# Lightly Surfaced Roads: Stabilized Aggregate Applications

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Minnesota has a large network of aggregate roads. The majority of the system is maintained by counties and townships. Some of the aggregate roads need to be upgraded with a sealed surface for dust control or to provide a smoother driving experience, as well as for local economic development. Local road officials are often faced with the responsibility of upgrading the roads with a limited budget. Light surface treatments (LSTs) are considered an economical alternative to the conventional upgrade approaches using hot-mix-asphalt (HMA) or concrete pavements. The currently used methods in Minnesota for the structural design of LSTs for aggregate roads were originally developed for structural design of flexible pavements. This research evaluated the design methods that can be used to design LSTs for aggregate roads. The methods evaluated include the MnDOT granular equivalent (GE) method and the MnDOT mechanistic-empirical method (MnPave design software), which are used in Minnesota, and the American Association of State Highway and Transportation Officials (AASHTO) flexible pavement design method and South Dakota aggregate road design method, which are practiced in other places in the United States. The results include a discussion of the applicable situations for each method. The research team also conducted a survey that was distributed to the county engineers in Minnesota to document their experiences with LSTs. Recommendations for improving the current design methods when applied to LSTs on aggregate roads are suggested based on the survey results.

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## Final Report

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# Executive Summary

The issue of furnishing all-season surfaces for low-volume roads is often neglected to the point that many local jurisdictions are considering the possibility of reverting paved roads to an unbound surface such as gravel, crushed rock, or milled asphalt. It would be desirable to consider light surfacing as an alternative that is halfway between the current Minnesota Department of Transportation (MnDOT) design criteria, which require a minimum of 3.5 inches of hot-mix asphalt (HMA) on an unpaved road.

This 3.5-inch HMA pavement is practical for 200,000 equivalent single-axle load (ESAL) road designs (or a 10-ton design). However, 69 percent of the 60,000 miles of Minnesota county state-aid highway (CSAH) roads have less than 1,000 vehicles average daily traffic (ADT) and most are under 200,000 ESALs per year. Furthermore, 40 percent of the under 1,000 ADT group (which includes 15,700 lane miles) is actually under 400 ADT.

Considerable savings would be possible if light surfacing designs could be developed for this group of roads. It was therefore desirable to investigate light surface treatments (LSTs) for low-volume road (LVR) surfacing.

This project report synthesizes the state-of-the-practice in the United States and also looks at solutions internationally. The report provides a review of potential solutions considering both technical applicability to Minnesota roads and cost effectiveness.

A survey was conducted of local transportation officials in Minnesota to determine which types of light surfacing solutions have been in use within the state and the extent to which these solutions were successful. The survey results were reviewed and case study sites were selected that had varying levels of success with light surfaces, desired to construct light surfaces, or both. Field trips were made to the case study sites and information was collected about road user needs, traffic, and structural support.

A review was then conducted regarding four design methods that could be used to select layer thicknesses and material types for lightly surfaced roads. The design methods reviewed included the MnDOT granular equivalent (GE) method, the MnDOT mechanistic-empirical method, which can be implemented using the MnPAVE software application, the AASHTO flexible pavement design method, and the South Dakota aggregate road design method. Sample designs were executed for three locations using each of the four design methods and comparisons were made.

The study found that several light surfacing methods are available including chip seal, Otta seal, and slurry seal; however, Otta seal and chip seal are most commonly used in Minnesota. Several methods are available to enhance the structural capacity of a road before light surfaces are placed. They include chemical stabilization, the addition of a macadam layer, and various geotechnical fabrics. Chemical stabilization can also be used to stabilize distressed asphalt pavements that are pulverized by full-depth reclamation.

Review of the case studies indicated that light surfaces are most successful in areas with strong supporting soils and light traffic. The case study designs indicated that, in many cases, it was possible to design light surface pavement sections with reasonable layer thickness. In some cases where supporting soils are weak, the thickness of full-depth reclamation required for a 20-year service life would exceed the capability of typical construction equipment to pulverize and compact the material. It may be possible to design thinner layers, if the required service life could be reduced and additional maintenance or strengthening planned near the end of the service life.

Some of the design methods require minimum thickness of and a hot-mix asphalt (HMA) surface layer, which is incompatible with an effort to provide a light surface. It may be possible to substitute a structural equivalent thickness of stabilized or granular material as a workaround. However, limitations of substituting a light surface over a stabilized material for HMA should be investigated, especially when heavy vehicles with high-pressure tires are expected.to use the road.

# Chapter 1
# Introduction

Local road officials in the US are often faced with the responsibility of maintaining road networks with a limited budget. As a result, they are considering alternative methods for upgrading aggregate-surfaced roads and damaged paved roads. One method of upgrading these road types is to build a thick road base that consists of aggregate or recycled pavement and apply a light surface treatment (LST) as a surface course.

The light surface provides a durable, impervious surfacing that increases the skid resistance and reduces the amount of gravel loss and dust on a gravel road (Øverby and Pinard 2013). Light surfaces add little to no structural strength to a road, but they enable the strength of the subbase or pavement to be preserved by preventing the ingress of water (Greening et al. 2001). As a result, it is particularly important to design the road structure to have sufficient strength to withstand the traffic loads.

The current practice for pavement engineers in the US is to use pavement design methods to design the road structure of a LST. A survey conducted by Hall and Bettis showed that local officials in 37 of 48 states in the continental US use the American Association of State Highway and Transportation Officials (AASHTO) method to design low-volume roads (LVRs) (Hall and Bettis 2000). Local road officials in the remaining states use local procedures to design LVRs.

Because AASHTO pavement design methods were established to design pavements that typically include a hot-mix asphalt (HMA) layer, features within the design methods do not address the specific conditions found with a LST. Therefore, it is important to understand the limitations of the design methods currently used in developing the structure for an aggregate road using LSTs.

Established design procedures that might possibly be used to design the road structures of LSTs in Minnesota include the MnDOT granular equivalent (GE) method and the MnDOT mechanistic-empirical method (MnPAVE program). The MnDOT 7-ton and 9-ton flexible pavement design table and the MnDOT 10-ton R-value design figure are considered the means to implement a MnDOT GE design. The AASHTO flexible pavement design method (AASHTO 1993) and the South Dakota aggregate road design method were also included in this study to compare the designs produced by these two to the design methods used in Minnesota.

Three county state-aid highways, CSAH 10, CSAH 14, and CSAH 23, were selected to use as case study projects. The aforementioned design methods were used to design the support structure for a LST for each road. Resulting recommendations are made based on the design results using the best estimate for design method inputs that could be obtained without engaging in field testing.

# Chapter 2
# Literature Review

This chapter includes a literature review for commonly used LSTs, base stabilization treatments, and current LST design methods and practices. The objective of this chapter is to understand the implementation, costs, benefits, and considerations of various LSTs and the base preparation technologies of aggregate-surfaced roads.

Throughout the literature review, the researchers found that traditional pavement design methods are currently used to design the structure layer to support a LST for an aggregate-surfaced road in the US (Hall and Bettis 2000) and some overseas countries (SADC 2003). It is important to understand the current design methods and their limitations of being applied to design the structure for an aggregate-surfaced road with a LST.

## Light Surface Treatments

A light surface treatment, which is also known as a bituminous surface treatment, is a thin layer of liquid asphalt covered with a layer of aggregate with an application thickness of 0.5 inch or less (Li et al. 2007). The technologies that are considered as LSTs include Otta seal, chip seal, slurry seal, cape seal, and sand seal. A summary of the required equipment and materials for each LST technology is presented in Table 1.

**Table 1. Equipment and material list for LSTs.**

| **Equipment** | **Otta Seal** | **Chip Seal** | **Slurry Seal** | **Cape Seal** | **Sand Seal** |
|---|---|---|---|---|---|
| Asphalt distributor | x | x | x | x | x |
| Chip spreader | x | x |  | x |  |
| Pneumatic tire roller | x | x | x | x | x |
| Trucks and loaders | x | x | x | x | x |
| Mechanical broom | x | x | x | x | x |
| Slurry mixing machine |  |  | x | x |  |
| Sand spreader |  |  |  |  | x |
| **Material** | **Otta Seal** | **Chip Seal** | **Slurry Seal** | **Cape Seal** | **Sand Seal** |
| Graded crushed rock |  |  | x | x |  |
| Graded aggregate (NMAS: 1/2 to 1 in.) | x |  |  |  |  |
| Graded aggregate (NMAS: < 3/8 in.) |  |  |  |  | x |
| Single size aggregate |  | x |  |  |  |
| Mineral filler |  |  | x | x |  |
| Emulsified asphalt | In Minnesota, HFMS-2S has been used | Usually CRS-2, but others are possible | SS-1, SS-1h, CSS-1, CSS-1h, or CQS | Use the same materials as the chip and slurry seals | CRS-1, CRS-2, or CSS-1 |

*Otta Seal*

This LST derives its name from the Otta Valley in Norway where it was first developed in 1963 (Thurmann-Moe and Ruistuen 1983). An Otta seal is an asphalt surface treatment constructed by placing a graded aggregate on an application of a relatively soft bituminous binding agent.

One benefit of using an Otta seal is that a relatively-inferior, locally-available aggregate (such as screened gravel) can be used (Johnson 2003). As a result, the material price and hauling costs are reduced compared to other LSTs. Lower maintenance cost can be expected for an Otta seal surface compared to a gravel road if the Otta seal is constructed properly.

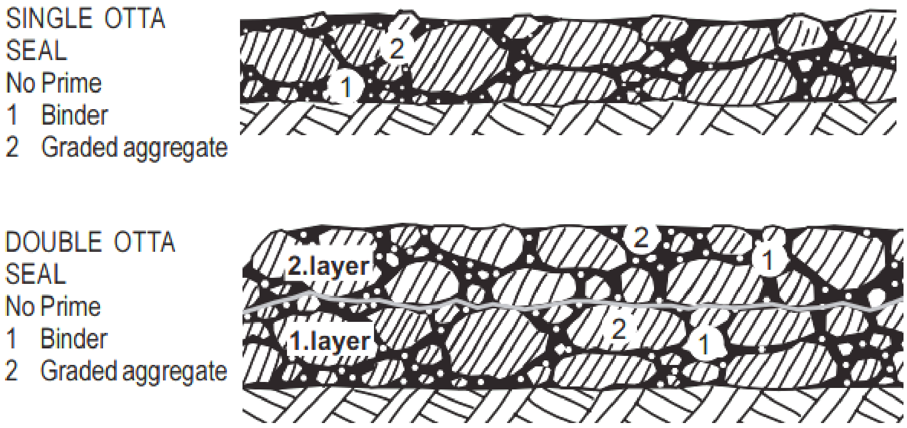
Otta seal surfacing technology is of particular interest for roads in remote areas where quality aggregates are not available. Research has shown that the Otta seal is more resistant to solar radiation, which reduces the aging rate of the bitumen better than a conventional chip seal

(Øverby and Pinard 2013). Otta seals also exhibit higher tolerance to construction faults, such as overapplication of bitumen, compared to other surface sealing technologies.

One disadvantage of Otta seals is that they exhibit a bitumen-rich appearance in the first six months after construction. The appearance of bleeding typically fades under compaction from traffic. Experienced personnel are critical for the successful application of the Otta seal because the design is empirical and usually requires on-site adjustments to the aggregate and bitumen application rate (Øverby and Pinard 2013).

The construction of the Otta seal starts with spraying emulsified asphalt onto the unbound road with an asphalt distributor. This is followed by the aggregate spreader that spreads the graded aggregate onto the binder agent. Typical Minnesota practices indicate that the application rate of 0.52 gallons per square yard and 50 pounds per square yard for the bitumen and aggregate applications, respectively, will be adequate (Johnson 2003). A pneumatic tire roller is then used to embed and realign the aggregate chips in the binder.

The construction rate of an Otta Seal is typically 40,000 square yards per day. In many cases, a double Otta seal is desired to provide a more protective wearing course by repeating the aforementioned construction procedures. A double Otta seal is less permeable and more resistant to aging and loading, while more costly. Figure 1 shows a scheme of single and double Otta seal surfacing.



Øverby 1999, Norwegian Public Roads Administration

**Figure 1. Single Otta Seal Surfacing (top) and Double Otta Seal Surfacing (bottom)**

*Chip Seal*

A chip seal is a surface seal consisting a rapid-setting asphalt emulsion and a single-sized aggregate cover. It is a conventional and widely used surface sealing method in the US (Øverby 1999). Compared to many other surface-sealing technologies, for which the design relies on engineers' experience, complete specifications exist for chip seal design (Caltrans 2008, Wood et al. 2006).

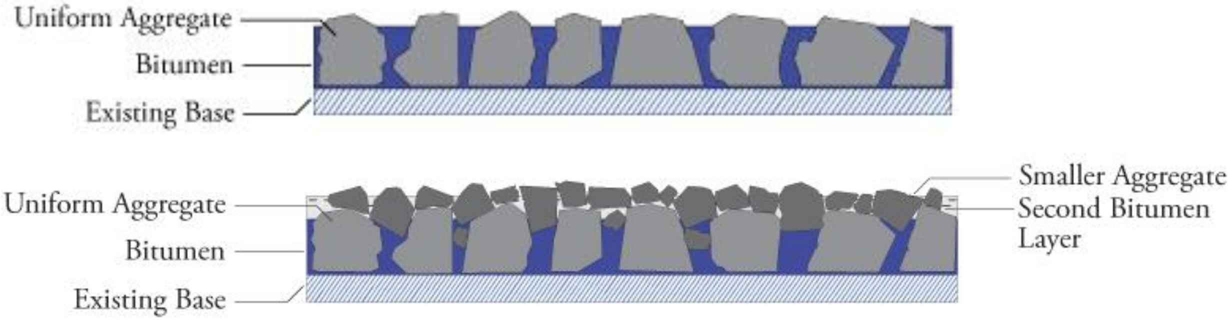
Proper design of aggregate size and aggregate and binder application rates, which can be obtained, assure about 70 percent embedment, which is considered a standard for a good application. The 70 percent embedment means the average thickness of the set binder is about 70 percent of the average cover aggregate thickness.

The primary advantage of chip seals is the high availability in terms of equipment, materials, and experienced contractors. However, bleeding is found in many chip seal projects that were not designed or constructed properly.

Chip seal application requires high-quality construction workmanship (Øverby 1999). The construction of a chip seal starts with the cleaning of the existing surface to remove sand, rocks, or debris. The cleaning step is critical to the proper bonding of the binder and aggregate as well as good performance. Then, an asphalt distributor is used to spray the emulsified asphalt onto the existing surface at a rate of 0.25 to 0.44 gallons per square yard and the application rate is aggregate-size dependent (Jahren et al. 2007).

The cover aggregate can be laid with a chip spreader. The chip application rate typically ranges from 20 to 30 pounds per square yard (Jahren et al. 2007). The placement of the materials is followed by rolling with a pneumatic roller. The aggregate particles are compacted to embed them into the binder. The loose particles are removed with a mechanical broom after about two hours of curing. Then, the road can be opened for traffic.

The chip seal can be constructed in a multi-layer structure. The upper layer of a double chip seal usually uses a smaller size of aggregate than the bottom layer. The schemes of the single and double chip seals are shown in Figure 2.



Adapted from ARRB Group 2010

**Figure 2. Single Chip Seal Surfacing (top) and Double Chip Seal Surfacing (bottom)**

### *Slurry Seal*

Slurry seal is a mixture of emulsified asphalt and crushed rock that can be spread over an existing road surface (such as an unpaved road). A slurry seal consists of a graded aggregate, a binder, fines, and additives. The slurry seal relies on a combination of mechanical particle interlock and the binding effect of bitumen for its strength, similar to that of an Otta seal.

Early trafficking and heavy rolling, or both, can be helpful in developing a relatively thick bitumen film around the particles.

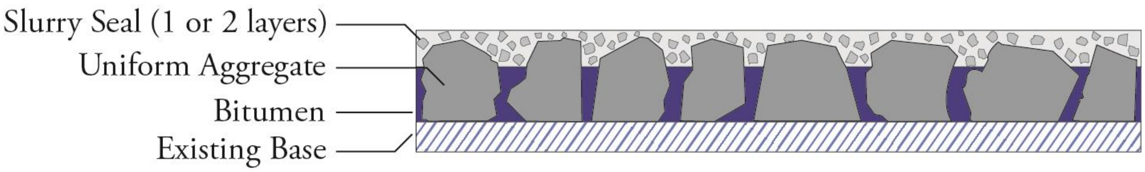
Microsurfacing is a special type of slurry seal that uses a higher-quality aggregate and polymer-modified asphalt binder. A microsurface slurry seal is applied to provide better surface texture and support higher traffic volumes than typically allowed for normal slurry seals.

Compared to other surface sealing technologies, the slurry seal generally has an enhanced appearance and better skid resistance (WSDOT 2003). Slurry seal construction requires special slurry-mixing equipment, which limits the application of the technology.

The construction of a slurry seal should start with cleaning the existing road surface. Optionally, an asphalt distributor can spray a prime coat onto the existing road surface. The same binder as used for the slurry mixture can be used to make the prime coat. Then, a slurry-mixing machine is used to produce the slurry mixture and distribute the slurry mixture uniformly onto the road. Rolling is typically performed after placement of the mixture and curing time is allowed for the asphalt emulsion to set after that. A mechanical sweeper can be used to clean the finished the surface before it opens to the traffic.

*Cape Seal*

A cape seal is a combination of a chip seal and a slurry seal (see Figure 3).



Adapted from ARRB Group 2010

**Figure 3. Cape Seal**

The slurry seal serves as a wearing course and helps to prevent the chip seal aggregate from being dislodged from the surface. The surface texture of the slurry seal also provides enhanced drivability, and the cape seal is more resistant to deterioration than either of the treatments individually. The cape seal can withstand heavier loads and is less prone to damage by snowplows. However, coordinating two separate surface treatment operations adds challenges to scheduling, coordinating, and managing different equipment and materials.

*Sand Seal*

A sand seal is similar to a chip seal in that it involves application of a slow-setting asphalt emulsion and an aggregate cover. The sand seal consists of an optional prime coat, a bitumen layer (.06 in. cutback bitumen or emulsion), followed by a graded sand layer (.125 in. to .25 in.), which require compaction (see Figure 4).

Øverby 1999, Norwegian Public Roads Administration

**Figure 4. Sand Seal**

Performance can be improved if a second seal is applied after 3 to 6 months. The sand seal uses a finer-graded aggregate, which creates a smoother surface compared to a chip seal. A CRS-2 binder is usually used in Minnesota (Wegman 1991).

The primary issues related to sand seals is that they may have non-uniformly distributed sand and flushing may occur if not properly constructed. Sand seal design is empirical and the main factors to consider are materials, climate, and available equipment.

Sand seals are primarily used as a temporary surfacing or for application on top of other LSTs. Sand seals are recommended for use in areas where the aggregate is difficult to find and a smooth surface is desired, or both (Greening et al. 2001).

## Base Stabilization Treatments

LSTs add little structural capacity to the road structure. The structural capacity required for the designed traffic is provided by the base layer. The base is usually treated with base stabilization agents that result in strengthening of supporting road layers to assure the successful implementation of the LSTs.

### *Base Stabilization Agents*

Various chemicals and mineral fillers can be added to the base layer of an aggregate road to reduce the permeability, control the moisture content within the optimum range, and increase the binding strength of the base layer. Such base stabilization agents are usually mixed with the base materials through the full-depth reclamation (FDR) process. Commonly used base stabilization agents include various chloride compounds, enzymatic stabilizers, lime, Portland cement, and fly ash.

#### Calcium Chloride and Magnesium Chloride

Calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) are salts that have the ability to draw moisture out of the atmosphere. The hygroscopic properties of calcium chlorides serve to bind fines and aggregates. The process creates a more compact and durable road surface. Because the fine particles are bound, fugitive dust emissions are dramatically decreased.

The chlorides can be applied using a solution that can be sprayed on a road using a distributor truck or as a solid form using a dump truck. If the chlorides are used as a solid, they are usually applied with fly ash. The typical application rates are shown in Table 2.

**Table 2. Calcium chloride and magnesium chloride typical application rates.**

| Chloride Product Type and Concentration | Chloride for Stabilization Percentage by Weight of Dry Aggregate | | Surface Application |
|---|---|---|---|
| | 1.5% | 2% | |
| $CaCl_2$ solid (94%) | 3.23 lb/sq yd | 4.31 lb/sq yd | 1.06 lb/sq yd |
| $CaCl_2$ solid (77%) | 3.94 lb/sq yd | 5.26 lb/sq yd | 1.30 lb/sq yd |
| $CaCl_2$ solution (36%) | 0.74 gal/sq yd | 0.99 gal/sq yd | 0.24 gal/sq yd |
| $CaCl_2$ solution (28%) | 1.01 gal/sq yd | 1.35 gal/sq yd | 0.33 gal/sq yd |

Data source: Monlux and Mitchell 2006

In some cases, sodium chloride can be used to replace some portions of the calcium chloride or magnesium chloride to reduce costs. However, use of chloride compounds can be undesirable for plants and animals and can be leached from the road and carried by surface water. This should be considered in the design of application rate and selection of the base-stabilization approach.

### Enzymatic Stabilizers

Enzymatic stabilizers, such as Perma-Zyme, is less problematic for nearby plants. It is a degradable catalyst that improves bonding of the soil particles (Patel and Patel 2012).

The product is recommended for use in base materials that contain about 20 percent cohesive fines. The application rate is typically about 5 percent by weight (Khan and Sarker 1993).

### Lime

Lime reacts with water and silica in the clay minerals creating a cementious product that improves the strength of the road base or subbase. The hydration and flocculation process of the lime-water reaction immediately increases the soil strength, while the cementation process enhances the load-bearing capacity of the material in a longer time period (Patel and Patel 2012).

Lime is usually used for clay soils due to the need of the silicates for the reaction. The typical application rate is 5 to 10 percent by the weight of the mixture and is dependent on the soil properties.

### Portland Cement

Cement provides greater strengthening compared to lime (Ampera and Aydogmust 2005). It was found that a cement-treated road base showed increased strength and density. Compared to lime, cement can be applied to a wider range of soil types (Patel and Patel 2012).

Fly Ash

Fly ash is a much less expensive than base stabilizer compared to the previously discussed products. Fly ash is often used to substitute a certain percentage of cement or lime to lower the material costs.

Fly ash needs to be applied at the optimum moisture content and compacted immediately after application. A compaction delay, which can occur surprisingly often during a construction project, can result in significant loss of strength (Senol et al. 2006).

*Geosynthetics*

Polymer fabrics are made in various forms to reinforce the road base. Geotextiles, geogrids, and geocells are three examples of geosynthetics that can be used to reinforce road structures.

Geotextile is usually placed on the subgrade to provide separation between the base materials and the subgrade soil (see Figure 5).

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**Figure 5. Non-Woven Geotextile Placed on Subgrade as a Separation Layer**

Geotextiles prevent the coarse aggregate particles or gravel in the base layer from penetrating into the subgrade and prohibits the fine soil particles from moving upward to the base layer.

The penetration of the base rocks into the subgrade reduces its load-bearing capacity, while the upward movement of the fines blocks the voids in the aggregate base and lowers the drainage capacity of the base layer (Hawkins 2008). By minimizing the effects of these phenomena, the strength of the road structure can be improved.

A geotextile also alters the pressure distribution of the traffic load, which reduces the stress exerted on the subgrade and the damage to the subgrade.

Geogrids are designed to have high tensile strength and serve as reinforcement for a road base (see Figure 6).

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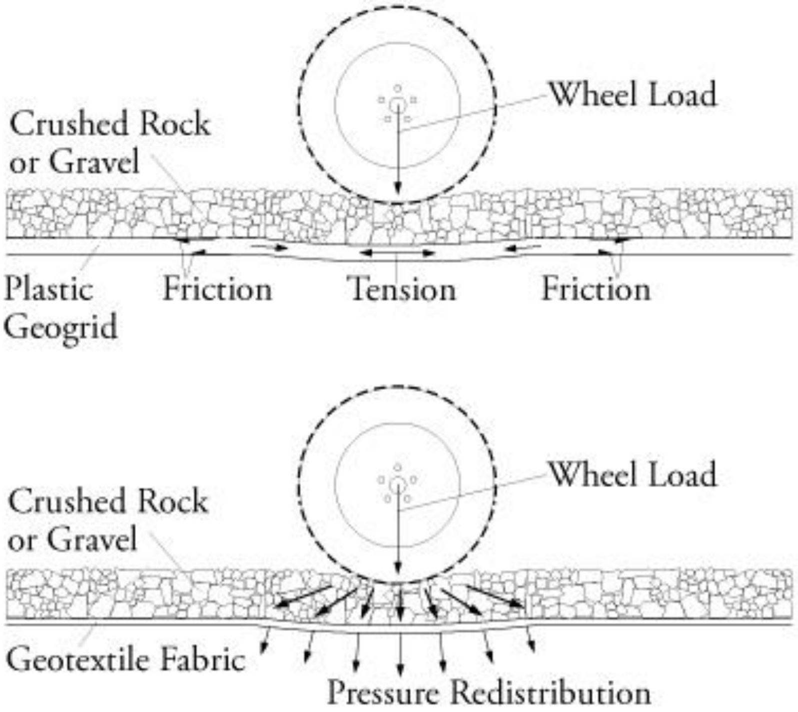
**Figure 6. Biaxial Geogrid Placed at the Interface of Subgrade and Base Layers for Stabilization**

A geogrid typically consists of a polymer sheet with uniformly distributed apertures that allow for vertical drainage. Geogrids can be used with geotextiles or geomembranes. The geogrid confines and stabilizes subgrade soils and reinforces the base course when tensile strains develop under load.

Figure 7 shows how geogrids can reinforce a road structure while geotextiles separate base courses from subgrades enhancing the ability of the base course to distribute loads more favorably.



Adapted from Ruhl et al. n.d., Ohio State University Extension

**Figure 7. The Reinforcing Effect of Geogrid (top) and the Separation Provided by Geotextile (bottom) Both Help to Increase the Strength of a Road Structure**

Geocells consist of a series of interconnected single cells that are manufactured from various types of polymers (see Figure 8).

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**Figure 8. 6-Inch Geocell over Non-Woven Geosynthetic Layer Placed on Subgrade**

The geocells are expanded at the construction site and filled with soil (see Figure 9).

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**Figure 9. Installation of 6-Inch Geocell over Non-Woven Geosynthetic Layer Placed on Subgrade and Expanded at Construction Site**

The geocell walls should completely encase the infill material. The various infill materials that have been used in the past are sand, gravel, ballast, concrete, and recycled asphalt pavement (RAP). The complete encasement of the infill material prevents lateral spreading. The layer acts as a stiff mat and distributes the vertical traffic loads over a much larger area of the subgrade soil.

An advantage to using geocells is that they reduce pressure on the roadbed and help control the total settlement of the road. The added strength reduces the amount of gravel that is needed for the subgrade noticeably (Emersleben and Meyer 2008).

### *Full-Depth Reclamation with Stabilizing Agents*

FDR recycles existing road materials by using a pulverizing machine to the full depth of the road structural layer. The thickness of the FDR layer is typically more than 6 inches. Stabilizing agents, as discussed previously, are usually added to improve the road base strength.

The stabilized full-depth reclamation (SFDR) layer exhibits higher load-bearing capacity and lower susceptibility to water damage. SFDR is considered an economical alternative to the reconstruction of a road base.

The construction of an SFDR includes sizing, stabilization, grading, and compaction. The construction can be performed using various operational procedures: a multi-step sequence, a two-step sequence, a single-machine operation, or a single-pass operation.

The multi-step sequence requires pulverizing, sizing, and mixing existing road materials individually and with different pieces of equipment for each step.

The two-step sequence uses a cold milling machine to pulverize the recycled materials into the required size. A mixing machine can be applied to blend the stabilizing agent with the recycled material (Tang et al. 2012).

The single-machine operation uses a special machine for the initial pulverization and sizing. The stabilizing agent is then laid on the road surface and a second pass with the same equipment is applied to mix the stabilizer and the road base material.

With a single-pass operation, an equipment train is used to perform all the steps in a single pass (Kandhal and Mallick 1997).

The required equipment for the multi-step and two-step sequences is usually readily available, while the single-machine and single-pass operations yield a higher production rate and consistency in construction (Kandhal and Mallick 1997).

## Structure Design Methods for Aggregate Roads with LSTs

Throughout the literature reviewed by the authors, no established structure design methods were found for the design of an aggregate road with LSTs. The thin LST layers are usually considered as a layer that does not add any structural capacity to the road structural system.

However, the base layer of an LST road should be designed to provide the full support capability for the design load. The base layer thickness of an LST is usually determined by using a conventional structural design method for aggregate or paved road design.

A survey showed that the local officials in 37 of the 48 states in the continental US use the AASHTO pavement design method to design the structure of a light-surfaced low-volume road (LVR) (Hall and Bettis 2000). The local officials in the remaining states used local procedures to design LVRs.

The following introduces four structure design methods that can be used for aggregate roads with LSTs: the MnDOT GE method, the AASHTO method, the MnDOT mechanistic-empirical method (MnPAVE program), and the South Dakota aggregate road design method.

### *MnDOT GE Method*

The granular equivalent factor is an indicator of the structural capacity of road material used extensively in the design of pavement structures in Minnesota. It represents the relative strength of a material compared to Class 5 and 6 base aggregates (MnDOT 2014).

Two road structure design methods are currently implemented by local agencies in Minnesota: soil factor procedures and R-value procedures. The soil factor design method was adopted by MnDOT during the 1950s (Skok et al. 2003). The method is suitable for the design of 7-ton and

9-ton routes, which are regulated by the springtime thaw restrictions that have single-axle weight limits of 7 tons and 9 tons, respectively (MnDOT 2010). The 7-ton and 9-ton routes include all of the unpaved highways and some low-volume roads with paved surfaces.

The R-value method was developed from a research project in the 1960s, which is part of the MnDOT efforts to adopt AASHTO road test results to local materials and climates in Minnesota (Kersten and Skok 1968). The method is more appropriate to the design of 10-ton roads, which include most of the asphalt pavement roads in Minnesota.

Both methods allow users to determine a required GE value based on the design traffic and subgrade soil strength. The thickness of each layer can be calculated using Equation 1 (MnDOT 2010).

$$GE = \sum a_i D_i \tag{1}$$

Where $GE$ = total required granular thickness (inch); $I$ = layer number, which is 1 for the surface course, 2 for the base course, and 3 for the subbase course; $D_i$ = thickness of the $i^{th}$ layer (inch); and $a_i$ = GE factor of the $i^{th}$ layer.

### MnDOT Soil Factor Method

The MnDOT soil factor method determines the required GE thickness (in inches) according to Table 3 using the soil factor (SF) and either average daily traffic (ADT), for 7-ton design, or heavy-commercial average daily traffic (HCADT), for 9-ton design (MnDOT 2010).

HCADT is the average number of trucks with six or more tires that travel the road every day. Instructions say to use projected ADT or HCADT for new construction or reconstruction and to use present ADT or HCADT for reconditioning.

A subgrade soil in AASHTO soil class A-4 or A-6 is considered to have a soil factor of 100. Engineering adjustments need to be applied to select the appropriate design soil factor according to the on-site soil property. MnDOT has developed typical soil properties, shown in Table 4, to use in the road design.

### MnDOT R-Value Method

The R-value method uses the design chart shown in Figure 10 to calculate the required minimum GE thickness.

## Table 3. MnDOT 7-ton and 9-ton flexible pavement design using soil factors.

| 7-Ton: Less than 400 ADT | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 7 | 7.3[1] |
| 75 | 7 | 9.4[1] |
| 100 | 7 | 11.5 |
| 110 | 7 | 12.4 |
| 120 | 7 | 13.2 |
| 130 | 7 | 14.0 |

| 9-Ton: 150-300 HCADT | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 7 | 14 |
| 75 | 7 | 17.5 |
| 100 | 7 | 21 |
| 110 | 7 | 22.4 |
| 120 | 7 | 23.8 |
| 130 | 7 | 25.2 |

| 9-Ton: More than 1100 HCADT[2] | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 8 | 20.3 |
| 75 | 8 | 26.4 |
| 100 | 8 | 32.5 |
| 110 | 8 | 35 |
| 120 | 8 | 37.4 |
| 50 | 8 | 20.3 |

| 7-Ton: 400 - 1000 ADT | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 3 | 9[1] |
| 75 | 3 | 12 |
| 100 | 3 | 15 |
| 110 | 3 | 16.2 |
| 120 | 3 | 17.4 |
| 130 | 3 | 18.6 |

| 9-Ton: 300-600 HCADT | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 7 | 16 |
| 75 | 7 | 20.5 |
| 100 | 7 | 25 |
| 110 | 7 | 26.8 |
| 120 | 7 | 28.6 |
| 130 | 7 | 30.4 |

| Type of Material | Spec | GE Factor |
|---|---|---|
| Bituminous Pavement | 2360 | 2.25 |
| Cold-Inplace Recycling (CIR) | 2331 | 1.5 |
| Rubblized Concrete | 2231 | 1.5 |
| Full-Depth Reclamation | 2331 | 1.0 |
| Stabilized Full-Depth Reclamation | 2331 | 1.5 |
| Aggregate Base Class 5 and 6 | 3138 | 1.0 |
| Aggregate Subbase Class 3 and 4 | 3138 | 0.75 |
| Select Granular Material | 3149.2B2 | .5 |

| 9-Ton: Less than 150 HCADT | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 7 | 10.3[1] |
| 75 | 7 | 13.9 |
| 100 | 7 | 17.5 |
| 110 | 7 | 19 |
| 120 | 7 | 20.5 |
| 130 | 7 | 22 |

| 9-Ton: 601-1100 HCADT | | |
|---|---|---|
| Soil Factor | Minimum Bit. GE | Total GE |
| 50 | 8 | 18.5 |
| 75 | 8 | 23.7 |
| 100 | 8 | 29 |
| 110 | 8 | 31.1 |
| 120 | 8 | 33.2 |
| 130 | 8 | 35.3 |

| AASHTO Soil Class | Soil Factor | Assumed R-Value | General Plasticity[3] |
|---|---|---|---|
| A-1 | 50 - 75 | 70 - 75 | NP |
| A-2 | 50 - 75 | 30 - 70 | SP |
| A-3 | 50 | 70 | NP |
| A-4 | 100-130 | 20 | SP |
| A-5 | 130 + | – | na |
| A-6 | 100 | 12 | P |
| A-7-5 | 120 | 12 | P |
| A-7-6 | 130 | 10 | P |

GE values are in inches and may not be exact due to rounding

[1] These GE values are for the finished pavement section; additional GE may be warranted for a construction platform during construction

[2] For HCADT over 1500, more advanced design procedures should be used; contact the MnDOT Pavement Design Unit

[3] NP= nonplastic, SP= semi-plastic, P = plastic, na = not applicable (i.e., an A-5 soil rarely occurs in Minnesota)

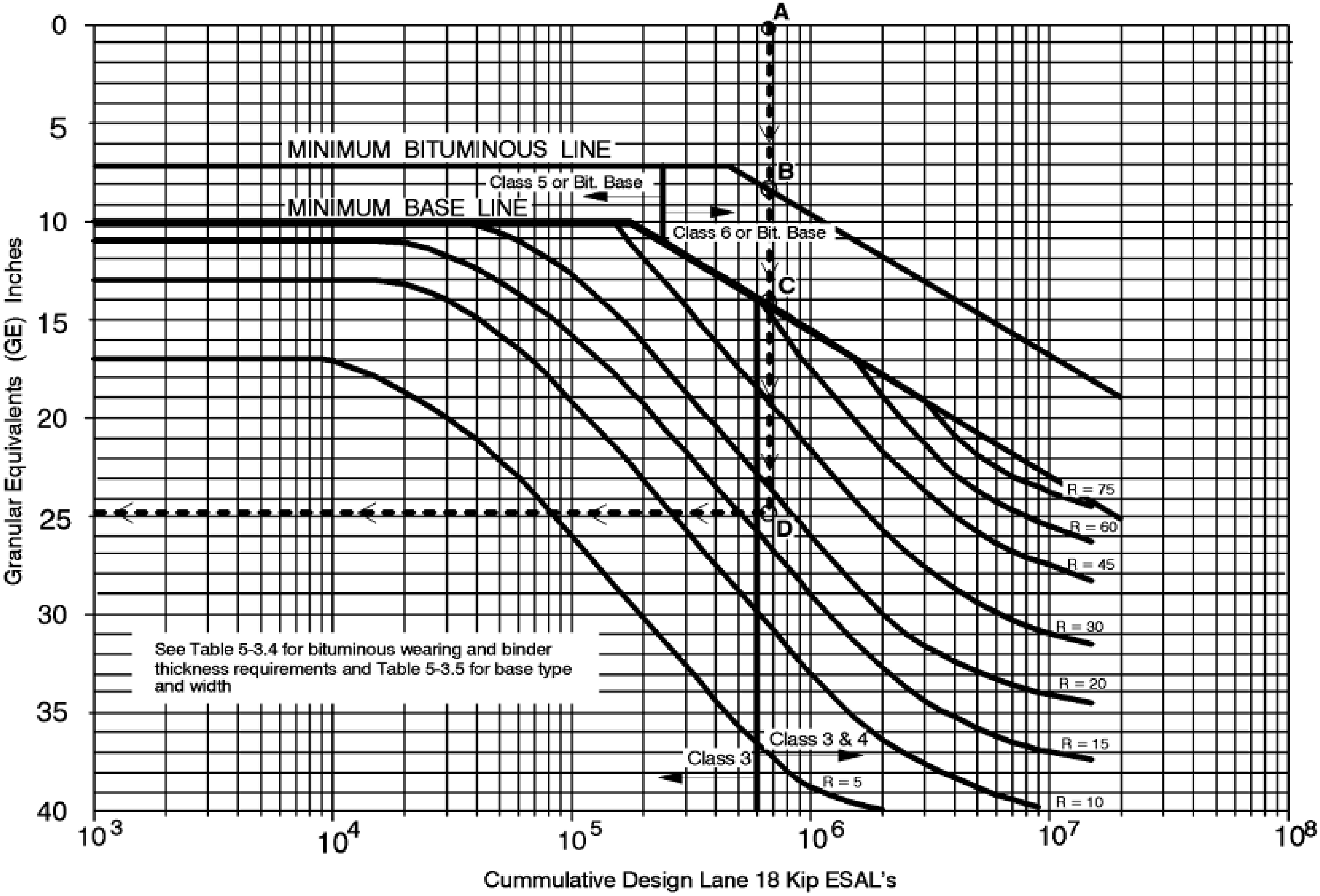
**Table 4. Typical soil properties (MN LTAP n.d.).**

| MnDOT Classification | Field Identification | Ribbon* Length (in.) | Rating | Possible Equivalent Classes | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | MnDOT Soil Factor | AASHTO ** | ASTM Unified *** | CBR | R-Value |
| Gravel (G) | Stones pass 75 mm sieve, retained on 2 mm. | 0 | Excellent | 50-75 | A-1 | GP-GM | – | 70 (assumed) |
| Sand (Sa) | Will form a cast when wet. Crumbles easily, 100% passes 2 mm sieve. | 0 | Good to Excellent | 50-75 | A-1, A-3 | SP-SM | 14.1 | 70 (assumed) |
| Loamy Sand (Lsa) | Grains can be felt. Forms a cast when Wet. | 0 | Good to Excellent | 50-75 | A-2 | SM, SC | 7.2 | 50-70 |
| Sandy Loam (SaL) Slightly plastic (<10% clay) | Slightly plastic. Sand grains seen and felt. Gritty. | 0-0.75 | Fair to Good | 50-75 | A-2 | SM, SC | 4.3 | 20-60 |
| Sandy Loam (SaL) Plastic (10-20% clay) | Slightly plastic to plastic. Sand grains seen and felt. Gritty. | 0.75-1.5 | Fair | 100-130 | A-4 | SM, SC | 3.9 | 15-30 |
| Loam (L) | Somewhat gritty, but smoother than SaL. | 0.25-1.5 | Fair | 100-130 | A-4 | ML, MH | 3.6 | 12-30 |
| Silt Loam (SiL) | Smooth, slippery or velvety. Cloddy when dry. Easily pulverized. | 0.0-1.5 | Poor | 120-130 | A-4 | ML, MH | 3.1 | 10-40 |
| Sandy Clay Loam (SaCL) | Somewhat gritty. Considerable resistance to ribboning. | 1.5-2.5 | Fair to Good | 100 | A-6 | SC, SM | 3.8 | 15-30 |
| Clay Loam (CL) | Smooth, shiny, moderate resistance to ribboning. | 1.5-2.5 | Fair to Good | 100 | A-6 | CL | 3.4 | 10-20 |
| Silty Clay Loam (SiCL) | Dull appearance, slippery. Less resistance to ribboning than CL. Very plastic but gritty. Long, thin ribbon, 0%-30% sand. | 1.5-2.5 | Poor | 120-130 | A-6 | ML/CL | 3.1 | 10-20 |
| Sandy Clay (SaC) | Very plastic but gritty. Long, thin ribbon, 50-70% sand. | 2.5< | Fair | 120-130 | A-7 | SC | – | 10-20 |
| Silty Clay (SiC) | Buttery, smooth, slippery. Less resistance to ribboning than CL. | 2.5< | Poor | 120-130 | A-7 | ML/CL | 3.1 | 10-20 |
| Clay (C) | Smooth, shiny when smeared, long thin ribbon or thread. | 2.5< | Fair | 120-130 | A-7 | CL, CH | 3.2 | 10-20 |

* See *MnDOT Grading and Base Manual*, Chapter 6, section 5-962-603(E)

** See Table 5 for typical $M_r$ and CBR ranges

*** CH= fat clay, CL= lean clay, GP-GM= well-graded gravel with silt, MH= elastic silt, ML= silt, ML/CL= silt/lean clay, SP-SM= poorly graded sand with silt, SM= silty sand, SC= clayey sand



Originally from *MnDOT Geotechnical and Pavement Manual*, April 1994 (MnDOT 2007, Skok et al. 2003)

**Figure 10. Bituminous Pavement Design Chart (Aggregate Base)**

The chart requires the design equivalent standard of 18 kips per equivalent single-axle load (ESAL) and the resistance value (R-value) of the subgrade soil as the input parameters. The R-value can be measured by following the standard American Society for Testing and Materials (ASTM) testing method D 2844 (ASTM International 2013).

In many cases, the R-value is estimated from the subgrade soil resilient modulus ($M_r$) or California bearing ratio (CBR). Christopher et al. (2006) recommend an equation (Equation 2) to estimate the $M_r$ value using the R-value. The equation can also be used to compute the R-value for a given $M_r$ value.

$$M_R(psi) = 1000 + 555 \times (R - value) \tag{2}$$

*AASHTO Method*

The AASHTO *Guide for Design of Pavement Structures* suggests the AASHTO flexible pavement design method for the design of the structure of LSTs (AASHTO 1993). The AASHTO method computes a structural number (SN) based on the design ESALs, expected serviceability loss, $M_r$ value, and design reliability using Equation 3.

$$\begin{aligned}\log W_{18} &= Z_R * S_0 + 9.36 * \log(SN+1) - 0.2 \\ &\quad + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log M_R - 8.07\end{aligned} \tag{3}$$

Where $W_{18}$ = number of 18 kips equivalent single axle load cycles, $Z_R$ = z value for a particular design reliability, $S_0$ = standard deviation, and $\Delta PSI$ = expected serviceability loss.

A nomograph (Figure 11) can be used to simplify the calculation.

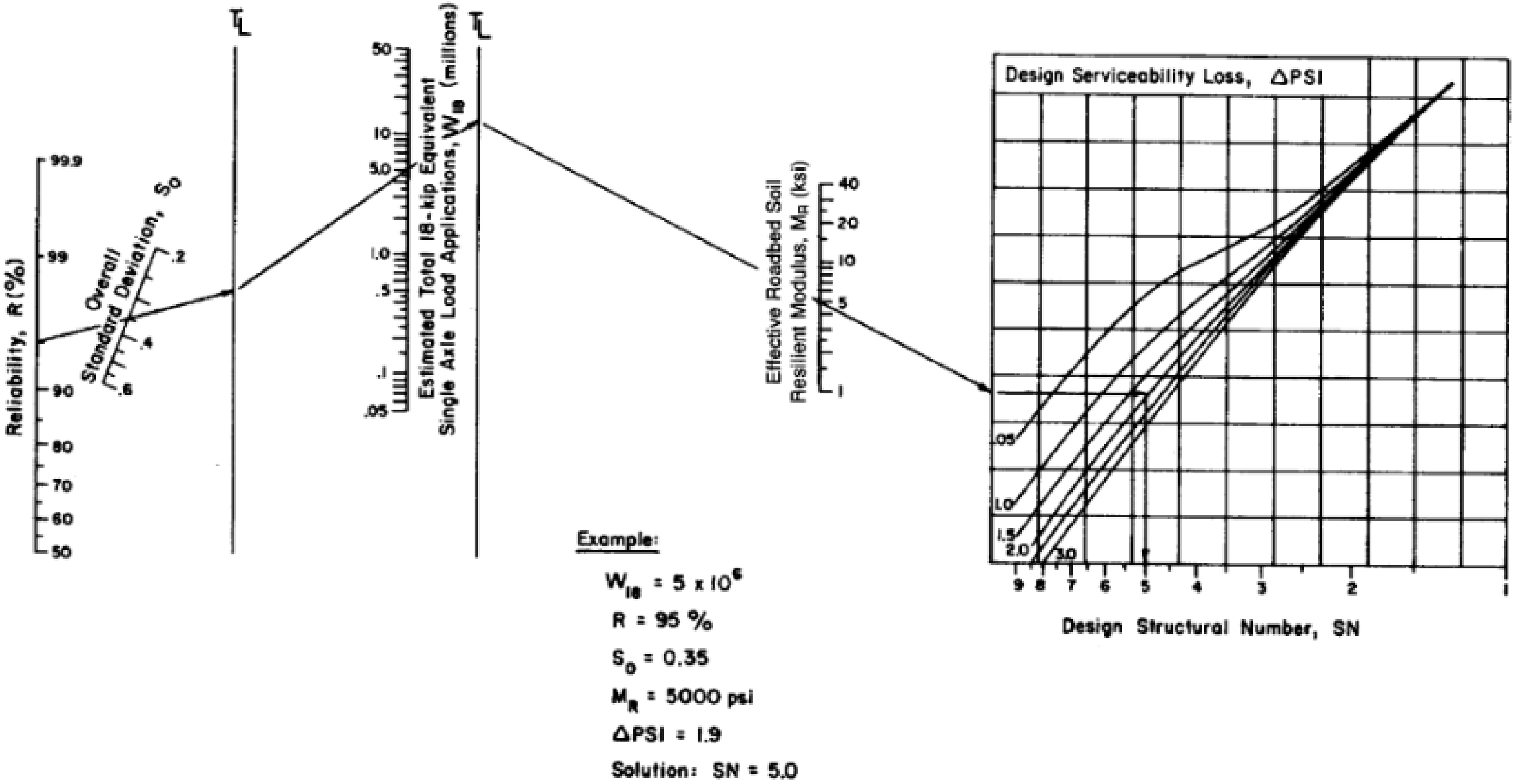


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**Figure 11. AASHTO Flexible Pavement Design Chart**

For LVRs, the design reliability is typically 50 percent. However, the reliability can be up to 80 percent depending on the project level. The z-value is 0 for 50 percent reliability and -0.841 for 80 percent reliability. The typical standard deviation ranges from 0.4 to 0.5 for flexible pavement. The subgrade $M_r$ value can be measured using the laboratory modulus test-specified by AASHTO designation T 274. The seasonal $M_r$ values are needed to compute the effective $M_r$ value, which is used as the input parameter in Equation 3.

However, performing laboratory testing is sometimes considered to be too time- and cost-consuming. The $M_r$ value can be estimated from the results of non-destructive tests or using the typical value of a specific soil type. An equation (Equation 4) is presented in the AASHTO *Guide for Design of Pavement Structures* (AASHTO 1993) to correlate the $M_r$ value to the deflection measured by a falling weight deflectometer (FWD) test.

$$M_R = \frac{0.24P}{d_r r} \tag{4}$$

Where $M_r$ = backcalculated subgrade resilient modulus (psi), $P$ = applied load (pounds), $d_r$ = measured deflection at radial distance r (inches), and $r$ = radial distance (inches).

The typical soil $M_r$ values are summarized in Table 5.

**Table 5. Typical $M_r$ and CBR values.**

| AASHTO Symbol | $M_r$ Range (ksi) | $M_r$ Default (ksi) | CBR Range |
|---|---|---|---|
| A-7-6 | 2.5 – 7 | 4 | 1 – 5 |
| A-7-5 | 4 – 9.5 | 6 | 2 – 8 |
| A-6 | 7 – 14 | 9 | 5 – 15 |
| A-5 | 9 – 15 | 11 | 8 – 16 |
| A-4 | 12 – 18 | 14 | 10 – 20 |
| A-3 | 14 – 25 | 18 | 15 – 35 |
| A-2-7 | 12 – 17 | 14 | 10 – 20 |
| A-2-6 | 12 – 20 | 15 | 10 – 25 |
| A-2-5 | 14 – 22 | 17 | 15 – 30 |
| A-2-4 | 17 – 28 | 21 | 20 – 40 |
| A-1-b | 25 – 35 | 29 | 35 – 60 |
| A-1-a | 30 – 42 | 38 | 60 – 80 |

Data source: ARA Inc., ERES Consultants Division 2001

The estimated $M_r$ values should be factored by 0.33 to account for the seasonal variations and to assure the adequacy of the design. For example, an A-6 soil would be assumed to have an $M_r$ value of 9 × 0.33 = 3 for year round design purposes.

The thickness of each structural layer can be then determined using Equation 5.

$$SN = \sum a_i D_i m_i \quad \textbf{(5)}$$

Where $i$ = layer number, which is usually 1 for the surface course, 2 for the base course, and 3 for the subbase course; $a$ = layer coefficient; $D$ = layer thickness (inches); and $m$ = drainage coefficient.

Figure 12 and Figure 13 can be used to determine the layer coefficient for the FDR base layer and the aggregate base of a LST road.

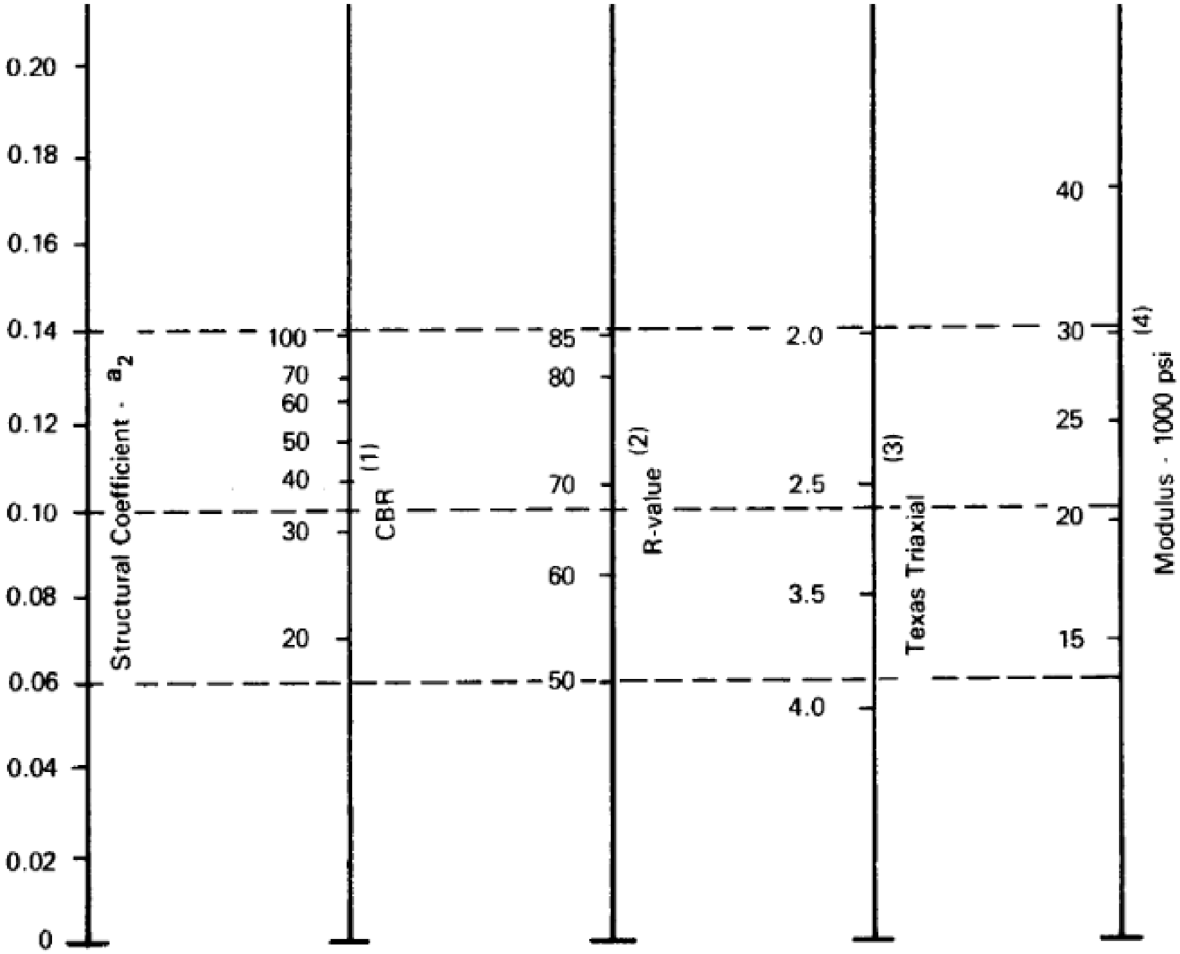

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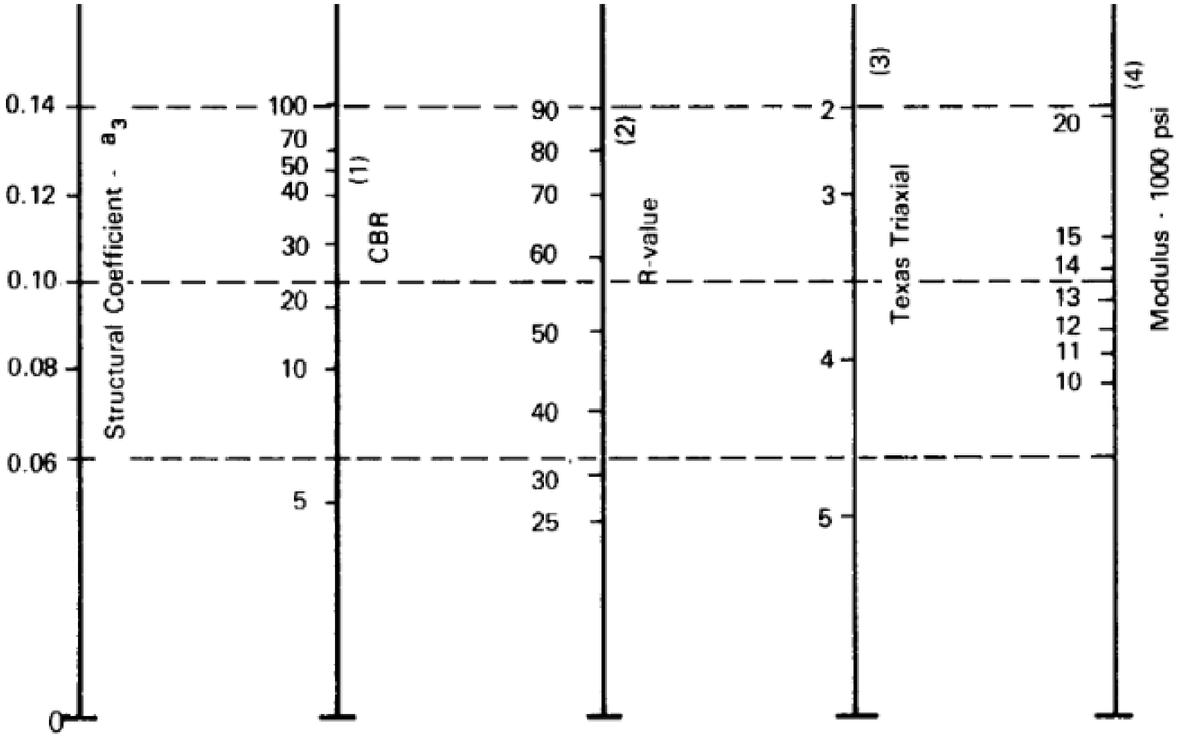
**Figure 12. Variation in Granular Base Layer ($a_2$) with Various Base Strength Parameters**



(1) Scale derived from correlations from Illinois.

(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming.

(3) Scale derived from correlations obtained from Texas.

(4) Scale derived on NCHRP project *(3)*.

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**Figure 13. Variation in Granular Subbase Layer Coefficient ($a_3$) with Various Subbase Strength Parameters**

The drainage coefficient is typically assumed to be 1 unless poor drainage is expected such as a road in a cut section with shallow ditches or subgrades with heavy soils that lack longitudinal subdrains. The designed layer thickness should fulfill the requirements for minimum layer thicknesses shown in Table 6.

**Table 6. AASHTO minimum thickness requirements.**

| Traffic (ESALs) | Asphalt Concrete (in.) | Aggregate Base (in.) |
|---|---|---|
| Less than 50,000 | 1.0 (or surface treatment) | 4 |
| 50,001-150,000 | 2.0 | 4 |
| 150,001-500,000 | 2.5 | 4 |
| 500,001-2,000,000 | 3.0 | 6 |
| 2,000,001-7,000,000 | 3.5 | 6 |
| Greater than 7,000,000 | 4.0 | 6 |

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### *MnPAVE Method*

MnPAVE is the pavement design software developed by MnDOT and the University of Minnesota based on an elastic-layered system and performance of test sections at the MnROAD facility. MnPAVE applies a mechanistic-empirical method that calculates pavement responses under the design climate, traffic, and material properties. Empirical correlations are used to predict the pavement performance over the 20-year typical design life of a flexible pavement.

The software contains a climate page, an ESAL page, a structure page, and an output page. The first three pages require input parameters that allow users to specify their particular project conditions and trail designs. The output page displays the number of years the road is expected to exist in good condition before failing with rutting or fatigue. The program is also capable of running a Monte Carlo simulations to calculate the probability that the road will fail in the way(s) that the software indicates.

MnPAVE requires at least one layer of HMA for all road designs and the minimum thickness for this HMA layer is one inch. The software assigns a structural value to the HMA layer, even though it is commonly understood that a one-inch thick layer of HMA does very little to improve the structure of the road.

### *South Dakota Method*

The South Dakota aggregate road design method uses two factors to design gravel layer thickness: daily number of heavy trucks on the road and soil support conditions measured using the CBR of the soil (Skorseth and Selim 2000). If the CBR of the soil is greater than 10, the soil is considered to have high subgrade support. If the CBR of the soil is greater than 3 and less than 10, the subgrade support is considered medium. If the CBR value of the soil is less than or equal to 3, the soil is considered to have low subgrade support. These factors are then used in Table 7 to calculate the minimum gravel thickness.

**Table 7. Suggested gravel layer thickness for new or reconstructed rural roads.**

| **Estimated Number Daily Heavy Trucks** | **Subgrade Support Condition** | **Suggested Minimum Gravel Layer Thickness (mm)** | **(in.)** |
|---|---|---|---|
| 0 to 5 | Low | 165 | 6.5 |
| | Medium | 140 | 5.5 |
| | High | 115 | 4.5 |
| 5 to 10 | Low | 215 | 8.5 |
| | Medium | 180 | 7.0 |
| | High | 140 | 5.5 |
| 10 to 25 | Low | 290 | 11.5 |
| | Medium | 230 | 9.0 |
| | High | 180 | 7.0 |
| 25 to 50 | Low | 370 | 14.5 |
| | Medium | 290 | 11.5 |
| | High | 215 | 8.5 |

Low = CBR ≤ 3 percent, Medium = 3 < CBR ≤ 10 percent, High = CBR >10 percent
Data source: Skorseth and Selim 2000

# Chapter 3
# Methodology

The objectives of this study were to understand the implementation status of LSTs in upgrading Minnesota aggregate roads and to evaluate the currently used methods for designing the road structure for aggregate roads that are surfaced with LSTs.

With the goals of better understanding the current practices in designing and constructing LSTs and identifying the factors that affect the success of LSTs, a survey was distributed to all 87 counties in Minnesota. The survey was distributed through email and web-based software.

Following that, phone interviews were scheduled with the county officials who had experience building LSTs on aggregate-surfaced roads. The phone interviews included 14 questions and interviews continued after that with open-ended discussions.

The survey and phone interview questions (Appendix A and B, respectively) asked for a list of the LST projects that the county had constructed, whether and why the LST projects were considered successes or failures, the benefits and disadvantages of LSTs, and the factors that affect the success of an LST project.

The construction to upgrade an aggregate road using LSTs usually includes base-stabilization construction and construction of the LST. Usually, it includes the creation of an SFDR layer underlying the surface layer. The research team identified the design methods that were currently used to design roads with these structures. Then, the recognized design methods were used to determine the thickness of the SFDR layers and aggregate base layers that are required to support the design traffic for three case study projects.

The three case study projects selected are county state-aid highways (CSAHs) in Minnesota with various traffic volumes and subgrade soil conditions. The results were used to compare the various design methods.

The pavement design methods that were considered in this study are MnDOT granular equivalent (GE) method, the MnDOT mechanistic-empirical method, which can be implemented using the MnPAVE software application, the AASHTO method, and the South Dakota aggregate road design method. A general assumption within these pavement designs is that the height of the bound and unbound layers will be equal to that of the existing road.

# Chapter 4
# Survey and Phone Interviews

The research team received 36 responses to the surveys that were distributed to the 87 counties in Minnesota. Of these responses, 10 counties reported experience building LSTs on aggregate-surfaced roads (see Table 8). The types of LSTs were Otta seal and chip seal.

**Table 8. Respondents to the survey with LST experience on an aggregate-surfaced road.**

| County | LST type | Application year | Phone Interview? |
|---|---|---|---|
| Becker | Otta seal | Once a year since 2004 | Yes |
| Cass | Otta seal | 2001 and 2002 | Yes |
| Clay | Otta seal | 2008 | Yes |
| Itasca | Otta seal | 2003 | Yes |
| Kandiyohi | Chip seal | 2012 | Yes |
| Morrison | Chip seal | 2007 | No |
| Olmsted | Otta seal | 2008 | No |
| St. Louis | Chip seal | 1998 | Yes |
| Stevens | Chip seal | 2001 | Yes |
| Wabasha | Otta seal | 2007 | Yes |

Dodge, Marshall, Pennington, Sibley, and Wantonwan counties said that they used base-stabilization products to treat aggregate-surfaced roads as an alternative to LSTs. The base-stabilization products that were used in these counties were calcium chloride, BASE ONE, and Perma-Zyme. Aitkin County had used RAP to treat aggregate-surfaced roads. The remaining respondents said that they do not have experience applying LSTs on aggregate-surfaced roads.

The survey was followed by phone interviews with county engineers who applied LSTs on aggregate-surfaced roads, which helped the researchers to better understand the current practices for constructing LSTs in Minnesota.

Three counties successfully applied LSTs, two counties considered the LSTs in their counties failures, and one county did not consider the LSTs either a success or a failure. The remaining counties were not available for phone interviews.

Through the phone interviews, the researchers found that some counties defined the success of a LST differently than others. The majority of counties deemed that a LST was successful if it is more economical than the conventional methods used to maintain an aggregate-surfaced road. Another opinion by the county engineers was that an LST is successful if it remains in good condition without major maintenance throughout its expected life.

Becker, Cass, and Wabasha counties successfully implemented LSTs on roads with a wide range of characteristics. The AADT of the roads surfaced with LSTs ranged from 200 to 580 vehicles per day (vpd). The type of traffic also varied between a low percentage and a high percentage of heavy traffic.

All three of those counties used various methods to prepare the road base. Becker County applied regular maintenance on the aggregate-surfaced road before applying the LST. Cass County applied BASE ONE on the road base, and Wabasha County placed and compacted 2 inches of aggregate base. Becker County typically has sandy loam soils whereas Cass and Wabasha have clay soils.

The two counties that did not have success applying LSTs were Clay and Stevens. Both roads had frequent heavy loads and were located in areas where the soils were clay. Both counties attempted to repair the roads by using asphalt patching and, in both cases, the patching did not resolve the road failures.

Itasca County found that applying the LST cost about the same as using chlorides to maintain the road, so it was determined that the LST was neither a success nor a failure. The conditions of the road were favorable for the LST. The subgrade was in good condition and the ADT was within the range of 50 to 150. However, timber-hauling trucks would travel on this road and damage the LST.

The benefits that the counties gained from applying the LSTs were as follows:

- Increased dust control
- Routine aggregate road maintenance no longer required
- Easier to maintain during the winter than aggregate-surfaced roads
- Improved surface condition and quality

The disadvantages of applying LSTs that were listed by the counties were as follows:

- Lack of competitive bid because not many qualified contractors in northern Minnesota have experience building LSTs
- Do not provide additional structural strength
- Costly repairs
- Susceptible to damage by heavy vehicles and equipment

# Chapter 5
# Case Studies

Three CSAHs were selected for case studies:

- CSAH 10 in Goodhue County
- CSAH 14 in Becker County
- CSAH 23 in Freeborn County

CSAH 10 and CSAH 14 were paved roads with HMA surfaces. CSAH 14 is a LVR, while CSAH 10 carries considerably higher traffic. CSAH 23 is a low-volume aggregate road. Detailed information about the existing road structures, subgrade soil properties, and present traffic conditions were provided by the county engineers of each county.

## Project Descriptions

### *CSAH 10*

The selected road segment on CSAH 10 for the case study is located between Trunk Highway (TH) 58 and County Road (CR) 48. The road was within the primary farming area in the county, which was expected to carry oversized farming equipment.

The road had an AADT of 1,562 with 4 percent heavy-commercial traffic. Historical traffic data indicated the road's AADT increases with an average annual growth rate of 4.7 percent (MnDOT 2012).

The existing road consisted of 7 in. HMA, 4 in. Class 3 aggregate base, and 8 in. granular subbase. The dominating subgrade soil type in the road region was A-6. The county engineer reported the R-value of the subgrade soil was 20.

### *CSAH 14*

The selected road segment on CSAH 14 for the case study was a two-lane highway located between CSAH 7 and CSAH 13. The primary land use of the surrounding area of the road was agriculture. Heavy agriculture equipment was expected during the harvest season.

The road had an AADT of 450 in 2011 (MnDOT 2012). Historical traffic data showed little change in the road's AADT since 2000.

The existing road consisted of 4.5 in. HMA and 9 in. aggregate base. The primary subgrade soil type in the region was A-6. The county engineer reported the subgrade soil had an R-value of 18.

*CSAH 23*

The selected road segment on CSAH 23 for the case study was a two-lane local road located between CSAH 26 and CR 92. The road was used primarily to provide access to the residents and agriculture facilities in the surrounding area.

The AADT of the road was 250. Although the actual traffic count for heavy-commercial vehicles was not available, the county engineer suggested that a heavy-commercial vehicle percentage of 10 to 12 percent could be assumed in the design.

The road surface consisted of 2 in. of magnesium chloride-treated Class 5 aggregate with 7 in. of gravel base. The dominating soil type in the road area was A-7. The subgrade soil had a CBR value of 2 and an R-value of 12, as reported by the county engineer.

## Material Property Determination

Due to lack of laboratory and in situ material characterization tests results, the assumption was made that typical values for the properties of certain types of subgrade soils, aggregate bases, and SFDR layers are used in the design procedures. Such assumptions are adequate for the purpose required here to compare various design procedures. However, it is strongly recommended that designers obtain dynamic cone penetration (DCP) or FWD test results and other soil and aggregate property characterizations in the process of developing construction contract documents to develop a reliable and economical design.

The material properties that need to be determined include the R-value and $M_r$ of the subgrade soil, subgrade soil factors, and structural layer coefficients of the aggregate base and the SFDR layer. Typical values in Table 4 and Table 5 were used to estimate the R-value and $M_r$ of the subgrade soils, respectively. The default values in Table 3 were used for the soil factors. The estimated subgrade soil properties are shown in Table 9.

**Table 9. Typical soil properties of case study project subgrades.**

| | **Predominating Subgrade Soil Type** | **Typical R-Value** | **Typical Soil Factor** | **Typical $M_r$ (ksi)** | **R-Value Provided by County Engineer** |
|---|---|---|---|---|---|
| CSAH 10 | A-6 | 10-20 | 100 | 7-14 | 20 |
| CSAH 14 | A-6 | 10-20 | 100 | 7-14 | 18 |
| CSAH 23 | A-7 | 10-20 | 120 | 2.5-9.5 | 12 |

The R-values provided by the county engineers indicated that the subgrades of CSAH 10 and CSAH 14 were a strong A-6 soil, while CSAH 23 had a weak A-7 subgrade. Therefore, the $M_r$ values selected to design the road structures of CSAH 10, CSAH 14, and CSAH 23 were 14 ksi, 12 ksi, and 5 ksi, respectively.

The South Dakota method requires subgrade soil CBR values to determine the thickness of the gravel layer. The CBR values can be determined using Equation 6 (Hashiro 2005), derived from the Asphalt Institute’s R-value and resilient modulus correlation equation (Asphalt Institute 1982) and the Heulelom and Klomp’s resilient modulus and CBR correlation equation (Heukelom and Klomp 1962).

$$R = \frac{1500CBR - 1155}{555} \tag{6}$$

However, the equation provides only rough estimations of the R-values tested on soil samples with moisture content less than the optimum moisture content (Hashiro 2005). If the South Dakota method is used, it is recommended to perform laboratory tests. The selected soil properties for structural design are shown in Table 10.

**Table 10. Selected subgrade soil properties for design of case study projects.**

| | R-Value | Soil Factor | $M_r$ (ksi) | CBR |
|---|---|---|---|---|
| CSAH 10 | 20 | 100 | 14 | 8 |
| CSAH 14 | 18 | 100 | 9 | 7 |
| CSAH 23 | 12 | 120 | 5 | 5 |

The structural coefficients for the aggregate base and SFDR layer can be determined using Table 11.

**Table 11. Structural layer coefficients proposed committee on design.**

| Pavement Component | Coefficient |
|---|---|
| **Surface course** | |
| Road mix (low stability) | 0.20 |
| Plant mix (high stability) | 0.44 |
| Sand asphalt | 0.40 |
| **Base course** | |
| Sandy gravel | 0.07 |
| Crushed Stone | 0.14 |
| Cement-treated (no soil-cement) | |
| Compressive strength at 7 days | |
| 650 psi or more | 0.23 |
| 400 psi to 650 psi | 0.20 |
| 400 psi or less | 0.15 |
| Bituminous-treated | |
| Coarse-graded | 0.34 |
| Sand asphalt | 0.30 |
| Lime-treated | 0.15-0.30 |
| **Subbase course** | |
| Sandy gravel | 0.11 |
| Sand or sandy clay | 0.05-0.10 |

Data source: Yoder and Witczak 1975

The aggregate base was assumed to have the same structural capacity as a crushed stone and a layer coefficient of 0.14 was applied for the aggregate base. The SFDR layer was considered as a bituminous-treated base course. Thus, an average layer coefficient of a coarse-graded bituminous-treated base and a sand asphalt base was used, which equaled 0.32.

## Structural Design

The MnDOT GE method, AASHTO method, MnPAVE software, and South Dakota method were applied to develop structural designs of an FDR layer with LSTs for the selected case study roads. An assumption was made that the design was trying to maintain the original road profile, not changing the overall layer thickness unless additional thickness was required to support the design load.

### *MnDOT GE Method*

Based on the AADT and HCADT, the 7-ton and 9-ton design tables were the most appropriate approaches to design road structures for CSAH 14 and CSAH 23. CSAH 10 was subjected to a higher AADT and HCADT, suggesting a 10-ton design may be more suitable than the 9-ton or 7-ton designs. Nevertheless, all three GE design methods were applied to each case study project with the exception that only 9-ton and 10-ton designs were applied to CSAH 10 study, due to the fact that its AADT exceeded the maximum allowable AADT for a 7-ton design.

The results are discussed in terms of rationality of the design. The designed road structure of each project is shown in Table 12.

**Table 12. Road design using MnDOT 7-ton and 9-ton method before adjustments to layer thickness.**

| | 7-Ton Road Design | | | 9-Ton Road Design | | |
|---|---|---|---|---|---|---|
| | Aggregate Base (in.) | SFDR (in.) | Required GE Thickness, (in.) | Aggregate Base (in.) | SFDR (in.) | Required GE Thickness, (in.) |
| CSAH 10 | - | - | - | 16 | 3 | 20.5 |
| CSAH 14 | 10.5 | 3 | 15 | 5.5 | 8 | 17.5 |
| CSAH 23 | 4 | 5 | 11.5 | -8 | 17 | 20.5 |

The 9-ton design generated a negative thickness for the aggregate base layer on CSAH 23. It indicated that the existing overall road thickness did not provide adequate support to the design load. Additional thickness needed to be assigned to the aggregate base with adjustments to the SFDR thickness to generate a more practical design. The adjusted designs are shown in Table 13.

**Table 13. Adjusted layer thickness using MnDOT 7-ton and 9-ton design method.**

| | 7-Ton Road Design | | 9-Ton Road Design | |
|---|---|---|---|---|
| | Aggregate Base (in.) | SFDR (in.) | Aggregate Base (in.) | SFDR (in.) |
| CSAH 10 | - | - | 16 | 3 |
| CSAH 14 | 10.5 | 3 | 5.5 | 8 |
| CSAH 23 | 4 | 5 | 5.5 | 8 |

The comparison of the overall thickness of the road structural layers in Table 14 indicates the thickness of CSAH 23 is increased by 4.5 inches for the 9-ton design, and that a significant road profile change is expected if a 9-ton GE design method is used.

**Table 14. Comparison of the overall thicknesses of the structural layers (7-ton and 9-ton design).**

| | Overall Thickness of Existing Road (in.) | Overall Thickness of Proposed Road (in.) | |
|---|---|---|---|
| | | 7-Ton Design | 9-Ton Design |
| CSAH 10 | 19 | - | 19 |
| CSAH 14 | 13.5 | 13.5 | 13.5 |
| CSAH 23 | 9 | 9 | 13.5 |

The design ESAL that is required for a 10-ton design can be calculated using the ESAL calculator spreadsheet developed by MnDOT (MnDOT 2013). The spreadsheet provides default truck percentages and vehicle types based on a selected AADT range and road type. Historical traffic counts are required to estimate the growth factor. Users can also define the traffic values using the spreadsheet. The calculated design ESALs for CSAH 10, CSAH 14, and CSAH 23 based on 10-year design life are 601,000, 184,000, and 353,000, respectively. The GE thickness requirements determined for the base layer and the bituminous layer are summarized in Table 15.

**Table 15. GE requirements and minimum SFDR thickness for 10-ton design.**

| | Aggregate Base (in.) | Bituminous Layer (in.) | Minimum SFDR Thickness (in.) |
|---|---|---|---|
| CSAH 10 | 25 | 9 | 6 |
| CSAH 14 | 21 | 7 | 4.5 |
| CSAH 23 | 29 | 8 | 5.5 |

The sum of the required GE values for the bituminous layer and the aggregate base is used as the required GE for the entire road structure. The minimum SFDR thickness is calculated from the GE requirement for the bituminous layer. The generated designs with adjustments to the constructability are shown in Table 16.

**Table 16. Adjusted layer thickness using MnDOT 10-ton design method.**

| | Aggregate Base (in.) | SFDR (in.) |
|---|---|---|
| CSAH 10 | 22 | 8 |
| CSAH 14 | 16 | 8 |
| CSAH 23 | 25 | 8 |

The results in Table 17 suggest the designed road structures are significantly thicker than the original road profile.

**Table 17. Comparison of the overall thicknesses of the structural layers (10-ton design).**

| | Overall Thickness of Existing Road (in.) | Overall Thickness of Proposed Road (in.) |
|---|---|---|
| CSAH 10 | 19 | 30 |
| CSAH 14 | 13.5 | 24 |
| CSAH 23 | 9 | 33 |

*AASHTO Method*

The required SNs can be determined using Equation 3 and are shown in Table 18 for the previously calculated design ESALs.

**Table 18. Required SN values for 50 and 80 percent reliability.**

| | Required SN for 50% | Required SN for 80% |
|---|---|---|
| CSAH 10 | 2.94 | 3.24 |
| CSAH 14 | 2.87 | 3.17 |
| CSAH 23 | 3.83 | 4.20 |

The designed layer thicknesses are shown in Table 19.

**Table 19. Layer thickness design using AASHTO method.**

| | 50% Reliability | | 80% Reliability | |
|---|---|---|---|---|
| | Aggregate Base (in.) | SFDR (in.) | Aggregate Base (in.) | SFDR (in.) |
| CSAH 10 | 17 | 2 | 15.5 | 3.5 |
| CSAH 14 | 8 | 5.5 | 6 | 7.5 |
| CSAH 23 | 9.5 | 8 | 12 | 8 |

The designed overall layer thicknesses shown in Table 20 are significantly higher than the existing road structures for CSAH 23, while the designed thicknesses for CSAH 10 and CSAH 14 are much more practical. This is primarily caused by the low subgrade strength of CSAH 23.

**Table 20. AASHTO method comparison of the overall thicknesses of the structural layers.**

| | Overall Thickness of Existing Road (in.) | Overall Thickness of Proposed Road (in.) | |
|---|---|---|---|
| | | 50% Reliability | 80% Reliability |
| CSAH 10 | 19 | 19 | 19 |
| CSAH 14 | 13.5 | 13.5 | 13.5 |
| CSAH 23 | 9 | 17.5 | 20 |

### *MnPAVE Method*

The MnPAVE software requires a minimum 1-inch HMA layer in the design of the road structure. According to Table 3, the typical GE factor is 2.25 for bituminous pavement and 1.5 for SFDR. Therefore, it is assumed that a 1-inch HMA layer provides the same structural capacity as a 1.5-inch SFDR layer. The minimum 1-inch HMA layer is converted to a 1.5-inch SFDR layer and added to the SFDR layer thickness determined using the MnPAVE software to compute the design SFDR thickness.

The software uses a Monte Carlo method to evaluate the possibility of the designed road failing before the design life is reached. The failure criteria are based on the predicted rutting and fatigue cracking. The analysis in this study indicated that the case study projects would fail first by rutting at the end of the design life and later by fatigue cracking.

The developers of the software recommend using 85 percent design reliability for roads with less than 1 million ESALs and 90 percent design reliability for roads with more than 1 million ESALs. The case study projects had less than 1 million ESALs, so the design reliability selected was 85 percent. However, the AASHTO method suggests LVRs should use 50 to 80 percent design reliability. The required layer thicknesses with 50 percent and 80 percent reliabilities were also computed using the MnPAVE software to compare the results from the AASHTO method. Table 21 summarizes the minimum layer thicknesses that are required to achieve the design reliability of 85 percent, 80 percent, and 50 percent.

**Table 21. Required minimum layer thicknesses to achieve the design reliability using MnPAVE.**

| | **Design Reliability** | | | | | |
|---|---|---|---|---|---|---|
| | **85%** | | **80%** | | **50%** | |
| | **Aggregate Base (in.)** | **SFDR (in.)** | **Aggregate Base (in.)** | **SFDR (in.)** | **Aggregate Base (in.)** | **SFDR (in.)** |
| CSAH 10 | 12.5 | 6.5 | 13.5 | 5.5 | 17.5 | 1.5 |
| CSAH 14 | 6.5 | 7 | 7 | 6.5 | 9 | 4.5 |
| CSAH 23 | 6.5 | 8 | 6 | 8 | 1.5 | 8 |

The comparison between the overall thicknesses of the existing and proposed road structures are shown in Table 22.

**Table 22. Comparison of the overall thicknesses of the structural layers using MnPAVE software.**

| | **Overall Thickness of Existing Road (in.)** | **Overall Thickness of the Proposed Road (in.)** | | |
|---|---|---|---|---|
| | | **50% Reliability** | **80% Reliability** | **85% Reliability** |
| CSAH 14 | 13.5 | 13.5 | 13.5 | 13.5 |
| CSAH 10 | 19 | 19 | 19 | 19 |
| CSAH 23 | 9 | 9.5 | 14 | 14.5 |

The results indicated that additional layer thickness needed to be constructed to support the design traffic for CSAH 23, while reasonable SFDR layers could be constructed for CSAH 10 and CSAH 14 without changing the current road profiles.

### *South Dakota Method*

With estimated CBR values for the subgrade soils of the case study projects between 3 and 10, the projects were considered to have medium subgrade support conditions. The number of heavy vehicles in the traffic were determined using the MnDOT ESAL calculator (MnDOT 2013) and are shown in Table 23.

**Table 23. Estimated heavy traffic on CSAH 10, CSAH 14, and CSAH 23.**

| Road | AADT | Heavy Vehicles (%) | Daily Heavy Traffic |
|---|---|---|---|
| CSAH 10 | 1,562 | 9.45 | 148 |
| CSAH 14 | 450 | 13.44 | 61 |
| CSAH 23 | 250 | 13.28 | 33 |

Table 7 shows that the maximum heavy traffic that the South Dakota method is able to design for is 50. Therefore, only the CSAH 23 case study project could be designed using the South Dakota method. The required gravel layer thickness determined from Table 7 was 11.5 inches for CSAH 23. The value can be used as the required GE thickness for the proposed LST road. The proposed aggregate layer thickness and the SFDR layer thickness were determined as 4 inches and 5 inches using Equation 1.

### Comparison of the Design Methods

The structural designs using various design methods for the case study projects CSAH 10, CSAH 14, and CSAH 23 are summarized in Table 24, Table 25, and Table 26, respectively.

**Table 24. Comparison of the structural designs of CSAH 10 using various methods.**

| Design Method | Aggregate Base (in.) | SFDR Layer (in.) | GE Thickness (in.) |
|---|---|---|---|
| MnDOT 7-ton soil factor method | Maximum allowable AADT is exceeded | | |
| MnDOT 9-ton soil factor method | 16 | 3 | 20.5 |
| MnDOT 10-ton R-value method | 22 | 8 | 34 |
| AASHTO method at 50% reliability | 17 | 2 | 20 |
| AASHTO method at 80% reliability | 15.5 | 3.5 | 20.75 |
| MnPAVE method at 85% reliability | 12.5 | 6.5 | 22.25 |
| MnPAVE method at 80% reliability | 13.5 | 5.5 | 21.75 |
| MnPAVE method at 50% reliability | 17.5 | 1.5 | 19.75 |
| South Dakota method | Maximum allowable heavy traffic is exceeded | | |

**Table 25. Comparison of the structural designs of CSAH 14 using various methods.**

| Design Method | Aggregate Base (in.) | SFDR Layer (in.) | GE Thickness (in.) |
|---|---|---|---|
| MnDOT 7- ton soil factor method | 10.5 | 3 | 15 |
| MnDOT 9- ton soil factor method | 5.5 | 8 | 17.5 |
| MnDOT 10- ton R-value method | 16 | 8 | 28 |
| AASHTO method at 50% reliability | 8 | 5.5 | 16.25 |
| AASHTO method at 80% reliability | 6 | 7.5 | 17.25 |
| MnPAVE method at 85% reliability | 6.5 | 7 | 17 |
| MnPAVE method at 80% reliability | 7 | 6.5 | 16.75 |
| MnPAVE method at 50% reliability | 9 | 4.5 | 15.75 |
| South Dakota method | Maximum allowable heavy traffic is exceeded | | |

**Table 26. Comparison of the structural designs of CSAH 23 using various methods.**

| Design Method | Aggregate Base (in.) | SFDR Layer (in.) | GE Thickness (in.) |
|---|---|---|---|
| MnDOT 7- ton soil factor method | 4 | 5 | 11.5 |
| MnDOT 9- ton soil factor method | 5.5 | 8 | 17.5 |
| MnDOT 10- ton R-value method | 25 | 8 | 37 |
| AASHTO method at 50% reliability | 9.5 | 8 | 21.5 |
| AASHTO method at 80% reliability | 12 | 8 | 24 |
| MnPAVE method at 85% reliability | 6.5 | 8 | 18.5 |
| MnPAVE method at 80% reliability | 6 | 8 | 18 |
| MnPAVE method at 50% reliability | 1.5 | 8 | 13.5 |
| South Dakota method | 4 | 5 | 11.5 |

To compare the various designs, the overall GE thickness for each design was computed using GE factors of 1 for the aggregate base layer and 1.5 for the SFDR layer. The results indicated that all of the design methods suggested a higher GE thickness for CSAH 10 than CSAH 14 with the exceptions of the MnDOT 7-ton soil factor method and the South Dakota method, which did not apply for the traffic conditions on CSAH 10. The MnDOT 7-ton soil factor method and the South Dakota method also generated higher GE thicknesses for CSAH 23 than the GE thicknesses for CSAH 14, except for the MnPAVE method at 50 percent reliability. Compared to CSAH 10, the AADT for CSAH 14 was significantly lower. Meanwhile, the subgrade soil strength for CSAH 14 was much higher than that of CSAH 23. Thus, the GE thickness comparison results showing that the GE thickness required for CSAH 14 was smaller than those for CSAH 10 and 23 could be expected.

This implied that the design methods evaluated in this study correctly reflected the influences of the subgrade soil strength and design traffic; however, the exceptions indicated limitations exist for implementing each method. The higher GE thicknesses for CSAH 14 compared to CSAH 23 suggested that the designs generated using the MnDOT 7-ton soil factor method and MnPAVE method at 50 percent reliability need to be carefully evaluated.

Compared to the design results using other methods, the MnDOT 10-ton soil factor method requires the pavement to be extremely thick to support the design load. The required overall thicknesses of the structural layers for the case study projects varied from 24 inches to 32 inches. Such thicknesses are considered too expensive and impractical for LSTs.

The AASHTO method and MnPAVE method allow designs at various reliabilities. The recommended reliability was 50 percent for the AASHTO method and 85 percent for the MnPAVE method under the situations for the case study projects. The reliability of the AASHTO method is established on the variations of the subgrade soil resilient modulus and traffic volume. However, the MnPAVE method computes the design reliability using the performance criteria.

For 50 percent reliability, the AASHTO method required a higher structural number or GE thickness compared to the MnPAVE method. The same trend was observed at 80 percent reliability with the exception of CSAH 10, which carried a higher AADT. Although there were differences in the resulting designs using the various design methods, the designed road structures using the MnDOT 9-ton soil factor method, AASHTO method, and the MnPAVE method were similar.

Implementations of the MnDOT 7-ton soil factor method and the South Dakota method were limited by their applicable traffic volume range. From the available designs, it was found that the MnDOT 7-ton soil factor method and the South Dakota method generated smaller GE thicknesses compared to other methods. This was probably because the two methods were developed to deal with very low traffic roads.

Among the methods evaluated in this study, the South Dakota method was specifically developed for the design of aggregate roads, while the other methods are used for flexible pavement design. The flexible pavement design methods assume a HMA layer placed on the surface of the structure, whereas the LSTs do not include such a HMA layer. Structures designed under that assumption may need adjustments because the load-transferring path for a LST is different from that of a road with a HMA layer.

## Selection of Design Method

The selection of a design method for a LST project depends on the extent to which soil and material properties are known, the traffic count and type of traffic, and the service level (collector, arterial, etc.). This section discusses the situations in which each method is appropriate for use under various circumstances.

### *MnDOT 7-Ton Soil Factor Method*

The factors considered using this method include daily traffic and subgrade soil strength. The subgrade soil factor can be determined from various sources, such as correlations to other soil parameters and soil type. Rough estimations of the traffic level and soil strength are usually satisfactory for this design method. Results of material property tests are generally not required for this method.

The method generates smaller required GE thickness for the same level of traffic and subgrade strength compared to the other methods evaluated in this study, except for the South Dakota method. The designed structure may fail to carry the load for which other methods might design.

The method is only applicable for roads with ADT less than 1,000. Thus, the method is recommended for use to develop preliminary design for roads with very low traffic and a small percentage of trucks. Other design methods should be used if the design traffic volume is high or a final design is going to be developed.

### *MnDOT 9-Ton Soil Factor Method*

The factors considered using this method include daily traffic volume, percentage of heavy commercial vehicles, and subgrade soil strength. Rough estimations of the HCADT and soil strength are usually satisfactory for the design method. Material property tests are generally not required for this method.

The generated design results using this method are close to the designs that would be developed using the AASHTO or MnPAVE method. The method is recommended for use to develop a preliminary design of an aggregate road structure with LSTs.

### *MnDOT 10-Ton R-Value Method*

The factors considered using this method include design ESALs and the R-value of the subgrade soil. Obtaining subgrade soil property tests is strongly recommended as part of the effort to obtain the R-value for the design. However, the R-values estimated using the typical value of a particular type of soil or from the correlations with other soil property parameters can be used to develop a preliminary design.

The design results are the most conservative among the methods that were evaluated in this study. It is recommended for use with high-traffic volume roads and weak subgrade strength. The results need to be carefully adjusted because the required layer thicknesses designed by this method are likely to be too thick to be economically constructed.

### *AASHTO Method*

The factors considered using this method include design ESALs, subgrade soil resilient modulus, climate, and design reliability. The method requires material property tests and reliable and detailed traffic information.

The developed design using the AASHTO method at 50 percent reliability is more conservative than the design at the same reliability level using the MnPAVE method. The AASHTO method is recommended for use for the final design of roads with various traffic volumes and subgrade soils. Fifty percent reliability can be used for roads with lower project levels, and 80 percent reliability is recommended for higher project levels.

### *MnPAVE Method*

The factors considered using this method include design ESALs, subgrade soil properties, aggregate and SFDR layer properties, climate, and design reliability. The method provides three design level options: basic, intermediate, and advanced. The basic level requires the minimum information required to complete a design. The intermediate level requires the R-value to be tested for the subgrade soil. The advanced level requires various materials tests to be conducted.

The software allows users to select the typical material properties to generate a quick design. The MnPAVE method can be used in versatile situations. It can be used to develop a preliminary design or a final design.

### *South Dakota Method*

The factors considered using this method include daily traffic and subgrade support condition. Rough estimations of the traffic and subgrade strength are satisfactory for this method.

The designed structures using this method have noticeably lower GE thicknesses compared to the other methods, except for the MnDOT 7-ton soil factor method. The method is only applicable to design roads with 50 or fewer daily heavy traffic vehicles. The South Dakota method is recommended for the preliminary design of roads with very low traffic volume and percentage of trucks.

# Chapter 6
# Conclusion

Fifty percent of rural trunk highways and 90 percent of rural county state-aid highways in Minnesota have traffic levels below 2,000 cars per day (Minnesota Office of the Legislative Auditor 1997). Rural paved and unpaved roads with low traffic volumes can be candidates for light surfacing. A light surface would serve to remedy deficient surface conditions (Oliver 1997) and maintain the integrity of the road structure.

This project included a survey at the county level to understand current practices for using LSTs to upgrade aggregate-surfaced roads in Minnesota, and the researchers performed a case study analysis of how MnDOT currently designs rural LVRs with light surfaces. Based on the results, the report discusses the limitations of various design methods and recommends applicable situations for each of the design methods.

The survey was distributed to all 87 counties, and about half of the counties that responded to the survey had experience constructing LSTs. Chip seal and Otta seal were the most popular types of LSTs.

A typical structure of a LST upgraded-aggregate road consists of a SFDR layer underlying the LST surface and an aggregate base. The researchers found through the survey that most of the counties that used LSTs for aggregate-road upgrades achieved their goals of reducing the construction and maintenance costs without compromising the performance.

The exceptions were Clay and Stevens counties. Quick deterioration, including cracks and potholes, were observed for these two counties, which resulted in considerable repair cost for asphalt patching and resurfacing with HMA overlays. The primary reason for the failures is believed to be clay subgrades. Clay and Stevens county engineers do not recommend constructing LSTs in locations where clay soil is the subgrade.

Moreover, traffic volume is another factor that noticeably affects the performance of a LST road. Furthermore, the most appropriate aggregate road candidates for LSTs should not carry considerable heavy traffic. However, future research is needed to establish the specific traffic criterion for which the LSTs would not be recommended to construct.

The case studies show the designed pavement structures are similar when using the MnDOT 9-ton soil factor design method, the AASHTO method, and the MnPAVE method.

The MnDOT 7-ton soil factor design method and the South Dakota method generate less-conservative designs in comparison to other methods. These two design methods are recommended for use for roads with very low traffic volume and low heavy vehicle percentages.

The MnDOT 10-ton R-value design method provides the most conservative design among the pavement structures designed in this study. However, the designed SFDR layer thickness and the overall road structure are too thick to be economically constructed. The change of the road profile due to the additional layer thickness also causes construction difficulties. The MnDOT 10-ton method is unlikely to be recommended for the design of LST roads unless adjustments are made to its results.

The MnDOT GE method and the South Dakota method usually require less information to complete a design compared to the AASHTO method and the MnPAVE method. Precise laboratory and field material property tests are generally not needed for the MnDOT GE methods and the South Dakota method. Thus, these design methods are appropriate to develop a preliminary design.

The AASHTO method requires that the subgrade soil properties and the traffic conditions be carefully evaluated. It generates a reliability-based design that allows users to justify the reliability of the road structures for various project levels.

The MnPAVE method also designs road structures for a specified reliability. The application of the method is versatile and can be used for both a preliminary design and a final design. Users can choose to specify the material properties and traffic conditions or to use the typical values.

Throughout the review of the design methods, the researchers found that the currently used design methods, except for the South Dakota method, were developed to design flexible pavement road structures. The methods typically require a minimum HMA thickness, which does not exist for a LST road. The differences between the load-transferring paths of the roads with and without a HMA surface may influence the reliability of the design results.

Again, the survey conducted in this study indicated that a LST is challenging to construct on a clay subgrade. The current design methods account well for the influences of the subgrade strength. Typically, a clay soil has lower strength than a sandy soil. However, exceptions exist. A clay soil is more susceptible to frost heave and spring thaw. The subgrade soil type factor needs to be considered during the design process of a LST road.

Moreover, the survey results indicate that traffic volume is a factor that affects the performance of a LST road. To improve the current design methods, further research is recommended to establish the traffic criteria for aggregate roads with LSTs.

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# Appendix A
# Survey Distributed to County Engineers in Minnesota

## Light Surface Treatment (LST) LRRB Informational Survey

The purpose of this survey is to gather information about the LSTs that have been implemented in counties in Minnesota. Once the information from this survey was collected, it was followed by a 20- to 30-minute phone interview to discuss the implementation of the treatments.

The follow-up interview included questions that discussed topics such as road conditions, traffic type, methods of application, and the performance of the LST. An agenda of the phone interview was sent out prior to the interview so the interviews would be most beneficial to the research team with the survey respondents able to gather answers to questions before their scheduled interview.

The survey was to be filled out by anyone with in-depth knowledge of the implementation of the LST(s) in the county.

1. Name: 2. Date: 3. Phone Number:
4. County or Township and State: 5: E-mail:
6. Check the Light Surface Treatments that your county has applied on low volume rural roads.

| **Treatments** | **Otta Seal** | **Double Otta Seal** | **Chip Seal** | **Double Chip Seal** | **Oil Gravel** | **Other (Specify):** |
|---|---|---|---|---|---|---|
| **Number of times applied** | | | | | | |

7. Provide the following details for the examples listed in question 6. Limit your response to three roads. Only include roads that have been available for use to the public since 2010.

| **Road Name and Location** | **LST Segment Length** | **What year were the LST applied** |
|---|---|---|
| | | |

8. Has your county applied Light Surface Treatments on more than 3 roads?

9. Please specify 3 time slots when you would be available to conduct the 20-30 minute phone interview. The research team is not available from January 12th-17th.

10. Comments and Concerns.

# Appendix B

# Interview with County Engineers who have Built Light Surface Treatments

| | | |
|---|---|---|
| Name: | State: | Phone Number: |
| County or Township: | Date: | E-mail: |

1. Circle one treatment that you have applied on an aggregate-surfaced road:

**Otta Seal** **Double Otta Seal** **Chip Seal** **Double Chip Seal** **Oil Gravel** **Other (Specify):**

2. In what month and year was the LST applied on the road?

3. Road Name:

4. Road Location:

5. LST segment length and road width:

6. Describe traffic type, median road speed, and provide ADT of road:

7. What work did your crew do in order to prepare the base for construction?

8. Was the treatment a **Success** or **Failure**? Discuss your answer.

9. What are the benefits and disadvantages of the LST?

10. Road conditions after LST (Circle answers which best apply)

| | | | |
|---|---|---|---|
| a. Thermal cracks: | Severe | Minimal | None |
| b. Rutting: | Severe | Minimal | None |
| c. Is maintenance needed? | Major | Minor (Patchwork) | None |

d. Has maintenance been applied on the road (If yes, please describe): Yes No

11. Cost per mile of LST (Use the most recent cost data available):

**Construction Costs of LST**

| Item | Cost |
|---|---|
| Oil Emulsion | |
| Aggregate | |
| Labor/Equipment | |
| Base Stabilizer and Gravel | |
| Other Cost (Specify) | |
| Other Cost (Specify) | |
| Total Construction Cost | |
| **Maintenance Costs of LST** | |
| Minor (i.e. Patching)/year | |
| *Major | |

*How often do you expect that major maintenance is required?

12. Application details

Application rate of binder/prime:

Equipment used to spread aggregate:

Was a pneumatic roller used?

13. Describe each layer of the road: include the existing condition/material/thickness.

Spray applied on surface (i.e. dust coat/fog seal):

Surface:

Base (was a stabilizer used?):

Sub-base:

Subgrade:

14. Did you use any specifications for the light surface treatments?