Performance of Aggregate Base Course Pavements in North Carolina

Judith Corley-Lay, Ph.D., PE *
Pavement Management Unit, NCDOT
1593 Mail Service Center
Raleigh, NC 27699-1593
919-212-6001
jlay@ncdot.gov

Jeffery Neil Mastin, PE
Pavement Management Unit, NCDOT
1593 Mail Service Center
Raleigh, NC 27699-1593
919-212-6020
jmastin@ncdot.gov

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ABSTRACT

North Carolina DOT owns and maintains a system of 79000 miles, which range from interstate to very low volume roadways. The state is rich in quarries, and aggregate base course has been a mainstay of paving for roadways on new location for many years. This paper uses the pavement management system (PMS) data to evaluate the performance of three categories of aggregate base pavements based on the thickness of hot mixed asphalt placed over the aggregate base: thin, mid-range, and thick.

Sections of pavement and their performance measures were pulled from the PMS by queries. Thin sections had asphalt thicknesses less than three inches. Mid-range sections had asphalt thicknesses of five to seven inches, and thick sections had asphalt thicknesses of more than nine inches. Aggregate base course thickness is generally eight inches, although six inches may be used on very low volume roadways. Aggregate thickness of 10 inches is common in the mountain region to avoid frost penetration into the subgrade.

Performance curves, graphs of pavement condition rating versus time, were generated for each section or group of sections. A polynomial curve of form $ax^2 + bx + c$, was fit to each curve and the time to reach a pavement condition rating (PCR) of 60 was calculated. Average, standard deviation, and histograms of the time to reach PCR of 60 was determined for each group. Time to PCR of 60 was highest for sections located in the coastal plain. The average times to PCR of 60 were 13.67, 15.2 and 14.03 years for the thin, mid-range and thick asphalt sections.

Key Words: pavement performance, aggregate base course pavements

INTRODUCTION

North Carolina has constructed thousands of miles of aggregate base course pavements, in part because of the presence of high quality aggregate over most of the state. Recently questions have been raised about the performance of aggregate base course pavements, as well as other pavements commonly used in the state.

The performance of aggregate base course pavements is also a topic for analysis in the Long Term Pavement Performance Specific Pavement Study 1. Hall and Crovetti (1) found that the weaker flexible pavements having dense graded aggregate base had higher percentages of cracking and higher initial roughness when compared to stabilized bases with or without drainage layers. An earlier effort by Ali and Tayabji (2) used the General Pavement Study 1 pavements to evaluate models for cracking, rutting and ride quality. Harvey, et al. (3) measured performance of drained and undrained flexible pavements in California using the Heavy Vehicle Simulator and found higher rates of cracking, but less rutting in undrained pavements with dense graded aggregate base. Work by Janoo and Bayer (4) evaluated the impact of aggregate angularity on base course performance, using resilient modulus and shear properties as measures of expected performance.
The effort reported here is based on performance as measured by the pavement condition rating and stored in the Pavement Management System. For purposes of comparison, the pavements were divided into three groups based on the thickness of hot mixed asphalt placed over the dense graded aggregate base course. Thin sections were those with hot mixed asphalt (HMA) thickness of less than three inches, mid-range were those with 5 to 7 inches of HMA, and thick were those with 9 or more inches of HMA. The gap between the thickness ranges was used to reduce the ambiguity of grouping a pavement with thickness of 8.95 differently from a thickness of 9 or similar issues at each breakpoint. These gaps also allow for variation in construction thickness within a particular section. The aggregate base course is generally 8 inches of compacted thickness, although six inches may be used for low volume roadways and 10 or more inches may be used in the mountains.

The three thickness groups are also a traffic volume indicator with the thin sections being common for low volume roadways and thick sections being high volume roadways. The sections are also located in all three major climatic and geotechnical regions of North Carolina: the coastal plain, the Piedmont, and the mountains. The three regions are shown on Figure 1. Where sufficient sections exist to compare regional performance, the sections were compared. There were only a few thick sections, and most are located in the Piedmont region, where most of the major cities in North Carolina are located.

The purpose of this report is to describe our evaluation process and compare the performance of aggregate base course pavements in North Carolina.

AGGREGATE BASE COURSE TYPICAL SECTIONS

The 1993 AASHTO Guide for Design of Pavement Structures defines a flexible pavement as one having either an asphalt surface or a surface treatment (5). The base course may consist of dense graded aggregate base course, hot mixed asphalt base course or cement treated aggregate base course. This paper is concerned with the actual performance of dense graded aggregate base course pavements. This monitoring of actual system performance is a fundamental part of integrated asset management, in the area of preservation of assets (6). Performance studies of other pavement types are ongoing in the Pavement Management Unit of NCDOT.

Figure 2 shows the cross sections for the three aggregate base course typical sections being evaluated. In all thickness ranges, the subgrade may be stabilized with either lime or cement if needed to reach required strength for service or construction. This subgrade stabilization would be uncommon for low volume roadways. It is very common for higher volume roads in the Piedmont region where subgrade soils tend to be clayey and moisture sensitive and where population growth is above the statewide average.

PAVEMENT CONDITION RATINGS AND PERFORMANCE CURVES

Pavement condition is obtained annually for interstates and every other year for the rest of the pavement system in North Carolina. For flexible pavements, deduction points are based on amount and severity of alligator cracking, transverse cracking, bleeding, edge
cracking, rutting, and patching, resulting in a pavement condition rating (PCR) between 0 and 100. Rating is done over a three month period by local maintenance engineers and bituminous supervisors following a refresher training class. Interstate pavement conditions are surveyed by four pavement area coordinators from the Pavement Management Unit. Biennial pavement condition surveys have been conducted since 1982 and results are stored in the Pavement Management System (PMS).

For pavements constructed on new location, the PCR immediately after construction (time 0) should be equal to or close to 100. Over time, the PCR should decrease as traffic loading and environment degrade the pavement. Eventually, a treatment will be applied to restore the surface or to provide additional pavement structure. This treatment will cause an increase in the PCR. The performance curve for a section used in this study began with a PCR at or near 100 and ended just prior to the jump in PCR associated with treatment. A typical performance curve, for a mid-range asphalt thickness pavement in Vance County, is shown in Figure 3. For this particular site, there were 5 segments along this route that were rated during each survey. When plotted in Figure 3, this results in a number of points above each year. An overall performance curve was fit for all the ratings for the five segments. If a rehabilitation treatment was applied to this roadway at year 12, the PCR would jump to a level close to 100 at the first survey following treatment.

Pavement condition rating is not done on projects when under construction. It may be that year 1 or year 2 is the first pavement condition rating following construction. Construction data was used to set the year=0 time.

Performance curves were developed for every section in the mid-range category and the thick HMA category. Multiple sections were grouped in the thin-pavement category, but at least one curve per county was developed, depending on the number of suitable sections in the county. A polynomial curve of the form $Ax^2 + Bx + C$ was fit to each curve. Several other curve forms were tried, but the polynomial fit most curves the best and was used for all with sufficient data.

**PERFORMANCE OF THIN SECTIONS**

Sixty performance curves were developed for aggregate base course pavements having three inches or less of hot mixed asphalt surfacing. The polynomials fit to these curves were used to calculate the time to reach a PCR of 60, the upper end of failing pavement condition. A PCR of 60 is the lowest PCR when light to moderate rehabilitation can be used to correct pavement defects. A histogram was constructed of time to reach PCR=60 which was used to develop a cumulative distribution function. Overall, the average time to reach PCR=60 was 13.67 years. Twenty percent of the sections had a time to PCR=60 greater than 18 years, and twenty percent of the sections had a time to PCR=60 less than 10 years. The frequency distribution and cumulative distribution function for thin HMA on aggregate base is shown in Figure 4.
When divided by region, only six sections were located in the coastal plain region. This region is most likely to have sandy or silty sand subgrade, flat grades, and high water tables. The region is also less densely populated than the Piedmont area. The average time to PCR=60 was 16.28 years. The Piedmont region had 38 thin HMA aggregate base performance curves. The average time to PCR=60 for the Piedmont sections was 13.5 years. The Piedmont region has the highest rate of change of traffic and increase in population. This region also has weaker and more moisture sensitive soils. The average time to PCR=60 for the 16 sections in the mountain region was 13.11. The mountain region has the most extreme winter weather in the state, and increased thickness of ABC is used to reduce risk of frost penetration to the subgrade. The cumulative distribution functions for the three climatic regions are shown in Figure 5.

**PERFORMANCE OF MID-RANGE SECTIONS**

Forty-six performance curves were generated for pavements consisting of five to seven inches of hot mixed asphalt over aggregate base course. As described for thin-HMA aggregate base course pavements, polynomials were fit to each performance curve and were used to calculate the time to PCR=60. The average time to PCR=60 for all pavements in the mid-range category was 15.2 years, or about 1.5 year longer than the thin sections.

The sections were also classified by region as noted in the thin-section discussion.

Average time to PCR=60 and standard deviation for each region is summarized below:

<table>
<thead>
<tr>
<th>Region</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Plain</td>
<td>18.75 yrs</td>
<td>10.1</td>
</tr>
<tr>
<td>Piedmont</td>
<td>13.97 yrs</td>
<td>9.08</td>
</tr>
<tr>
<td>Mountains</td>
<td>only two data points in this region.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 shows the cumulative distribution functions for the coastal plain and piedmont regions for mid-range asphalt thickness ABC pavements.

The time to PCR=60 was also grouped by construction era: 1980 to 1990 and 1990-2000. For sections constructed in the years 1980 to 1990, the average time to PCR=60 was 16.2 years. A much steeper cumulative distribution function was obtained for sections constructed between 1990 and 2000. The average time to PCR=60 for this group was 13.0 years. Figure 7 shows the cumulative distribution functions for the two time ranges for the mid-thickness HMA aggregate base course pavements. Only a few sections were available for construction after 2000, and they had insufficient time series data to develop meaningful performance curves.

Pavement condition survey traffic estimates were used to estimate the traffic for pavements in this category. Eighteen sites had sufficient data to make a growth rate estimate. The time since construction for the initial traffic estimate varied between 0 and 7, with more than half of the sections having an initial estimate of average daily traffic by year 2. The final traffic estimate also varied by section, and ranged from 5 to 11, with more than half of the sections having the final traffic estimate at 6 to 8 years from time of
construction. The average growth in ADT for the 18 sections was 13.29%. Half the sections had traffic growth rates between six and ten percent.

Two other measures were used to evaluate traffic growth in North Carolina. Figure 8 shows the vehicle miles traveled in North Carolina from 1980 to 2006 from the Federal Highway Administration annual Highway Statistics documents (7). Vehicle miles travelled increased by just over 20,000 million from 1980 to 1990, but by almost 30,000 million from 1990 to 2000. In 1992, the vehicle miles travelled was almost equal for urban and rural designations. Urban vehicle miles travelled has exceeded rural vehicle miles traveled since that year. Vehicle registrations are plotted for the same period in Figure 9. The dramatic increase in truck registrations demonstrates the heavy truck use of NC roadways during the late 1980’s to 2000. These changes in traffic levels and freight growth would contribute to the reduced “life” of pavements constructed after 1990.

PERFORMANCE OF THICK-HMA ABC PAVEMENTS

Seven sections having thick hot mixed asphalt over aggregate base course had sufficient data to develop a performance curve. Eleven other sections had the pavement type, but had only PCR=100 for all years. For example, at year 2, 120 of 124 data points, or 96.8 percent, had a PCR of 100. At 6 years, 85.6% had a PCR of 100. It was nine years before all data points were non-100, and then there were only seven data points. Two additional sections had only two years of data, not sufficient to develop a performance curve.

Figure 10 shows the performance curve for all thick sections combined. Several anomalous data points were deleted; those with time zero numbers significantly less than 100 and followed by a PCR higher than the time zero value. The trend-line polynomial expression indicates a time to PCR=60 of 14.03 years.

As should be expected, the thick pavement sections are located on interstate, US and NC routes. The average daily traffic for these sections was 14890 vehicles per day. Traffic growth rates were calculated from the traffic estimates included in the pavement condition survey. The average daily traffic growth rate for these thick HMA pavements over ABC was 10.9% per year.

PAVEMENT FAILURE MODES

A detailed look was taken at the pavement performance in the mid-range pavement sections to determine initial distress types and to look at dominant distresses as the pavement is progressing towards required rehabilitation or resurfacing.

Of 216 sections evaluated, 170 or 78.7% experienced fatigue cracking as the initial distress. Rutting was the second most common issue with 29 cases or 13.4%. All other distresses made up only 7.9% of the total. Raveling was present on one interstate pavement where the driving surface was open graded friction course.
Looking for the dominant distress as pavement deterioration progressed, 112 sections were sufficiently distressed to allow evaluation. Of these, 106 or 94.6% were controlled by fatigue cracking. Rutting controlled on 5 sections and transverse cracking on 1.

These results are consistent with observed behavior. On the whole, North Carolina experiences small amounts of significant rutting and the dominant mode of pavement failure is fatigue cracking.

CONCLUSIONS

North Carolina has had favorable performance from most aggregate base course pavements over a wide range of applications. Thin HMA sections over ABC are commonly used for local roads and had an average time to a pavement condition rating of 60 equal to 13.7 years. Climatic region had an effect on the time to failure for pavement with thin HMA over ABC: 16.3 years for the coastal plain, 13.5 years for the Piedmont, and 13.1 years for the mountains.

The mid-range thickness HMA over ABC pavements had an average time to PCR=60 of 15.2 years, or 1.5 years longer than the thin HMA ABC pavements. The mid-range pavements constructed between 1980 and 1990 had a time to failure of 16.2 years, compared to 13.0 years for those constructed between 1990 and 2000. Traffic levels and freight traffic increased dramatically after 1990 and may have contributed to the reduced life of pavements constructed after the high traffic growth period. It will be necessary to continue to monitor this pavement type and thickness range to see if this performance trend continues for construction after 2000.

Thick HMA over ABC has a very favorable performance with almost half of all data points showing a PCR of 100 after 7 years from construction. Many locations could not have a performance curve developed because of the high number of PCR=100 data points. When an overall performance curve was generated for all thick sites, a time to PCR=60 of 14.03 years was obtained. The thick asphalt layers result in reduced stresses at the bottom of the asphalt layers, slowing the formation of bottom-up fatigue cracking.

Pavement Condition Ratings and performance curves based on PCR can be used to evaluate pavement performance using a pavement management system. Data must be carefully screened to identify the time of a maintenance treatment. Otherwise, fitting of a polynomial may result in a curve that shows performance increasing over time. Even with careful screening, performance data is highly variable and not every available section will provide a suitable performance curve. Based on the results of this study, North Carolina will continue to construct aggregate base course pavements, and will continue to track their performance.
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