategies to Improve and Preserve Flexible Pavement at Intersections: Information Search

by

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Research Project 0-5566

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Center for Transportation Infrastructure Systems
The University of Texas at El Paso
El Paso, TX 79968-0516
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INTRODUCTION

Many rural intersections originally constructed with thin untreated flexible base and hot mix or a two-course surface treatment experience severe pushing, shoving and rutting. These failures cause an extremely rough surface that can cause damage to small vehicles and potentially cause motorists to lose control of their vehicle. These distresses almost always result in complete failure of the existing pavement that must be repaired several times during the life of the roadway by maintenance forces. In most cases, pavement sections constructed with the same materials adjacent to the intersection perform adequately until the approach (approximately 150 ft in advance) of the intersection and in the intersection itself when the failures become apparent.

This project would seek to understand the mechanisms of intersection pavement failures and determine the best practices to minimize the failures at existing intersection pavements. The outcome of this project should help to reduce the frequency of maintenance needed at rural intersections. This project would also determine how the mechanisms causing the surface failures at intersections can be mitigated through design and construction modifications.

A flowchart of tasks associated with this project is summarized in Figure 1. The flowchart outlines the highlights of the nine tasks proposed and the anticipated outcome of each task. This technical memorandum represents the work progress of Task 1 of this project. Also incorporated in this technical memorandum is the schedule of research activities (see Figure 2). The schedule highlights the original work schedule and the work completed “work progress” of Task 1.
<table>
<thead>
<tr>
<th>Task</th>
<th>Activity Highlights</th>
<th>Work Product</th>
</tr>
</thead>
</table>
| 1. Information Search | • A comprehensive Literature Review | • A document of practices for mitigating rutting at intersections worldwide  
• A matrix of solutions, when they are effective, their advantages and disadvantages, their economical feasibility |
| 2. Understanding and Documenting Extent of Problems and Solutions in Texas | • Surveying Districts  
• Reviewing Forensic Reports  
• Interviewing District Personnel and site visits  
• Interviewing CST Personnel | • A document of typical intersections with problem  
• A catalog of sources of problems  
• A catalog of effective and ineffective solutions  
• A comparison of TxDOT solutions with those from other states and countries |
| 3. Selection of Candidate Sites for In-Depth Evaluation | • An in depth statistical and trend analysis of results from Task 2 to categorize typical problems | • At least twelve sites that cover the inference space of the problems, pavement types, environmental conditions, subgrade types etc. for in depth field and laboratory evaluation |
| 4. Thorough Forensic Study of Candidate Sites | • Structural and Functional evaluation of sites  
• Coring and Sampling  
• Laboratory tests of Pavement Materials  
• Recommending solutions  
• Conducting thorough structural design of the existing and recommended Solutions  
• Life Cycle Cost Analysis of Solutions | • A catalog of solutions based on the type of the problem, and the field and laboratory testing results |
| 5. Preliminary Guideline Based on Results from Tasks 2 through 4 | • Develop a Comprehensive Decision tree  
- to guide TXDOT personnel through the process of field and Laboratory evaluation of intersections  
- to select the most appropriate rehabilitation solutions | • A flow chart that will lead TXDOT personnel through steps necessary for selecting best rehabilitation solutions for a given intersection  
• A document that can be used as a guideline by TXDOT personnel  
• An electronic version of the document with hyperlinks that provide additional information to TXDOT personnel |
| 6. Develop Final Design and Construction Guideline | • Incorporate the outcome of Task 5, the remaining outcome of field work and feedback from PMC in a final guideline | • A software that will ask a series of simple if-then questions from users to guide them through the process of selecting the best solution, determining the most appropriate mix or mineral, and suggestions for reconstruction of the sections |
| 7. Develop an Expert System | • Incorporate the outcome of Task 5 and 6 in an expert system shell to readily guide TXDOT personnel in determining the best solution | • A technical memorandum at the end of each task  
• A final report documenting all work performed, method used, and results achieved  
• A Project Summary Report (PSR) |
| 8. Recommend changes to TXDOT Policies | • Based on the outcome of all tasks, recommend changes to the TXDOT 2004 Specifications | • A document that can be used as a guideline by TXDOT personnel |
| 9. Submit Reports | | • A software that will ask a series of simple if-then questions from users to guide them through the process of selecting the best solution, determining the most appropriate mix or mineral, and suggestions for reconstruction of the sections |

Figure 1: Summary of Tasks as an Overview of Research Approach
<table>
<thead>
<tr>
<th>Research Activity</th>
<th>Estimated % of Total Project Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1 Information Search</td>
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</tr>
<tr>
<td>Task 2 Understanding and Documenting Extent of Problems and Solutions in Texas</td>
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</tr>
<tr>
<td>Task 3 Selection of Candidate Sites for In-depth Evaluation</td>
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<tr>
<td>Task 4 Thorough Forensic Study of Candidate Sites</td>
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</tr>
<tr>
<td>Task 5 Preliminary Guideline Based on Results from Task 2 through 4</td>
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</tr>
<tr>
<td>Task 6 Develop Final Design and Construction Guideline</td>
<td>14%</td>
</tr>
<tr>
<td>Task 7 Develop an Expert System</td>
<td>20%</td>
</tr>
<tr>
<td>Task 8 Recommend Changes to TxDOT Policies</td>
<td>7%</td>
</tr>
<tr>
<td>Task 9 Submit Reports</td>
<td>4%</td>
</tr>
</tbody>
</table>

Note: A Tech Memo will be submitted to the PD & RTI at the end of each non-deliverable task.

Figure 2: Schedule of Research Activities
REVIEW OF LITERATURE

A substantial literature review that documented strategies to preserve and rehabilitate flexible pavement at intersections is incorporated in this technical memorandum. The memo is organized starting with a review that is focused on most common flexible pavement distresses at intersections. Next, a review of current TxDOT specifications for flexible pavement rehabilitation is documented. What is followed is a set of summaries of the flexible pavement at intersection specifications adopted by several organizations and state agencies. Also incorporated is previous research by agencies and strategies to stabilize and remediate base and subgrade problems.

BACKGROUND

A vast majority of the TxDOT highway system consists of secondary roads that are constructed with thin pavement structures and thin hot mix asphalt surface or two-course surface treatment. This network of low-volume roads has served the public well, and for the most part, performs satisfactorily with periodic maintenance. One of the weakest links in this network is the performance of the pavement at the intersections. Severe permanent deformation (pushing, shoving and rutting\(^1\)) have been reported at intersections of some of these low-volume roads while pavement sections constructed with the same materials adjacent to the intersection perform adequately. These failures occur because of the higher severity of loads exerted to the pavement at the intersections.

COMMON TYPES OF DISTRESSES ON ASPHALT PAVEMENTS

Rutting

Rutting is defined as the longitudinal permanent deformation or plastic movement of the asphalt pavement under the action of repeated loadings over the wheel path. Rutting is usually caused by the densification and shearing of the different pavement layers. It is visually identified by the depression in the pavement surface along the wheel paths. Even though visible on pavement surface rutting may occur on any of the layers.

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\(^1\) In this memo the term permanent deformation is used to imply to rutting as well as shoving and pushing.
Rutting is a serious safety issue for drivers. When water accumulates in the ruts, there is a potential for hydroplaning. The hydroplaning phenomenon consists of the buildup of a thin layer of water between the pavement and the tire and results in the tire losing contact with the surface, with the consequent loss of steering control (Yoder and Witczak, 1975).

Three main mechanisms lead to the following three types of rutting: Structural Rutting, Instability Rutting and Surface/Ware Rutting. It is important to differentiate between these three types of rutting and their potential causes. Different mechanisms lead to a variation in visual characteristics of rutting. According to Fang (2001), shapes of transverse surface profiles differ between failures in the HMA surface mixtures and failures in the underlying support layers.

Structural Rutting

The deformation of one or more layers underlying the HMA layer results in structural rutting. Base and/or subgrade materials are unable to sustain the load stresses resulting in depressions and lack of support to the superior layers, manifesting on surface rutting.

A cross sectional diagram of structural rutting is shown in Figure 3. Structural rutting can be visually identified rather easily. Two main characteristics distinguish structural rutting from other modes of rutting. Structural ruts are wide and do not have humps on their sides as compared with instability rutting described later.

![Figure 3: Structural Rutting on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council, 2003).](image)

The surface deformation is dependent on which of the layers is failing to support the load. The visual characteristics will be different when the subgrade is failing as compared to the base. Figures 4 and 5 illustrate and compare the difference between the surface deformation profiles due to base and subgrade failures. When the base is failing, a small hump will be visible at the surface in the middle of the two wheel paths, while the deformation due to subgrade failure will have no humps at all with a wider wheel path depression (Fang, 2001).
Inadequate design, poor construction, and improper material specification in asphalt pavement systems generally cause structural rutting. Traffic conditions, weak substructure, or even poor drainage are essential parameters in pavement design. Miss-estimation of these parameters leads to inadequate design and affect the pavement system which could induce structural rutting.

**Instability Rutting**

Instability rutting or plastic flow is the type of rutting that is due to inadequate HMA mix design rather than the structural design. Epps (1999) reported that the shear deformation, rather than densification, is the primary rutting mechanism in HMA surface mixtures when the supporting layers are reasonably stiff. This kind of rutting is visually recognized by the humps formed on the sides of the rut as shown in Figure 6.

This type of distress is more visible in slow trafficked area of the pavement such as intersections which represent a variance in the loading conditions applied to the pavement. Braking, accelerating, turning, standing, and slow moving stresses at intersections induce instability rutting. It may also be contributed to factors such as:

- High pavement temperatures.
- Improper materials.
- Rounded aggregates.
- Too much binder and/or filler.
- Insufficient or too high air voids.
According to Colorado DOT Pavement Design Guide (2009), during warm summer months the sun radiation and the exhaust of the slow/standing vehicles raise the pavement temperature. At higher temperatures a reduction in the HMA stiffness occurs, which may induce instability rutting in the HMA layer. Dripping engine oil and other vehicle fluids are also concentrated at intersections and tend to soften the asphalt (CDOT, 2009). At intersections, stopped and slow moving traffic allow exhaust to elevate asphalt surface temperatures even higher. A properly designed mixture with a stiffer asphalt binder and strong aggregate structure will resist plastic deformation of the hot mix asphalt pavement.

Surface/Wear Rutting

Wear rutting is the consolidation in the wheel paths of the HMA layer due to insufficient compaction effort which is usually reflected in not achieving the target density. Consequently additional compaction to the asphalt layer is generated by vehicle loading without any base/subbase yielding or the formation of HMA humps as seen in Figure 7. According to the Colorado Department of Transportation (2009) the following list of factors contributes to this type of rutting:

- Insufficient compacting effort within the lower base layers
- Not enough roller passes while paving
- HMA cooling before target density
- Asphalt moisture or dust
- Low asphalt content in the mix
- Lack of cohesion in the mix (tender mix, gradation problem)

Wear rutting is also the result of chains and studded tires wearing away the pavement surface during winter season. This problem is not common in Texas.

![Figure 7: Wear Rutting on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council 2003).](image-url)
Shoving

Shoving of an asphalt concrete pavement is defined as the longitudinal surface displacement of the HMA. Shoving is usually caused by an unstable asphalt layer that is not strong enough to resist horizontal stresses. Acceleration and deceleration of vehicles represent a continuous load in the same direction that generally causes shoving as shown in Figure 8. Excess binder in the mix, mistakes on the gradation, and erroneous temperature during compaction are parameters that cause a weak asphalt mixture. These potential problems along with poor bonding between the HMA and the underlying layer decrease the resistance to horizontal stresses leading to shoving. Shoving can be easily identified by distortion of pavement markings, and vertical displacements (dips and bumps). In many cases shoving is manifested with a large “bow wave” in front of the braking section or areas where HMA abuts a rigid object such as utilities. Shoving affects ride quality and may represent a safety hazard.

Figure 8: Shoving on Asphalt Pavements.

Fatigue Cracking

Fatigue in asphalt pavement manifests itself in the form of cracking from repeated traffic loading (Suo et. al., 2007). Three main factors that affect the initiation and propagation of fatigue cracking are the mix design, pavement structure, and construction procedures. The main visual characteristics of fatigue cracking are the interconnection of cracks in a chicken wire/alligator pattern as seen on Figure 9.

Fatigue cracking is an important mechanism in the deterioration of asphalt pavement because of the harmful effect this cracking has on the stiffness and strength of pavement. Cracking allows water to percolate to the underlying layers, weakening the support and therefore accelerating permanent deformation of the pavement sections.

Other Distresses

The dominant distresses at intersections are rutting, shoving and fatigue cracking, however other distresses may manifest at the intersections. The sources of the dominant distresses can also generate additional distresses and the distresses themselves can represent a source of other distresses. Such is the case of moderate to high severity fatigue cracked areas, where the interconnected cracks form pieces that when moved while subjected to traffic leave a Pothole behind. Another surface defects such as bleeding, raveling and polished aggregates are
distresses present at intersections which according to the LTPP “Distress Identification Guide” (2005) are potential mixture related performance problems.

**REMEDIATION STRATEGIES OF ASPHALT PAVEMENT AT INTERSECTIONS**

An extensive review of the literature indicates that the sources of and solutions for failure of the intersections in urban areas are well researched and a number of solutions (e.g., full-depth concrete slabs, whitetopping, high quality HMA overlay etc.) have been implemented. For example, the National Asphalt Pavement Association (NAPA) and the American Concrete Pavement Association (ACPA) have several documents and training materials available for this purpose. On the other hand, less attention has been focused intersection on the rural low-volume road in the US. In many countries in Africa and Southeast Asia, and in Australia and New Zealand the majority of their highway networks are either unpaved or are only covered with surface treatment. Much can be learned from their operations and incorporated into this research. In this section a review of international strategies is presented. The strategies and operations from this collection of work will help provide the initial framework for developing implementable solutions for the rural.

**Current TxDOT Specifications for Flexible Pavement Rehabilitation**

TxDOT’s Flexible Pavement Rehabilitation methods are listed in the TxDOT Pavement Design Guide (2006) found in [http://onlinemanuals.txdot.gov/manuals/](http://onlinemanuals.txdot.gov/manuals/). According to such guide developing a rehabilitation design generally requires extensive investigation into the condition of the existing pavement structure, performance history, and laboratory testing of materials to establish suitability of existing and proposed materials for use in the rehabilitation design. The field investigation will require a deflection survey, drainage survey, and perhaps additional nondestructive testing (NDT) surveys such as ground penetrating radar (GPR), dynamic cone penetrometer (DCP), and seismic. Examination of multi-year Pavement Management Information System (PMIS) distress and ride data will show performance related issues. Once these preliminary surveys are conducted, locations for material sampling can be established. In addition, for projects where full-depth reclamation is being considered, samples of the structure should be taken at intervals not to exceed 0.5-mi. These samples will be evaluated in the lab to...
verify field survey conclusions and establish basic properties necessary to quantify moisture susceptibility, stabilizer compatibility, blending requirements, etc.

The preferred rehabilitation strategy should:

- be cost-effectiveness
- address the repair of the specific problems of the existing pavement
- prevent of future problems, and
- meet all existing constraints of the project.

TxDOT currently does not have a specific strategy to approach problems with flexible pavement at intersections; therefore such problems have been approached with regular road procedures, even though intersections represent a different situation. The outcome of this research study is to provide at minimum a handbook designed for maintenance personnel showing “best practices” for maintaining flexible pavements at intersections and a expert system that allows for selecting the optimal remediation strategy at intersections.

**Asphalt Institute**

Knowing that pavement at intersections require special attention due to their high-stress conditions, the Asphalt Institute (AI) published a set of articles named “Intersection Strategy” (Walker and Buncher, 1999). These articles include guidelines to diagnose the sources of the pavement distress and to select the proper methods to repair them. Different agencies have adopted the AI strategies and/or developed guidelines that are similar to them. The Plant Mix Asphalt Industry of Kentucky (PAIKY), Asphalt Pavement Alliance (APA), Maryland Asphalt Association and the National Asphalt Pavement Association (NAPA) are among the agencies that follow the AI strategy. States such as Oregon have also adopted the strategies promoted by the AI in their Pavement Design Guides. Canada’s strategy goes along with the Asphalt Institute’s as reflected in their 2003 publication entitled “Rut Mitigation Techniques at Intersections.”

The intersection strategy consists of the following four steps to minimize distresses and rehabilitate intersections.

1. Evaluate Performance Problems and Causes
2. Ensure Pavement is Structurally Adequate
3. Select appropriate Materials Selection and Mix Designs
4. Adapt proper Pavement Construction Techniques and Selection of Rehabilitation Method

Each step is described below.

*Evaluate Performance Problems and Causes*

The main concern at HMA intersections is the presence of rutting owed to a weak mix or higher than normal stress conditions. Identification of rutting problems at intersections can be through user complaints, staff inspections, or visual and/or measured monitoring. A forensic
investigation is the key to find the root of the problem. It is important to monitor the pavement surface condition to establish the rate of deterioration.

A visual inspection of the pavement surface conditions should be the first step to initiate a forensic study. It should be performed by a pavement engineer who has experience in identifying distresses in pavements. It is important that the location (lane), extent (distance the rutting extends before and after the intersection), and severity of the rutting are established.

After identifying the severity, an evaluation of the causes should be carried out. The evaluation of any roadway that may need rehabilitation may include:

- Deflection testing (FWD, Dynaflect, or Benkelman)
- Coring pavement and subgrade samples
- Thickness measurements for all layers of the pavement
- Determination of material properties of the subgrade, granular base and asphalt concrete
- A review of the construction and maintenance information.

The findings are then analyzed to determine the type (or types) of rutting that has occurred and its causes, to determine the most appropriate rut mitigation strategy.

The analysis of the pavement structure will allow for determining the type or types of distresses present at the intersection, and help choosing a rehabilitation strategy from the following alternatives:

- Pavement preservation (e.g., with low severity instability rutting);
- Pavement overlay (e.g., with medium severity instability rutting);
- Pavement rehabilitation (e.g., with high severity instability rutting); or
- Pavement reconstruction (e.g., with pavement structural rutting).

A life cycle cost analysis should be performed to select the most cost-effective method.

*Ensure Pavement is Structurally Adequate*

An intersection pavement system must provide the structural capacity to withstand the traffic conditions. A proper structural design must take into account the subgrade strength, base thickness and traffic. The middle of the intersection receives loading from several approaches and should be considered in the traffic evaluation. Overlaid, rehabilitated, or reconstructed existing pavements must have structural adequacy for current and anticipated future traffic loads (ESALs). For existing pavements, the structural capacity of the in-place materials must be checked, and any failed or weak areas removed or replaced (Buncher, 2002; Walker and Buncher, 1999). A new design has to be carried out. Replacing the asphalt with the same mix design or paving on top of existing failed pavement will most likely result in recurring failure.
Appropriate Materials Selection and Mix Designs for HMA

The long term performance of an asphalt pavement is dependent on the stiffness of the asphalt binder and the characteristics of the aggregates. The binder’s stiffness plays a critical role in the permanent deformation resistance of an asphalt pavement. So is the shape and strength of the aggregates, which combined represent the skeleton providing strength from stone-to-stone contact. The binder should be stiff enough to prevent rutting while the aggregate must be angular to ensure a better aggregate interlocking and bonding than rounded aggregates.

The use of the Superpave’s Performance Grade (PG) binder system is highly recommended. The PG system selects a binder based on its ability to perform at the temperatures to which the pavement will be subjected. It is a common practice for slow moving design loads to “bump up” the binder one grade, and for standing loads two grades. According to previous experiences at numerous sites across the United States, PG 76-XXs should perform well at intersections (Buncher, 2002). Table 1 indicates the Superpave binder selection adjustments for different ESAL and loading rates.

The aggregate structure carries the load and the shearing forces while the binder holds it together. A proper aggregate selection and gradation is essential. A strong, coarse, and angular aggregate with multiple faces will provide more internal friction and create an aggregate matrix that will resist better the shearing forces that lead to rutting. The amount of rounded aggregates should be limited.

A rut-resistance mixture that has proven to be of great reliability for intersections is Stone Matrix Asphalt. This gap-graded mixture relies on stone-to-stone contact and can be a good option to be applied as a base mixture.

Table 1: Superpave Binder (PGAC) Selection Adjustments (Bumping) for Design ESALs and Loading Rate.

<table>
<thead>
<tr>
<th>Design ESALs Million</th>
<th>High Temperature Grade Increase in 6 °C Grade Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heavy Traffic (Trucks and/or Buses) Loading Rate (Speed)</td>
</tr>
<tr>
<td></td>
<td>Standing &lt; 20 km/hr</td>
</tr>
<tr>
<td>&lt; 0.3</td>
<td>-</td>
</tr>
<tr>
<td>0.3 - &lt; 3</td>
<td>2</td>
</tr>
<tr>
<td>3 – 10</td>
<td>2</td>
</tr>
<tr>
<td>10 - &lt; 30</td>
<td>2</td>
</tr>
<tr>
<td>≥ 30</td>
<td>2</td>
</tr>
</tbody>
</table>

Proper Pavement Construction Techniques

The performance of any pavement is highly dependent on the pavement construction techniques followed, and the quality of construction achieved. Proper construction techniques include the following.
• Prepare the substrate properly. Thoroughly clean old or milled surfaces, remove any old patches or thin asphalt concrete areas that may debond, and uniformly tack prepared surfaces at the appropriate application rate.
• Produce, place, and compact hot-mix asphalt at appropriate temperatures (i.e., avoid overheating).
• Avoid segregation with proper aggregate stockpiling, and hot-mix asphalt production, transportation, and placement techniques.
• Place a uniform and smooth mat.
• Construct transverse and longitudinal joints properly for durability and to prevent the ingress of water.
• Achieve the compaction (density) requirements.
• Follow an appropriate quality control plan to achieve the proper construction techniques and overall quality.

Selection of Rehabilitation Method

The rehabilitation method selection for a rutting problem at an intersection should be based on a life cycle cost comparison analysis. Any pavement used for rehabilitation should follow the recommendations above.

Mill and Overlay with Asphalt Concrete

Resurfacing is the most common rehabilitation method for flexible and composite pavements. It is necessary to mill a superficial portion of rutted asphalt pavement, and then replace a surface layer of the pavement with rut-resistant HMA. An intimately bonded interface between the milled surface and the HMA overlay has to be ensured. It has to be clean, any loose material has to be removed and a properly tack coat needs to be placed in between.

Rut Filling Using Spray Patching, Thin Overlays, or Micro-Surfacing

On wear rutting and low severity instability rutting, the wheel path ruts can be filled by spray patching, or by micro-surfacing, and/or tacking, as necessary, before the HMA overlay/micro-surfacing. Spray patching is appropriate for lower volume, rural or surface-treated pavements. Rut filling should only be viewed as a relatively short-term mitigation measure.

Grinding and Precision Milling

This procedure can be used to restore the surface texture and profile of pavement, when medium severity instability rutting is present. It consists of removing the rutted surface of the concrete to the rutting depth. It offers a short-term solution to instability rutting.

Whitetopping (Conventional and Concrete Inlay)

Whitetopping is defined as the construction of a new Portland Cement Concrete (PCC) over an existing flexible pavement. Whitetopping can be a technically and cost-advantageous rehabilitation alternative for badly deteriorated asphalt concrete at intersections, particularly for
flexible pavements exhibiting instability, rutting, shoving, and alligator cracking (Smith et al, 2002).

The interface between the old asphalt pavement and the new PCC overlay may be a milled surface, a HMA leveling course, or direct placement (no treatment at all). Conventional whitetopping is generally suitable for the traffic loading associated with all classes of roads intersections. PCC is designed as if it was on a treated base course.

**Ultra-Thin Whitetopping**

A thin layer of PCC is placed over a prepared distressed flexible pavement. The deteriorated asphalt concrete surface is cold milled to enhance the bond between the PCC and asphalt concrete. Ultra-thin whitetopping is intended for parking areas, urban streets, bus bays, and intersection flexible pavements where instability rutting is a problem, but no other significant deterioration is present (ACPA, 1998; Smith et al., 2002). The UTW is generally intended for flexible pavements subject to lower volumes of heavy traffic (Smith et al., 2002).

**Thin Composite Whitetopping (TCW)**

TCW is defined as “a concrete overlay intentionally bonded to an existing asphalt pavement to create a composite pavement section. Joints are spaced at close intervals to reduce stresses in the concrete overlay (Cole et al, 1997). This is an emerging technology and it is intended for high volume roadways. Pavement thickness is based on engineering judgment and performance of previously placed TCW pavement installations.

**Roller Compacted Concrete (RCC)**

Roller compacted concrete is a very dry zero-slump cement-aggregate mixture with supplementary cementing materials so that it remains stable for compaction by vibratory rollers like those used for asphalt pavement compaction. Asphalt pavement is placed over the RCC to provide a smoother ride for the driving public.

**Interlocking Concrete Pavements**

Concrete pavers are placed in a herringbone pattern and vibrated into a 25 mm layer of screeded bedding sand conforming to the grading requirements. Dry joint sand is then swept into the joints and vibrated with a plate compactor until the joints are full. A geotextile fabric is placed over the milled asphalt prior to placement of the bedding sand and concrete pavers.

**Hot in Place Recycling (HIR)**

The Colorado DOT Pavement Design Manual (2009) indicates that the HIR should be used to fix surface distresses when the cause of the problem is not structural, but merely from the upper asphalt layer, such as cracking and minor rutting. The process is performed by heating and mixing equipment which preheats the asphalt to soften it and then mills it so it can be mixed with
binder, new aggregates, or any other additives to be finally re-compacted. The main benefit from this process is the conservation of both materials and energy by recycling on site.

Cold in Place Recycling (CIR)

CIR is defined as a rehabilitation technique in which the existing pavement materials are reused in place. The CIR process usually uses 100% of the reclaimed asphalt pavement (RAP) without the application of heat for the recycling process. CIR can be useful in eliminating rutting within a range of 2 to 4 in. in depth, eliminate potholes, rough areas and restore the design profile. Although cold recycled mixes can produce stable surfaces, a wearing surface over the recycled mix is normally required.

Canada

The Federation of Canadian Municipalities and Canadian National Research Council (2003) “Rut Mitigation Techniques at Intersections” has a comprehensive guideline for rehabilitation of intersections. Figure 10 provides the flowchart of their activities to address the instability rutting at intersections. The flowchart of activities displays how important is the communication and feedback between the different levels of design. The process starts with analyzing the pavement performance by identifying the type of distresses and the sources of the problem. With loops through the design procedures it aims to ensure structure adequacy and meanwhile trying different rehabilitation methods starting from the most economical targeting cost-effectiveness.

Colorado Department of Transportation (CDOT)

The CDOT present a slight variation on addressing strategies at intersections. The Colorado Pavement Design Manual (2009) considers the intersections separately since they hold merged traffic directions over a same pavement section. As a result, the number of vehicles from each of the intersecting roads is accumulated and thereby exceeding the traffic design of each of the roads. Another factor they consider is the drainage within intersections, since improper drainage can lead to moisture damaging the pavement and saturating the so underlying base and subgrade layers leading to lack of support and thereby deformation of the complete pavement structure.

The keys used by CDOT for proper scoping of the projects are the following:

- Identify the problem with existing intersection.
- Remove enough pavement to find the problem.
- Design and reconstruct with a high performance HMA mix especially formulated.

Colorado DOT design asphalt pavements for a period of at least 20 years and for restoration and resurfacing of 10 years. General considerations by CDOT to design a HMA intersection include the following:

- Heavy truck and high volume traffic intersections require extra considerations in their design and construction. High performance intersection design should be considered when 20-year traffic loading of the two traffic streams add up to one million ESALs or more.
Figure 10: Flowchart of Activities for Mitigating Intersection Rutting.
Intersection pavements suffer from slow traffic and sharp turns, and such factors must be included in the design. The road is also vulnerable to deceleration and acceleration of vehicles approaching an intersection. A stronger transition pavement should be applied before and after every intersection. If there is two-way traffic, the transition should extend 300 feet on both directions. When one-way traffic, transition should be at least 300 feet on the deceleration side and 100 feet on the acceleration side of the intersection.

A PG 76-28 binder is suggested by the Colorado DOT for intersection pavement. Bumping grades would improve performance of asphalt. Superpave procedure to select binder grade for asphalt intersections is recommended.

Australia

The Australian Asphalt Pavement Association (AAPA) provides the advisory note 15 for “Bituminous Surfacing for Intersections on Light & Medium Duty Flexible Pavements” (1999) as a guide to utilize sprayed seals and other bituminous treatments over unbound and lightly bound granular pavements, especially in rural areas. A Spray Seal (Chip Seal in the US) is done by spraying a layer of binder on top of a damaged road surface and then covering it with aggregate. The binder waterproofs the pavement while the aggregate provide extra damage protection to the pavement. Sprayed seals provide an effective and economical resurfacing alternative in a large number of situations, but the turning and braking of heavy vehicles at intersections grind away the surface aggregate inducing the bleeding of the seal.

The performance of the sprayed seals can be improved by different methods, but substituting the sprayed seal with a thin layer of HMA can improve smoothness and appearance, representing a longer term cheaper alternative. Performance of sprayed seals for high stress situations can be enhanced by:

- Polymer Modified Binders (PMB): also called High Stress Seals (HSS). They help boost binder cohesion, toughness and improve temperature resistance.
- Multiple applications of binder and aggregate: produce a stronger sprayed seal. With two applications of aggregate, the second one being half the size of the first one. This will allow the smaller aggregate to accommodate within the void left by the larger aggregate, providing a better clutch and therefore a stronger structure against vehicle shearing forces.
- Multiple application of aggregate (“racked in” or “dry lock” techniques): light application of a small size aggregate (5 mm) over a coarser aggregate sprayed seal. This in order to prevent the coarse aggregates from rolling away during seal compaction.

Asphalt

Guidelines for asphalt surfacing come for intersections and roundabouts are as follows:

Lightly Trafficked Pavements

The surface of the pavement has to be primed before all. For clean and in good condition primed surfaces tack coat may not be necessary, so it may be either reduced or discarded. A dense
surface finish and durability are the main requirements. Small aggregate size, fine texture and workable mixes are usually used.

**Medium Trafficked Pavements**

They are commonly used over sprayed seal pavements, but applied to high stress sections such as intersections, roundabouts and median openings. Cutters and oils in the seal have an effect on asphalt, causing bleeding. If possible, some time need to be given to the seal to allow compaction under traffic and cutters to evaporate before any asphalt surfacing is performed. Time will also help to identify the surface weaknesses of the pavement. Mix design has to be developed according to the road requirements. In Australia 10 or 14 mm size dense graded asphalt mixes are used for most medium to heavy traffic conditions.

**New Zealand**

New Zealand has a supplementary document to the Austroads “Pavement Design – A Guide to the Structural Design of Road Pavements” (2004) which considers the high lateral stresses induced at intersection and thereby requires attention while designing and constructing all the layers in a pavement structure. Intersections are exposed to loading from different directions and this parameter should be considered in the design. Intersection must extend into the approach road by an appropriate distance.

For structural adequacy, the thickness and configuration of each layer has to satisfy the critical strain criteria. In case of a flexible pavement at the intersection, elastic deflection (based on the Benkelman Beam) must not exceed an acceptable level of approximately 1mm to prevent fatigue cracking.

The upper pavement materials must have high shear strength in order to resist the high levels of shear stress applied on the pavement surface as a result of vehicles slowing down, accelerating, breaking, and cornering at intersections. The use of structural asphalt, concrete or modified aggregate materials should be considered by New Zealand personnel. In New Zealand, Stone Matrix Asphalt (SMA) has shown very good performance in terms of shear resistance and favorable surface properties.

**Illinois DOT**

The Illinois Department of Transportation Pavement Design (2002) contains specific criteria to classify high-stress intersections and thereby select the required materials. High-stress intersections are defined as those under stop control, either signal or sign that have one or more of the following conditions:

- The approach grade on any stop-controlled leg of the intersection is greater than or equal to 3.5%.
- The two-way Average Daily Traffic (ADT) for Multiple Unit (MU) vehicles is greater than or equal to 400 vehicles in rural areas or 800 vehicles in urban areas. For ramps and other one-way facilities, use one-half of this ADT criterion.
The ADT for turning MU vehicles on any one leg of the intersection is greater than or equal to 200 vehicles in rural areas or 400 vehicles in urban areas. This also applies to sharp turning movements that are not under stop control.

The materials for intersection pavement are chosen depending on the existing pavement and the traffic conditions at the location. Pavement types for high-stress intersections are limited to either PCC; or AC Superpave Ndesign ≥ 90.

The pavement materials for high-stress intersections have to be used for a minimum distance of 150 ft from the stop sign. Such length may be extended if a traffic study indicates it.

Complete reconstruction, instead of resurfacing, of an existing distressed pavement at an intersection should be considered in case of present rutting and/or shoving.

Intersections not meeting the mentioned criteria are not considered high-stress intersections. Still they can develop similar signs of permanent deformation as those on the high-stress intersections. Non-high-stress intersections paved with PCC pavement may use PCC for repair if the improvement consists of minor widening without resurfacing.

Non-high-stress intersections with asphalt pavement showing signs of permanent deformation (rutting, shoving) should be examined to determine the source of the problem. An evaluation of the complete structure must be performed to determine what material might be inadequate. Such material has to be removed and replaced before any resurfacing. In case that the mixture results to be stable but the problem persists, then an exception to the criteria should be considered. Example exceptions include:

- Lower urban ADT for MU vehicles if all are required to stop or if the approach speed is greater than 40 mph;
- Lower urban and rural ADT for MU vehicles if the majority are fully loaded at intersections near warehouse facilities, landfills, grain elevators, etc.;
- Demonstrated problems with shoving of a bituminous overlay related to tight turning movements; and
- Including SU trucks in the MU truck count where the SU vehicles are primarily fully loaded hauling vehicles (e.g., grain trucks, concrete trucks, coal trucks).

**Hot Mix Asphalt Mixtures for Nevada’s Intersections**

The Nevada Department of Transportation (NDOT) uses a coarse dense gradation HMA which has successfully resisted rutting under normal highway traffic loading throughout the entire state. However, the performance of the mixture at the intersection has been inadequate.

A research project to investigate and develop specific requirements for hot mix asphalt mixtures at intersections was conducted by Hajj (2007). This study evaluated the Asphalt Pavement Analyzer (APA), the Repeated Shear at Constant Height (RSCH), and the repeated load triaxial test (RLT) as potential candidates for a mix design test for intersection mixtures in addition to
the triaxial compression strength test (Hajj, 2007). Hajj proposed a new list of recommendations to assess permanent deformation for intersections and stopping areas as follows:

- **RSCH**: maximum of 1.9% permanent shear strain at 158°F after 5,000 cycles.
- **RLT**: maximum of 2.0% permanent axial strain at 158°F after 12,000 cycles.
- **APA**: maximum of 0.06 inch at 140°F after 8,000 cycles.

**National Center for Asphalt Technology**

Kandhal (1998) conducted a field investigation to determine the cause of rutting at intersections. A list of considerations to minimize permanent deformation collected through a literature search by Kandhal are as follows:

1. **Lower Asphalt Content**: Higher asphalt content is needed for improved fatigue life and durability of the asphalt mix, but it tends to enhance the rutting and shoving problems. The mix needs to be maximized for fatigue and permanent deformation through a compromise.
2. **Coarser Gradation**: Finer gradations or over-sanded mixes are more susceptible to permanent deformation.
3. **Angular and Rough Textured Aggregate**: This is especially applicable to the fine aggregate fraction. It has been demonstrated by Kalcheff and Tunicliff (1982) and Brown and Cross (1992) that mixtures utilizing angular manufactured sand are more resistant to permanent deformation than mixes produced with rounded or sub-rounded natural sand.
4. **Increased Air Void Content**: Mixtures with low voids in the mineral aggregate (VMA) and higher asphalt contents have a tendency to have very low air void contents after densification by traffic. Such mixtures lose stability after reaching a critical compaction level and start to rut and shove.
5. **Higher Viscosity Asphalt Binder**: An asphalt binder with a high viscosity at 60°C will be more resistant to horizontal thrust as far as plastic flow in a mix is concerned compared to a low viscosity asphalt binder.
6. **Higher Fines Content**: Increase in the minus 75 microns fraction of the mix will tend to stiffen (increase the viscosity) the binder.
7. **Larger-Size Aggregate**: At proper asphalt content larger-size aggregate (such as 19.5 mm) mix in the wearing course tends to be more resistant to permanent deformation.
8. **Reduced Overlay Thickness**: If the existing pavement is structurally sound (for example, portland cement concrete), thicker asphalt mix overlays are unnecessary in the critical areas like intersections. Thinner overlays (for example, binder course can be eliminated) in these areas will minimize the problem.
9. **Improved Bond between Pavement Layers**: A lack of good bond between the pavement layers (especially in top 150 mm of the pavement) can cause slippage due to horizontal thrust.

The following mixtures were recommended by Kandhal (1998):

1. 2 in. Stone Matrix Asphalt (SMA) wearing course (nominal maximum size 12.5 mm)
2. 2 in. Stone Matrix Asphalt (SMA) binder course (nominal maximum size 19.0 mm)
3. 2 in. mm dense-graded large stone mix base course (nominal maximum size 25 mm)
REMEDICATION STRATEGIES CONSIDERING SUBSURFACE LAYERS OF PAVEMENTS

Base Layer

Structural inadequacy can be caused by subsurface layers as much as the HMA layer. Therefore, it is of utmost importance to identify the layer(s) that contribute to the excessive permanent deformation of the intersections. If the base layer is the contributing factor to distress, treatment of the top layer does not solve the problem. The remediation strategy needs to address the base layer. Most of the time the base layer is under designed and can be easily remedied by stabilization and modifying the gradation.

Stabilization is achieved by adding proper percentage of additives such as cement, lime, fly ash, bitumen, or combinations of these materials to the base. The selection of the type and determination of the percentage of additive are dependent upon the soil classification and the desired degree of improvement. Generally, smaller amounts of additives are required to modify soil properties such as gradation, workability and plasticity. Larger quantities of additives are used to significantly improve the strength, stiffness and durability (Army TM 5-822-14, 1994). Spreading and compaction are achieved by conventional means after the additive has been mixed with the base. The most common improvements achieved through stabilization include:

- Reducing plasticity index
- Reducing swelling potential
- Increasing durability and strength
- Reducing dust during construction
- Waterproofing the soil
- Drying of wet soils
- Conserving aggregate materials
- Reducing cost of construction
- Providing a temporary wearing surface

The South African “Guideline on Low-Volume Sealed Roads” (2003) considers that the main objective of chemical stabilization is to enhance the suitability of locally available natural gravels for pavement construction, thereby avoiding the need to import other materials. This can often lead to a more cost-effective alternative for construction.

The selection of stabilizer type depends on the type of material present and their location in the pavement structure (Terrel et al., 1979). Table 2 provides varying stabilization methods for different materials. Coarse and fine grained soils, as well as clays are suitable for stabilization with portland cement and lime-fly ash and lime. Typically, several criteria must be followed for the selection of a stabilizer. Figure 11 demonstrates a basic flowchart used by TxDOT for the selection of additive used for base treatment. Aside from the physical properties of the soil, TxDOT also considers the goals of the treatment, mechanisms of additives, desired engineering and material properties, design life, environmental conditions and economical factors.
### Table 2: Stabilization Methods for Different Soil Types (Terrel et al., 1979)

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Most Effective Stabilization Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse granular soil</td>
<td>Mechanical blending, soil-asphalt, soil-cement, lime-fly ash</td>
</tr>
<tr>
<td>Fine granular soil</td>
<td>Mechanical blending, Portland cement stabilization, lime-fly ash, soil-asphalt, chlorides</td>
</tr>
<tr>
<td>Clays of low plasticity</td>
<td>Compaction, Portland cement stabilization, chemical waterproofers, lime modification</td>
</tr>
<tr>
<td>Clays of high plasticity</td>
<td>Lime stabilization</td>
</tr>
</tbody>
</table>

Select initial additive(s) based on criteria: gradation, plasticity index, goals of treatment, mechanisms of additives, desired engineering and material properties (strength, modulus, etc.), design life, environmental conditions (drainage, water table, etc.), engineering economics (cost savings vs. benefit).

Obtain samples of base material source in accordance with Tex-40-E. Perform material testing required by Item 247 (Table 1) requirements.

Does the material meet Item 247 (Table 1) requirements?  

**YES**  
No treatment is required, unless additional strength and quality is specified for the project.

**NO**  
Perform mix design to determine the improvement of engineering properties at varying concentrations of selected additive.

Evaluate the overall improvement and durability of the enhanced engineering and material properties.

Do the improved properties meet the min. project requirements?  

**YES**  
Select another additive(s) and repeat mix design.

**NO**  
Proceed with construction.

**Figure 11: TxDOT Flowchart for Base Treatment (TxDOT, 2005)**
A simple mechanical stabilization alternative is exercised in South Africa often satisfies the specifications of a standard material. This alternative consists of blending two natural materials, gravel with sand, to form a mechanical stable layer by lowering the PI and optimum moisture content (OMC), and by improving the strength and the workability of the material.

A large variety of industry by-products and commercially produced additives is available for use in pavement stabilization, such as:

- Air-cooled blast furnace slag
- By-product lime
- Fly ash
- Ground granulated blast furnace slag
- Reclaimed asphalt pavement
- Recycled concrete material

Full-Depth Recalmanation

Full depth reclamation (FDR) is a form of cold in-place recycling of flexible pavements. During this procedure, the hot mix layer and a predetermined amount of the underlying base course are pulverized simultaneously by special equipment. As a common practice, the two materials are mixed with stabilizing agents described above. Depending on the severity of structural problems of the original base course, additional virgin base material (add-rock) or RAP is sometimes mixed with the pulverized materials. The result of this process is an entirely new base material. Increasing shortages of virgin aggregate, rising fuel costs, as well as environmental concerns have led to an increased utilization of FDR in many states and countries. Like many other road rehabilitation procedures, FDR has both its advantages and disadvantages.

Recycling using the FDR process has many advantages which encompass a broad range of engineering concerns, from improving the economics of the project to safeguarding the environment. FDR facilitates complete reconstruction of a pavement system while utilizing all or most of the existing material. The process allows for grade corrections and small adjustments in road geometry, but more importantly, remedies structural pavement problems (Kearney and Huffman, 2000). The ability to utilize almost 100% of the existing materials reduces project costs associated with the transportation of virgin material to the site while concurrently eliminating disposal costs of the old aggregates. This is a great benefit for states such as Texas, where fresh aggregate is sometimes shipped from locations as far as Guadalajara, Mexico. Aside from the obvious economic benefits, FDR addresses “deeper” pavement problems as well.

Cracking and other defects are sometimes caused by inadequate base materials in flexible pavement systems. In these cases resurfacing of the road with another hot mix layer will not solve the problem. FDR can be implemented on these roads to strengthen the base materials (Kearney and Huffman, 2000). The new base that is formed from the combination of the existing pavement and part or all of the base material along with a stabilizing agent is often times stronger than the original materials. For this reason, roads that have undergone the FDR process are often considered to be structurally sounder than the original flexible pavement.
Since the pulverization process reaches deep into the base material, changes in the profile of the road are attainable during the FDR process. Epps (1990) states that significant pavement structural improvements can be made in horizontal and vertical geometry and without shoulder reconstruction. Old pavement profile, crown, and cross slope may be improved. This is possible since the entire layer of flexible pavement as well as part of the base is taken up. The advantages of FDR are not only limited to road improvements, it is also an environmentally sound choice for pavement rehabilitation as well.

With the strategy of “greener” roads being advocated by policy makers worldwide, FDR fits in as a viable solution to flexible pavement problems. The process as a whole conserves energy. Roads can be recycled in-place without any fuel being expended for heating of bituminous materials. Also, extra fuel is not required nor added emission produced during the transportation of new aggregate to the job site. This in turn leads to overall project savings in transport costs. In terms of aggregate, scarce supplies are not depleted for reasons of structural improvements.

Some problem areas have also been associated with the use of FDR. No comprehensive guidelines are currently in place that governs the implementation of the process. This has lead to large variations in the results of such projects, even within the same state. Another concern with FDR is the curing time required for strength gain. Curing time is a major factor in the decision of when to let traffic back on that particular section of road. This in turn causes inconvenient disruptions in traffic. However, advances in equipment used for FDR has helped streamline the process so that road closures can be kept to a minimum (Epps, 1990). Also, the entire process is susceptible to climactic conditions, especially when asphalt emulsions are used as a stabilizing agent. Since the strength gain is dependent on the rate of moisture loss by the emulsion, it is not recommended that the process be carried out on days when heavy rainfall is expected.

**Subgrade Layer**

Ideally the subgrade should be strong and stiff enough to prevent excessive rutting. However, for fine-grained silt and clay soils, poor strength, high volumetric instability, and freeze/thaw durability problems are predominant. For expansive soil the volumetric change may be more severe and thus become a bigger challenge. The expansion action may result in intolerable differential heaving of pavements. Commonly used remediation methods can be categorized into two groups: (1) to improve strength and (2) to minimize moisture variation. In order to improve soft subgrade bearing capacity and strength, thick layers of granular material may be used on top of the problematic subgrade. In other instances, stabilization and geosynthetic reinforcement can be used. On the other hand, to minimize moisture variations and fluctuations, the commonly used strategies as summarized by Raymond and Ismail (2003) include:

- Treat the soil with lime or other additives to reduce expansion in the presence of moisture;
- Replace the material with a better material to a depth below which the seasonal moisture content will remain nearly constant;
- Provide an overlaying structural section of sufficient thickness to counteract the expansion pressure by surcharge;
• Stabilize the moisture content by minimize the access of water through surface and subsurface drainage and use waterproof membrane such as rubberized asphalt membrane, geosynthetics. Put moisture barrier and/or remove nearby vegetations.

Admixture Stabilization

Admixture stabilization refers to mixing and blending a liquid, slurry, or powder with soil to improve soil strength and stiffness properties. Lime stabilization is a widely used means of chemically transforming unstable soils into structurally-sound construction foundations. Lime stabilization creates a number of important engineering properties in soils, including improved strength; improved resistance to fracture, fatigue, and permanent deformation; improved resilient properties; reduced swelling; and resistance to the damaging effects of moisture. The most substantial improvements in these properties are seen in moderately to highly plastic soils, such as fat clays (Little, 2000). Little (1999) claimed that lime stabilization often induces a tenfold stiffness increase over that of the untreated soil or aggregate. Croft (1967) found that the addition of lime significantly reduces the swelling potential, liquid limit, plasticity index and maximum dry density of the soil, and increases its optimum water content, shrinkage limit and strength.

Cement has been found to be effective in stabilizing a wide variety of soils, including granular materials, silts, and clays; byproducts such as slag and fly ash; and waste materials such as pulverized bituminous pavements and crushed concrete. These materials are used in pavement base, subbase, and subgrade construction (Little, 2000). It is generally more effective and economical to use it with granular soils due to the ease of pulverization and mixing and the smaller quantities of cement required. Fine-grained soils of low to medium plasticity can also be stabilized, but not as effectively as coarse-grained soils. If the PI exceeds about 30, cement becomes difficult to mix with the soil. In these cases, lime can be added first to reduce the PI and improve workability before adding the cement (Hicks, 2002). Addition of cement to clay soil reduces the liquid limit, plasticity index and swelling potential and increases the shrinkage limit and shear strength (Nelson and Miller, 1992).

Stabilization of soils and pavement bases with fly ash is an increasingly popular option for design engineers. Fly ash decreases swell potential of expansive soils (Ferguson 1993, White et al., 2005a, b). Soils can be treated with self-cementing fly ash to modify engineering properties as well as produce rapid strength gain in unstable soils. Tests results show that fly ash increases the compacted dry density and reduces the optimum moisture content (White et al., 2005a). Fly ash can also dry wet soils effectively and provide an initial rapid strength gain, which is useful during construction in wet, unstable ground conditions. Çoçka (2001) found that plasticity index and swell potential decrease with increasing fly ash contents. Ferguson (1993) noted that the decrease in plasticity and swell potential was generally less than that of lime because fly ash did not provide as many calcium ions that modify the surface charge of clay particles.

Lime and lime fly ash stabilized materials cure much slower, in general, than portland cement stabilized layers. As with strength properties, resilient properties of lime-soil mixtures are very sensitive to level of compaction and molding moisture content. Lime-stabilization may substantially increase shear and tensile strengths. This strength increase provides a stiffer layer with improved load distributing capabilities. However, as the stiffness of the layer increases
through the development of cohesion within the stabilized layer, the layer becomes more susceptible to load-induced tensile stresses that can lead to fatigue failure unless proper design steps are taken to reduce the potential of load induced damage. This is generally accomplished by ensuring that the layer thicknesses are such as to insure the development of acceptable flexural stresses within the stabilized layer. Typically the design parameter is the flexural tensile stress ratio. Thompson (1966) determined that the indirect tensile strength of lime-soil mixtures is approximately 0.13 times the unconfined compressive strength. Chou (1987) stated that the flexural tensile strength of lime-soil mixtures is approximately 0.25 times the unconfined compressive strength.

For sulfate rich soils, a phenomenon called sulfate-induced heave can happen that can severely reduce the long-term strength and durability of stabilized soil. Sulfate concentration can be determined in accordance to Tex-145-E. If the sulfate levels are above 3000 ppm, further recommendations and guidelines can be found in the ‘Guidelines for Treatment of Sulfate-Rich Soils and Bases in Pavement Structures Soils’ by TxDOT. Puppala et al. (2004, 2003) studied the effectiveness of sulfate resistant stabilizers such as cement Types I/II, V, lime mixed with fibers and Class F fly ash in providing better treatment of sulfate rich soils. Test results indicate sulfate-resistant cement provided the most effective treatment. The combined lime and fibers stabilization method provided the next best effective treatment. The Class F fly ash treatment provided low-to-moderate strength improvements that could be attributed to the low amounts of calcium present in this type of fly ash. On the other hand, the fly ash stabilization method was more cost-effective than the other methods. Kota et al. (1996) provide some suggestions to minimize the damage caused by sulfates and calcium-based stabilizers such as double application of lime, use low calcium stabilizers (e.g. cement and fly ash), use non-calcium stabilizers, geosynthetic soil reinforcement, stabilization of the top with non-sulfate select fill, pretreatment with barium compounds, asphalt stabilization of the sulfate bearing soils and compacting to lower densities.

Organic contents in the soil are another consideration when selecting stabilization additives. Organic soil is a soil that would be classified as a clay or silt except that its liquid limit after oven drying (dry sample preparation) is less than 75% of its liquid limit before oven drying (wet sample preparation). Organic content can be determined in accordance to ASTM D-2974. If the organics content exceeds 1%, additional additive will need to be added to counter the cationic exchange capacity of the organic material.

Although chemical stabilization has proven successful in increasing the strength of the natural expansive soils by twenty to fifty times, and is widely used throughout Texas, situations arise where above mentioned approaches cannot be used. For example, chemical stabilization cannot be used when the temperature is below 40°F and in cases there are not enough time for curing before traffic is routed back (Hopkins et al., 2005)

**Moisture Control**

For some types of subgrade, the fluctuation in moisture content is quite detrimental. In those cases, the most effective remediation method is to control and minimize seasonal moisture variations.
One of the most important aspects of a successful road design is drainage. Rollings and Christie (2002) noticed that the lack of adequate surface drainage is one of the critical factors leading to problems with both collapsible and expansive subgrade soils. Some obvious drainage problem signs should be monitored such as water ponding in the drainage ditches, soft spots in the ditch, or the presence of plants and weeds that grow best in saturated or submerged environments. The new Mechanistic-Empirical (M-E) Design Guide (AASHTO, 2002) recommended improving surface drainage by lowering the ground water level, intercepting the lateral flow of subsurface water beneath the pavement structure, and removing the water that infiltrates the pavement’s surface. To be more specific, special solutions should be considered when feasible. For instance, where climate is suitable, it may be possible to place a permeable layer over a swelling soil and limit or prevent drainage from it. Moisture buildup in this layer maintains the soil in a stable, saturated condition. Drainage ditches, sloped sections, water bars, cross-drains and inlet-outlet protections are recommended so that water does not accumulate in the median.

Vegetation transpiration may significantly decrease the moisture content of active soils and cause shrinking and deformation. Researchers reported that climatic extremes played a major role in causing and exacerbating damage to pavements and lightly-loaded structures, and that large vegetation often interacts with climatic extremes to heighten the problem (Ravina, 1984 and Snethen, 2001). Researchers believe that types and locations of trees should be considered in landscaping decisions, particularly involving soil having LL > 40 and PI > 25. Based upon the relative average rank analysis, the most influential trees are in the order of Poplar, Elm, oak, and Ash. Experience and observations show that these types of trees should be planted at 1.6 to 3.3 ft (0.5 to 1.0 m) beyond the anticipated mature drip line or the anticipated mature height of the tree from pavements or pavements or building foundations (Snethen, 2001). Chen and Tian (1985) suggested using a lime trench between the structure and the tree to create a moisture transfer barrier. The depth of the trench should be 6.5 ft (2 m) and the lime fillings should be 4 to 8 in. (10 to 20 cm). The first “proximity rule” of distance to height of tree ratio (D:H) greater than one are widely used to avoid soil shrinkage settlement and damage to structures (Ward, 1953; Biddle, 1983 and 2001; Tucker and Poor, 1978) In New Zealand, Wesseldine (1982) indicated a threshold value of D:H of 0.75 for single trees to cause damage and 1.0 to 1.5 for groups of these trees.

Geosynthetics

The adoption of geosynthetic for pavement aims to improve long-term bearing capacity and performance of the road. There are eight types of geosynthetics: geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners, geopipe, geofoam, and geocomposties (Koerner, 2005). Geotextiles and geogrids are the most popular types of geosynthetics used in the road construction industry. Geotextiles are textiles consist of synthetic fibers rather than natural ones. These synthetic fibers have woven, non-woven, or knitted textile fabric. Geogrids are plastics formed into a very open, grid-like configuration. Geofoams are lightweight foam blocks that can be stacked and provide lightweight fill in numerous applications. Geocomposites consist of a combination of geotextiles, geogrids, and/or other geosynthetics in a factory-fabricated unit.

Geogrids have higher tensile strengths than geotextiles. Geogrids should be used on weak subgrades with CBR values less than 3 (Tutumluer and Kwan, 2005). Several researchers believe
that the use of geogrids can effectively reduce the aggregate base thickness requirements when compared to the unreinforced section results. Geogrids with higher tensile strength and high aperture stability moduli were found to give overall higher geosynthetic stiffness and hence work better than geotextiles (Giroud and Han, 2004a, b). Stiff biaxial geogrids were first used for the reinforcement of pavement in 1982 at Canvey Island, near London, England to control reflective cracking and use of geogrids and geotextiles is becoming more common nowadays (Austin and Gilchrist, 1996).

The four major functions of geosynthetics used for pavements are: reinforcement, separation, filtration and drainage. Adding a geosynthetic layer can increase bearing capacity of a pavement structure by forcing the potential bearing capacity surface to develop along alternate, higher shear strength surfaces. The geosynthetic reinforcement can absorb additional shear stresses which would otherwise be applied to the problematic subgrade. If rutting occurs, geosynthetic reinforcement is distorted and thus tensioned. Due to its stiffness, the curved geosynthetic exerts an upward force supporting the wheel load and thus the lateral restraint and/or membrane tension effects may also contribute to load carrying capacity (Hufenus et al., 2006).

Geosynthetics have been used successfully for many pavement projects. Their benefits include: extend service life, reinforce and inhibit reflection of cracks, facilitate compaction, improve bearing capacity, reduce necessary fill thickness, diminish deformations, delay rut formation, prevent water penetration to subgrade and reduce subgrade moisture susceptibility (Gurung, 2003; Hufenus et al., 2006; Steward et al., 1977).

The inclusion of geosynthetics in flexible pavement design is difficult since number of uncertainties arise when geosynthetics is applied under distress. The absence of an accepted design technique explains why this topic is still being researched despite the use of geosynthetics in pavement design and construction over many years ago. Following sections summarized methods and procedures identified in the literature search. These approaches shed some light on: (1) Where to place geosynthetics layer; (2) How to decide required thickness of aggregate; and (3) How to select appropriate geosynthetic type and appropriate strength to prevent pavement failure, or rutting, under traffic stresses.

The four main applications for geosynthetics in roads are overlay stress absorption, overlay reinforcement, base reinforcement, subgrade separation and stabilization. Based on their main targeted function, geosynthetics can be placed below or within the overlay, within base layer, near base-subgrade interface, or within subgrade layers. For low-volume roads, typically there will be an asphalt surface layer over an aggregate base layer. The combined surface and base layers act together to support and distribute traffic loading to the subgrade. However, weak clayey subgrades are often water sensitive and, when wet, may soften and deflect. Stresses will develop at the bottom of the granular layer, which will cause deep rutting and eventually, pavement cracking (Hopkins and Sharpe, 1985; Hopkins and Beckham, 2000). To lessen, or prevent, rutting of the aggregate layer during construction, or cracking due to base deflection after construction, geosynthetics may be placed at, or near, the bottom of the granular base, or on top of the finished subgrade (Figure 12). Use of geosynthetic reinforcement in such situation is gaining favor (Hufenus et al., 2006; Hopkins et al., 2005)
Table 3 gives an example of suggested appropriate geotextile for different survivability levels. Data are summarized by Cicoff and Sprague (1991) based on their test results of using lightweight geotextiles as permanent road stabilization.

**Table 3: Geotextile Specifications for construction Survivability in Low-Cost Low-Volume Roads (from Cicoff and Sprague, 1991)**

<table>
<thead>
<tr>
<th>Survivability Level</th>
<th>Subgrade Conditions</th>
<th>Base course Thickness*</th>
<th>Geotextile Mass/Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Dry, firm, flat</td>
<td>&gt; 6” compacted</td>
<td>4 oz/sy</td>
</tr>
<tr>
<td>Moderate</td>
<td>Water sensitive, flat</td>
<td>&gt; 3”-4” compacted</td>
<td>6 oz/sy</td>
</tr>
<tr>
<td>High</td>
<td>Water sensitive, grade&gt;2%</td>
<td>&gt; 3”-4” compacted</td>
<td>8 oz/sy</td>
</tr>
</tbody>
</table>

* For base course lifts less than 3”, required survivability should be increased one level (i.e. low to moderate).

Use of geosynthetics inclusions in both wet and dry conditions increased tensile strength of the subsoil (Gurung, 2003, 1983; Abd El Halim et al., 1985). The placement of a geotextile beneath an aggregate section increases the permissible stress on a subgrade by a factor of 1.64 to 2.0 (Steward et al., 1977; Giroud and Noiray, 1981) Similar result is reported by Montanelli, et al. (1999) with an increased 1.5 to 2 structural layer coefficient of geogrid reinforced flexible pavement. The authors of the RACE design software (www.geotextile.com) therefore recommended using an average design improvement factor of 1.8. Kwon, et al. (2008) proved the technical response benefit of using geogrids in pavement base course reinforcement based on a full-scale test study. Much lower subgrade vertical deformations and base course vertical and horizontal deformations were measured in the geogrid reinforced section when compared to the deformations recorded for the unreinforced control section. Cicoff and Sprague (1991) concluded that geosynthetics may or may not enhance initial pavement performance, but will likely enhance future pavement performance. However, the benefit data could not be utilized for section to section comparisons, measured values of stress, strain and deflection are highly case specific.
**MATRIX OF SOLUTIONS**

The results from the maintenance and rehabilitation methods for flexible pavements search are listed in Figure 13. The information is resourced from the documentation summarized literature review. The diagram provides a link between probable distresses, their sources and the appropriate remediation. It divides the different distresses by the structural member or layer that is failing. The different rehabilitation methods to repair flexible pavement are listed and divided into subcategories depending on what type of distresses they might be suitable to repair. This figure is being developed into a matrix that will be incorporated into TXDOT remediation strategies. The matrix will also be expanded to include the items enumerated in the proposal such as:

- *Under what traffic volume, environmental condition, pavement structure the solution is effective?*
- *Which alternative is appropriate for maintenance, rehabilitation or reconstruction?*
- *What are the advantages and disadvantages of each solution?*
- *What is the cost-benefit of the solution?*
- *How adaptable the solution is to TxDOT operation?*

<table>
<thead>
<tr>
<th>Layers</th>
<th>Distresses</th>
<th>Maintenance &amp; Rehabilitation Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>Surface Rutting, Instability Rutting, Shoving, Fatigue Cracking</td>
<td>Microsurfacing, Fog Seal, Crack Seal, Sand Seal, Slurry Seal, Ultra Thin Wearing Course, Chip Seals, Hot in Place, Cold in Place, PCC Overlay (Thick), Ultra-Thin Whitetopping, Hot Mix Overlay</td>
</tr>
<tr>
<td>Base</td>
<td>Structural Rutting, Shrinkage Cracking</td>
<td>Full Depth Reclamation, Roller Compacted Concrete (Base), Stabilization, Moisture Control</td>
</tr>
<tr>
<td>Subgrade</td>
<td>Moisture Intrusion, Structural Rutting, Shrinkage Cracking</td>
<td>Stabilization, Moisture Control</td>
</tr>
</tbody>
</table>

*Figure 13: Probable Appropriate Remediation for Different Layers*
REFERENCES


• Illinois Department of Transportation (2002) “Pavement Design – Chapter Fifty-Four”.
• Suo, Zhi and Wong, Wing Gun (2007) “Analysis of Fatigue Crack Growth Behavior in Asphalt Concrete Material in Wearing Course”, Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.
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