Review of Multi-Year Experience with Geogrid Stabilized Flexible Pavements in Novi, MI

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ABSTRACT

The City of Novi, Michigan, a suburb of Detroit, has used geogrid stabilization of flexible pavement sections as a standard practice since 2013, resulting in enhanced performance and reduced life cycle cost. This paper reviews the decision drivers and cost-benefit analysis that supported this innovative practice, and discusses results and lessons learned over the five years that geogrid stabilization has been used.

INTRODUCTION

The City of Novi is located in southeast Michigan, with a population of approximately 60,000 and a total area of 31.28 square miles. It was organized in 1832, and incorporated as a city in 1969, and is a suburb of Detroit.

Historically, Novi relied on standard sections for the construction of flexible pavements, with fixed thicknesses for the aggregate and asphalt layers depending on the expected traffic level of the road. The expected life span for these pavements was 20 years. In 2013, the Public Works and Engineering Departments concluded that a significant portion of the roads in the City were not achieving their expected life, and they started to look for alternative approaches that would improve performance.

STANDARD SECTIONS

Prior to 2013, the City used two standard flexible pavement sections, as shown in Figure 1. The thinner section, referred to here as Section A, consisted of 102 mm (4 in) total thickness of hot mix asphalt (HMA) over 203 mm (8 in) of aggregate base course (Michigan 21AA limestone). The thicker section, referred to here as Section B, consisted of 127 mm (5 in) total thickness of HMA over 305 mm (12 in) of aggregate base course. These designs were implemented based on the range of expected traffic loadings for the road at the time of construction.
The practice of using standard pavement sections is common at the municipal level in the United States for a variety of reasons, including limited staff to perform pavement designs, uncertainty in anticipated traffic loadings, and a lack of resources to thoroughly characterize construction conditions, particularly subgrade strength. (In most cases, there is an assumption that the subgrade will be prepared to a designated minimum strength, and a requirement in the standard specification that this be done.) It necessarily results in some fraction of pavements being either over designed or under designed, due to variation in traffic loadings and construction conditions. In general, it can be expected to work best when the sections are somewhat conservative so that the cases of under design (and therefore premature failure) are minimized.

Ideally, each road would be designed individually for the expected traffic over its design life and the site conditions where it is to be constructed. However, the lack of resources and personnel to perform designs, coupled with a lack of precise traffic loading projections over the road’s useful life, often make this impractical in the real world.

The City concluded that it was not feasible to move away from the use of standard sections due to the reasons cited above, and therefore undertook an effort to review the existing standard sections and identify the most efficient and reliable means to improve their performance to the necessary levels.

**PAVEMENT SECTION EVALUATION**

The City conducted a design evaluation of the existing standard pavement sections using American Association of State Highway and Transportation Officials (AASHTO) 1993 methodology. Table 1 shows key design input parameters for this analysis. This analysis was performed using SpectraPave4-PRO™ software, which incorporates AASHTO 1993 methodology. The analysis showed that Section A has an expected traffic capacity of 138,000 Equivalent Single Axle Loads
(ESALs), and Section B has an expected traffic capacity of 1,091,000 ESALs with the selected design input parameters.

Table 1 – Design Input Parameters

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA Wearing Layer Coefficient</td>
<td>0.43</td>
</tr>
<tr>
<td>HMA Leveling Layer Coefficient</td>
<td>0.43</td>
</tr>
<tr>
<td>Aggregate Base Coefficient</td>
<td>0.14</td>
</tr>
<tr>
<td>Subgrade Resilient Modulus</td>
<td>5,000 psi</td>
</tr>
<tr>
<td>Change in Serviceability</td>
<td>2.5</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.49</td>
</tr>
<tr>
<td>Reliability</td>
<td>90%</td>
</tr>
</tbody>
</table>

The City then evaluated three enhanced design scenarios for each of the standard sections:

- Maintain HMA and aggregate base course layer thicknesses, while adding a multi-axial geogrid to stabilize the aggregate base course
- Add the multi-axial geogrid while reducing the HMA and aggregate base course layer thicknesses slightly, so that the total unit construction cost of the section remains the same
- Add the multi-axial geogrid while reducing the HMA and aggregate base course layers further, so that the total unit construction cost of the section is as low as possible without a reduction in traffic capacity from the original standard section

Each scenario was evaluated using the same design input parameters that were used for the original sections. Table 3 presents the calculated layer thicknesses and traffic capacities for each scenario, as compared to the original sections.

METHODOLOGY FOR INCORPORATING GEOGRID BENEFIT

The analysis of the scenarios which included geogrid for stabilization of the aggregate base course was conducted in compliance with AASHTO methodology and guidance. This was a critical factor in the development of the City’s strategy, because the decisions to be made would affect the performance of its roads for years to come. The discussion below provides an explanation of the rationale for the approach used. Readers who are not well-versed in pavement design or who are primarily interested in the results of the analysis are invited to move to the next section.

The use of geogrid for the stabilization of unbound aggregate base layers in flexible pavements offers both performance advantages and design options that allow the designer to optimize the pavement section to the requirements of each specific project. The design of flexible pavement sections using geogrid is based on the increase in stiffness of a mechanically stabilized aggregate layer and reduced deterioration of stiffness over the design life of the pavement, as compared to a conventional unbound aggregate layer. The resulting performance improvement can be used by the designer to:

- Reduce the construction cost of a flexible pavement while delivering equivalent design life
- Dramatically increase the design life of a flexible pavement without increasing the thickness of the pavement section
• Optimize a flexible pavement design to the specific needs of the project by maximizing the design life for a given construction budget or section thickness.

The quantification of the performance of the mechanically stabilized layer (MSL) is the primary challenge in the development of appropriate methodologies for the use of geogrid in flexible pavement design. Because of the complexity of flexible pavement design and the extraordinary number of variables which can impact pavement performance, the reliable quantification of the performance of flexible pavements in general, and geogrid stabilized pavements in particular, is highly dependent on full-scale accelerated pavement testing.

AASHTO provides guidance on the use of geosynthetics in pavement structures. A Standard Practice document, AASHTO R50-09, provides clear direction on how to attribute performance benefit for any geosynthetic product in flexible pavement applications. It is important to note that unlike most other government bodies (State DOTs, County and Municipal agencies, for example), AASHTO has avoided the development of material property specifications for geogrid products in roadway applications. While material properties are often used in other applications to create generic specifications, this approach is not valid for pavement design applications because no correlation has been established between material index properties of any geosynthetic and performance benefit.

In Section 3 of the R50-09 document, AASHTO states that ‘Because the benefits of geosynthetic reinforced pavement structures may not be derived theoretically, test sections are necessary to obtain benefit quantification.’ In Section 5 of the same document, it is stated that design procedures ‘use experimentally derived input parameters that are often geosynthetic specific’ and ‘users of this document are encouraged to affirm their designs with field verification of the reinforced pavement performance.’ In the same document, AASHTO later states that ‘traffic benefit ratio (TBR) and base course reduction factor (BCR) are the parameters that need to be quantified through full-scale testing’.

The TBR is defined as the ratio of the traffic capacity of a geogrid stabilized section to the traffic capacity of an otherwise identical unstabilized section. From the earliest use of geogrid for pavement optimization, it was understood that TBR varies based on numerous factors, including subgrade resilient modulus, the thickness of aggregate and asphalt layers, and the quality of the aggregate base material. As early design methodologies were developed, a constant TBR was often attributed to a particular type or grade of geogrid, due to the lack of comprehensive data which would allow the variability of TBR to be characterized accurately. This approach was taken with the implicit understanding that the range of applicable pavement sections was limited, and it was incumbent upon the designer to account for these limits. While this was the best approximation that could be made based on the limited data available at the time, the best current design methodologies now account for the variation in performance benefit of geogrid in the flexible pavement section in response to varying design input parameters.

(In the FHWA (2008) Geosynthetic Design Manual, reference is made to an earlier version of the AASHTO (2009) document, AASHTO PP46-01. As AASHTO R50-09 remained unchanged from AASHTO PP46-01, it is therefore reasonable to conclude that the design procedure recommended by AASHTO retains the support of the FHWA.)

Over time, numerous full-scale empirical or accelerated pavement studies on geogrid performance have been conducted, which have greatly increased the data available across a broad spectrum of design conditions. As expected, this work has validated our understanding that TBR is not a constant for each geogrid type or grade, and the benefit gained from the MSL is
significantly influenced by a wide range of other factors. In order to accurately define geogrid performance across varying conditions, individual test ratios have been defined (based on control and stabilized sections containing the same materials and geometry), and are referred to as Traffic Improvement Factors (TIF). Conditions affecting each experimental TIF value include:

- Aggregate Quality and Layer Thickness
- Location of Geogrid
- Asphalt Quality and Layer Thickness
- Partially confined zone and fully confined zone of aggregate above the geogrid (MSL Stiffness)
- Subgrade strength or resilient modulus

In addition, the accumulated research tells us that TBR or TIF values greater than 6 fall outside the normal distribution of data, and must be treated with caution. High TBR values derived from empirical testing should not be interpreted as evidence that the stabilized pavement will have an infinite lifespan.

In the AASHTO 1993 empirical design formula (Equation 1 below), the predicted pavement life is a function of the structural number (SN), serviceability limits, and reliability. Pavement life using a geogrid is calculated from an enhanced SN based on the increased stiffness of the MSL. The “a” value of the geogrid-stabilized MSL is the key component of the enhanced SN value (Equation 2) that is calculated for the pavement section. The “a” value is representative of aggregate quality and degree of enhanced confinement achieved with a particular geogrid. Calibration and validation of this “a” value must be performed with an extensive catalogue of pavement structures (layer thicknesses & material types), subgrade conditions, and TIF data. Algorithms that are based on the “a” value calibrations have been created and incorporated into the design methodology and software used for analysis. The program automatically assigns the proper calibrated “a” value to the MSL for the user-defined input conditions.

\[
\log_{10}(W_{15}) = Z \Delta S + 9.36 \log_{10}(SN + 1) - 0.20 + \log_{10} \left( \frac{\Delta PSI}{4.2 - 1.5} \right)_{0.40 + \frac{1094}{(SN + 1)^{1.19}}} + 2.32 \log_{10} M - 8.07
\]

(Equation 1)

\[
SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3
\]

(Equation 2)

Where:
- \(a_i\) = layer coefficients representative of surface, base and subbase courses;
- \(D_i\) = actual thickness (in inches) of surface, base and subbase courses, and;
- \(m_i\) = drainage coefficients for base and subbase courses.

The TIF is converted to an appropriate modified layer coefficient for the Mechanically Stabilized Layer (MSL) within which the geogrid is incorporated, based on the results of full scale
testing. This approach more accurately accounts for the variable performance benefit (effective TIF values) associated with the enhanced confinement effect.

Layer coefficients presented in the AASHTO 1993 Design Manual for pavement materials are empirically derived correlations to material properties. As such, the layer coefficient is a measure of the relative ability of the material to function as a structural component within the pavement. The use of enhanced layer coefficients for MSLs is consistent with this approach. It is important to note that the new increased layer coefficient is not a reflection of the aggregate material alone, but is adjusted to account for the improved long-term performance due to inclusion of the geogrid, yielding a stiffened composite of aggregate and geogrid. In addition, current AASHTO correlations for the resilient modulus of a granular base layer and its layer coefficient are not valid for a composite material that consists of granular aggregate material and a stabilization geogrid.

Because of increased contact forces and stresses around the geogrid resulting from efficient aggregate confinement, stiffness compared to the unbound aggregate increases significantly and improves overall pavement performance. This increase in, and retention of, stiffness results in a reduction in the amount of rutting and increased fatigue life of the pavement.

**COST EVALUATION**

Once all the scenarios had been analyzed, the resulting pavement sections were compared on a unit cost basis. This analysis used the estimated unit prices shown in Table 2, which were estimated from previous years’ bid data.

<table>
<thead>
<tr>
<th>Table 2 – Estimated Unit Material Prices (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Unit Prices</td>
</tr>
<tr>
<td>HMA Wearing Course</td>
</tr>
<tr>
<td>HMA Leveling Course</td>
</tr>
<tr>
<td>21AA Limestone</td>
</tr>
<tr>
<td>Tensar TX5 Geogrid</td>
</tr>
<tr>
<td>Excavation / Disposal</td>
</tr>
</tbody>
</table>

Table 3 shows the calculated cost variances for the evaluated sections, and also includes the performance enhancement (improved traffic capacity) of the geogrid stabilized scenarios, allowing the comparison of the change in cost to the change in performance. The section geometries for the cost neutral and minimum construction cost scenarios were developed using analyses of multiple layer thicknesses to select the best option. Options were constrained by constructability considerations, for example, minimum aggregate thickness on geogrid of 150 mm (6 in.), and asphalt layer thicknesses in 13 mm (½ in.) increments.
Table 3 – Cost Variances for Evaluated Sections  
(Shaded cross sections were selected for use)

<table>
<thead>
<tr>
<th>Cross Section</th>
<th>HMA Thickness, mm (in)</th>
<th>Aggregate Thickness, mm (in)</th>
<th>Geogrid Stabilized?</th>
<th>ESALs</th>
<th>% Change in Performance</th>
<th>% Change, Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Standard, thin</td>
<td>102 (4)</td>
<td>203 (8)</td>
<td>No</td>
<td>138,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Original Standard, thin w/geogrid</td>
<td>102 (4)</td>
<td>203 (8)</td>
<td>Yes</td>
<td>742,000</td>
<td>+438%</td>
<td>+14%</td>
</tr>
<tr>
<td>Optimized, Cost Neutral</td>
<td>89 (3.5)</td>
<td>178 (7)</td>
<td>Yes</td>
<td>319,000</td>
<td>+131%</td>
<td>+2%</td>
</tr>
<tr>
<td>Minimum Construction Cost</td>
<td>89 (3.5)</td>
<td>152 (6)</td>
<td>Yes</td>
<td>205,000</td>
<td>+49%</td>
<td>-2%</td>
</tr>
<tr>
<td>Original Standard, thick</td>
<td>127 (5)</td>
<td>305 (12)</td>
<td>No</td>
<td>1,091,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Original Standard, thick w/geogrid</td>
<td>127 (5)</td>
<td>305 (12)</td>
<td>Yes</td>
<td>5,204,000</td>
<td>+377%</td>
<td>+9%</td>
</tr>
<tr>
<td>Optimized, Cost Neutral</td>
<td>114 (4.5)</td>
<td>254 (10)</td>
<td>Yes</td>
<td>2,295,000</td>
<td>+110%</td>
<td>-2%</td>
</tr>
<tr>
<td>Minimum Construction Cost</td>
<td>102 (4)</td>
<td>254 (10)</td>
<td>Yes</td>
<td>1,552,000</td>
<td>+42%</td>
<td>-8%</td>
</tr>
</tbody>
</table>

**SELECTED SECTIONS**

After reviewing the analysis presented above, the City decided to implement new standard sections that maintained the same layer thicknesses as the original sections, but with multi-axial geogrid added for stabilization of the aggregate base course. Figure 2 shows the new standard sections.
RESULTS AND LESSONS LEARNED

Over the past five years, the City has seen significant improvement in the performance of its flexible pavements where the new standard sections have been implemented, with fewer premature failures and reduced maintenance effort.

In addition, the actual costs of the new standard sections have increased less than anticipated by the cost analysis above, averaging around 5% more than the original standard sections. Table 4 shows cost information from available bid tabulations since the new standard sections were implemented.

### Table 4 – Geogrid Cost in New Standard Sections

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Total Geogrid Cost (low bidder)</th>
<th>Total Project Cost (low bidder)</th>
<th>Geogrid % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014 Streets</td>
<td>$11,088</td>
<td>$1,198,945</td>
<td>0.92%</td>
</tr>
<tr>
<td>2014 Roads 2</td>
<td>$17,962</td>
<td>$454,915</td>
<td>3.89%</td>
</tr>
<tr>
<td>2015 Streets</td>
<td>$80,920</td>
<td>$1,251,422</td>
<td>6.47%</td>
</tr>
<tr>
<td>Karim Blvd.</td>
<td>$26,910</td>
<td>$681,770</td>
<td>3.95%</td>
</tr>
<tr>
<td>Crescent Blvd.</td>
<td>$58,331</td>
<td>$1,874,417</td>
<td>3.11%</td>
</tr>
</tbody>
</table>

The implementation of such a change is rarely without a few lessons, and this case is no exception. Among the issues encountered and overcome as part of the program were the following:

- Contractors were initially unfamiliar with geogrid and how to install it properly. This problem disappeared over time as the firms who regularly build roads for the City became familiar with installation procedures.
- Both the City and its contractors had to adapt to construction staging that builds one half of the road at a time to maintain traffic, and they had to develop sequencing that allowed
for overlap of the geogrid at the centerline. Now they take this into consideration up front and account for it in their designs and bids.

- The City had to adapt procedures for utility trenching through pavement sections that were built using geogrid for stabilization. This is a routine procedure with geogrid stabilized pavements, and the geogrid manufacturer provided guidance to the City on proper procedures for trenching through the grid and backfilling the trenches.

FURTHER EVALUATION

While results to date have been extremely positive, a comprehensive understanding of the performance of the new standard pavement sections will be gained over time as the roads move through their life cycle. The authors intend to continue engagement with the City wherever possible moving forward, to further enhance knowledge of long term performance and identify new opportunities to implement improved technologies and processes.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Public Works and Engineering staff of the City of Novi, for their cooperation and assistance over the past five years in improving the performance of the City’s roads.

REFERENCES


