Minnesota Road Research Project

MnROAD
Automated Laser Profile System
“ALPS”

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December 2003

This report represents the results of research conducted by the authors and does not necessarily represent the view or policy of the Minnesota Department of Transportation. This report does not contain a standard or specified technique.
Abstract

This paper is a review of development of the Automated Laser Profile System (ALPS) designed for use at the Minnesota Road Research Project (MnROAD). The initial development was designed to replace the six-foot straight edge rutting measurements conducted on the hot mix asphalt test cells for both the mainline and low volume road (LVR).

This paper discusses not only the development of the equipment but also covers other possible uses of this equipment along with an initial comparison of the ALPS data compared to the six foot straight edge measurements at MnROAD.

The MnROAD site is located 40 miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments containing fifty-one 500-foot long distinct test cells constructed between 1990-1994. The 3 ½-mile Mainline Test Roadway (Mainline) is part of westbound interstate 94 and contains 31 test cells and carries an average of 20,000 vehicles daily. Parallel and adjacent to the Mainline is a Low Volume Roadway that is a 2 ½-mile-closed loop that contains the remaining 19 test cells. Traffic on the LVR is restricted to a MnROAD operated 18 wheel, 5-axle, tractor/trailer with two different loading configurations of 102kips and 80kips. Subgrade, aggregate base, and surface materials, as well as geometric design methods vary from cell to cell. Daily information is gathered via a computerized data collection system that monitors more than 4500 mechanical and environmental sensors.
INTRODUCTION
Summary
This paper is a review of development of the Automated Laser Profile System (ALPS) designed for use at the Minnesota Road Research Project (MnROAD). The initial development was designed to replace the six-foot straight edge rutting measurements conducted on the hot mix asphalt test cells for both the mainline and low volume road. This paper discusses not only the development of the equipment but also covers other possible uses of this equipment along with an initial comparison of the ALPS data compared to the six foot straight edge measurements at MnROAD.

The MnROAD site is located 40 miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments containing 51 500-foot long distinct test cells constructed between 1990-1994. The 3 ½-mile Mainline Test Roadway (Mainline) is part of westbound interstate 94 and contains 31 test cells and carries an average of 20,000 vehicles daily. Parallel and adjacent to the Mainline is a Low Volume Roadway that is a 2 ½-mile-closed loop that contains the remaining 19 test cells. Traffic on the LVR is restricted to a MnROAD operated 18 wheel, 5-axle, tractor/trailer with two different loading configurations of 102kips and 80kips. Subgrade, aggregate base, and surface materials, as well as geometric design methods vary from cell to cell. Daily information is gathered via a computerized data collection system that monitors more than 4500 mechanical and environmental sensors.

Mainline Test Road
The 3½-mile Mainline Test Roadway (Mainline) is part of westbound Interstate 94. The two-lane facility contains 31 test cells. The Mainline consists of both 5-year and 10-year pavement designs. The 5-year cells were completed in 1992 and the 10-year cells were completed in 1993. Originally, a total of twenty-three cells were constructed consisting of fourteen HMA cells and nine Portland Cement Concrete (PCC) test cells. In 1997, two SuperPave HMA test cells and six ultra-thin whitetopping concrete cells were added.

Traffic on the mainline comes from the traveling public on westbound I-94. Typically the mainline is closed once a month and the traffic is rerouted to the original interstate highway to allow MnROAD researchers to collect data and record test cell performance. The Traffic volume has increased 40% since the test facility first opened in 1994.

The mainline Equivalent Single Axel Loads (ESALS) are determined from two weigh-in-motion (WIM) devices located at MnROAD. This data is collected, shared and used to calculate the mainline ESALS, which are stored in the MnROAD database. An IRD Inc. hydraulic load scale was installed in 1989, East of the mainline test cells. In 2000, a Kistler quartz WIM was installed between two PCC cells #10 and cell #11.

Low Volume Road
Parallel and adjacent to the Mainline is the Low Volume Road (LVR). The LVR is a 2-lane, 2½-mile-closed loop that contains 20 test cells. Traffic on the LVR is restricted to a MnROAD operated vehicle, which is a typical 18-wheel, 5-axle, tractor/trailer with two different loading configurations. The "heavy" load configuration results in a gross vehicle weight of 102 kips (102K configuration). The "legal" load configuration has a gross vehicle weight of 80 kips (80K configuration). On Wednesdays the tractor/trailer
MnROAD Automated Laser Profile System (ALPS) operates in the 102K configuration and travels in the outside lane of the LVR loop. The tractor/trailer travels on the inside lane of the LVR loop in the 80K configuration on all other weekdays. This results in a similar number of ESALS being delivered to both lanes. ESALS on the LVR are determined by the number of laps (80 typical per day) for each day and are entered into the MnROAD database.

FIELD RUTTING
Need for a Updated Data Collection Method
The primary method used to determine maximum rut depth is a 6-foot straightedge, which has been used throughout the experiment since MnROAD started monitoring in July 1994. Drill bits are inserted under the straightedge to measure the maximum rut depth at each location. This measurement was made three times per year. In the early stages of MnROAD, rutting data was collected at two stations per test cell. This was increased to 10 stations per test cell in 1997 in order to study the variation of rut depth over the length of cell. This method is effective but time consuming not to mention physically demanding on the data collection personnel. It also only provided researchers with the maximum rutting in each wheel path. It was not able to determine what the offset for the maximums, what the volume was, or how much water the rut would hold using the cross slope. In order to save time and collect the additional information Mn/DOT developed the ALPS system. This system will also allow MnROAD to collect other data than rutting which includes transverse crack cupping for hot mix asphalt pavements (crack depression around the cracked area) to lane/shoulder drop-off, faulting, and curl & warping for concrete pavements.

DESCRIPTION OF THE ALPS EQUIPMENT
The equipment was researched and assembled using Mn/DOT personnel at the MnROAD facility in the summer of 2003. Three pictures (Images 1,2,3) are attached in the appendix along with (Table-1), which contains the part description, 2003 costs, manufacturer, and vendors used. The cost of the equipment came to $10,000 but this does not include our labor, lawn tractor, laptop computer, or $1,000 contract needed to customize the data collection software. This software was needed to coordinated the equipment into a working “system”, make it easy to use, and to customize the data collection into a EXCEL spreadsheet.

Laser Specifications
The first and foremost the laser had to be able to provide reliable data from both black asphalt and light colored concrete pavements in bright sunlight. Secondly, it needed to have a working range (distance from laser to ground) that would allow the measurement of the cross slope of the roadway along with the rutting. Other considerations were the ability to work in a 12 Volt environment, variable scanning rate, software interfacing and finally cost. The Acuity Research AR600-6RP was the one selected. It met all of the specifications required. The laser was modified by the manufacturer especially for road profiling by increasing the laser output from 5 to 20 milliwatts. We also added filtering to reduce the effect of ambient light. The laser is able to collect data in the range from 7 to 13 inches. The operating voltage is from 12 to 24 VDC. The laser has a programmable scan rate of up to 1250 samples per second. A software interface library of commands was available for easy interface into C, C++, Visual Basic and Visual Basic for Applications. The whole package came at a cost significantly less than any other manufacturer at the time of purchase.
**Drive Motor Specifications**

The original plan to move the laser across the beam with a simple 12 Volt motor with no regulation at all. After more consideration of how the measurement spacing was going to be accomplished, it was decided to use either a stepping motor or a servomotor. The final decision was made with the help of Lee Alexander of the University of Minnesota Intelligent Transportation Studies (ITS) lab. The Kollmorgan motor and servo controller were both units that could also be used as replacement devices for the ITS’s Safetruck project or the ALPS equipment, so this method was selected over other possible methods. The combination provided a constant reliable motor speed needed to maintain the proper measurement spacing for data collection. By varying the motor speed and the laser scan rate, any data collection sampling or spacing can be accomplished.

**Data Format**

MnROAD had many options on what form the data could be collected and stored. It was decided to collect the data every quarter of an inch (1/4") over the length of the 14-foot beam. The actual data collection of the laser is 12 foot 10 inches (12’10") after everything was assembled on the beam. This resulted in 616 data points collected for each pass of the laser during data collection. The distance of travel also allowed some other lane and shoulder overlap when collecting rutting data at MnROAD because it contains 12-foot lanes. Table-2 shows the data that is collected in the EXCEL field data collection and entered into the MnROAD database. It also shows the database structure and how the field names are defined.

Figure 1 shows the orientation of the data we are collecting at MnROAD. This allows the ALPS system to collect any type of data and place it into the MnROAD database in one database table. We defined the orientation of the X-Y-Z as the following:

- X is the offset in feet from the centerline where negative is in the driving lane and positive is in the passing lane for the mainline.
- Y is the distance in feet describing the stationing of the roadway. The station is defined at the center of the beam and is the same for rutting/drop-off measurements but will change if faulting or cupping measurements are done.
- Z is the laser data measurement in inches. Negative is defined below the beam/laser.

**FIELD DATA COLLECTION**

**Rutting Measurements**

Rutting measurements were the primary purpose of the ALPS equipment. Rutting measurements are conducted by centering the ALPS beam on the lane in question. This beam is stationary while testing is conducted. MnROAD uses two paint marks, on which the two ALPS beam supports are placed. This insures that the 12 foot 10 inch beam collects 5 inches on both the other lane and the shoulder. The beam then is leveled (see Figure-8) and the data collection is started from the EXCEL spreadsheet. This orientation sets the X as the offset from the centerline, Y is the station of the roadway (consistent), and the Z is the laser readings in inches. Figure-2 shows the typical data collected for rutting. It also shows the 16-point smoothing of the data needed to analyze the data to develop the comparisons between the ALPS data and the straight edge data collected. This is covered in the comparison later in this report.
Lane Shoulder Dropoff Measurements
Lane shoulder dropoff measurements can also be collected using the ALPS, but MnROAD has not developed the anaysis tools to work with the data to date. This is accomplished by centering the ALPS beam on the dropoff. The beam is leveled and the data collection is started. This orientation sets the X as the offset from the centerline, Y is the station of the roadway (consistent), and the Z is the laser readings in inches. (Figure-3) shows the typical data collected for this drop-off.

Faulting/Cupping Measurements
Faulting and transverse cracking cupping measurements can also be collected using the ALPS, but MnROAD has not developed the analysis tools to work with the data to date. This is accomplished by centering the ALPS beam on the joint or fault. The beam is leveled and the data collection is started. This orientation sets the X as the offset from the centerline (consistent), Y is the station of the roadway (+6 to –6 feet on the beam), and the Z is the laser readings in inches. (Figure-4) shows the typical data collected for a typical cupped transverse crack.

Comparisons of ALPS and Straight Edge Rutting
Rutting comparisons were done in August 2003. The ALPS data was collected along with the 6-foot straight edge at the same time. The ALPS data was then analyzed by using a macro in EXCEL that smoothes the data and simulates straight edges on the inside and outside wheel paths (See Figure 2). The data is smoothed using a 16-point moving average. The simulated straight edge procedure is conducted as follows:

1. Start at the center point of the pavement (X_OFFSET_FT = 0).
2. Locate the point with the highest elevation (maximum Z_DATA_IN value).
3. Define a line with slope = 0 and intercept = maximum Z_DATA_IN value.
4. Reduce the slope by 0.001 increments and cycle through the elevation data until a point within the range (3.0 < X_OFFSET_FT < 8.0) intersects the line.
5. Adjust the intercept if any point on the straight edge is below the pavement elevation at the corresponding offset.
6. Cycle through the elevation data to find the maximum perpendicular distance from the straight edge (rut depth).
7. Simulate a second straight edge from the center of the lane to the outside edge of the pavement.

The Visual Basic for Applications (VBA) code and EXCEL spreadsheet can be obtained by contacting the authors. This will insure users of the current version.

In general, the processed ALPS data showed greater rut depths than the straight edge data (see Figures 5 and 6). There are several possible reasons for this discrepancy:

1. Edge effects: There may be a ridge at the center of the pavement due to a pavement surface treatment that was completed prior to the measurements. This may affect the ALPS measurements, but the straight edge operator avoided this ridge. An attempt was made to minimize this effect by starting the data analysis at the zero point specified by the ALPS operator. Future measurements will be improved by instructing the ALPS operator to set the zero point inside of any unusual edge formation.
2. Increment for straight edge measurements: The straight edge data is measured by selecting the largest drill bit that can easily fit beneath the straight edge and the pavement. The size increment for the drill bits is 0.031 in. (0.79 mm). If the space between the straight edge and the pavement is only slightly less than a given drill bit, the next size down will be selected. This will result in an error of nearly 0.031 in. (0.79 mm).

3. Straight edge wearing: The straight edge used is made of aluminum, and over time the edges that contact the pavement wear down. This wearing can reduce the rut measurement by up to 0.063 in. (1.6 mm) before the straight edge is inverted or replaced.

4. Indentations: The ALPS device will detect indentations in the pavement that may not be detected by a drill bit inserted under a straight edge.

The average discrepancy between the ALPS and straight edge rut measurements is 0.066 in. (1.7 mm), and 95 percent of the ALPS measurements exceed the straight edge measurement by less than 0.16 in. (4.1 mm). These discrepancies will undoubtedly improve with refinements in the ALPS collection and analysis methods. Mn/DOT will continue to develop the ALPS method as a possible replacement for manual straight edge measurements.

We plan to continue collecting 6-foot straight edge measurements next spring for an additional comparison along with multiple ALPS data collection per stationing to study its repeatability.

Summary
This report covered the development of the testing equipment and some of the initial analysis of rutting measurements. The ALPS compared well to 6-foot straight edge measurements when each measurement type and equipment was reviewed. ALPS measurements tend to be greater than straight edge measurements due to:

1. Edge effects.
2. Increment for straight edge measurements.
3. Straight edge wearing.
4. Indentations.

Even with these differences we are satisfied with the results of the comparison and will develop other analysis tools to analyze other characteristics of the ruts. These include offset to the maximum rutting, rut volume, and water-holding volumes using the cross slope. We also will start work to develop tools to analyze other types of measurements such as crack cupping, faulting, lane-shoulder drop-off, and possible curl and warp concrete panel measurements.
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### Table 1 – Part Description, Cost, Vendors

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<th>Part Description</th>
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### Table 2 – MnROAD ALPS Database Table (DISTRESS_ALPS_DATA)

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Figure 1 – Roadway Orientation Used at MnROAD

Orientation Definitions

X  Offset in feet from the centerline. Negative is in the driving lane and positive is in the passing lane for the mainline.

Y  Distance in feet describing crack cupping or faulting. Note the STA is centered on the beam at roughly 6-foot distance in the Y direction.

Z  Laser data measurement in inches.

Figure 2 – ALPS “Rutting” Data
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