Cross Slope Collection using Mobile Lidar

ACEC/SCDOT Annual Meeting

December 2, 2015
Adequate cross slopes on South Carolina Interstates result in:

- Proper drainage
- Enhance driver safety by reducing the potential for hydroplaning.

SCDOT is seeking to have an efficient method for collecting interstate cross slope data so that an accurate and comprehensive cross slope database can be maintained.

Mobile Scanning to collect accurate cross slope data on South Carolina interstates.

- save over 90% of the cost on cross-slope verification
- reduce four to six months of contract time for each interstate rehabilitation project.
Research Approach

- Comprehensive technical and economic evaluation of multiple mobile scanning systems in terms of the accuracy and precision of collected cross slope data
- Procedures to calibrate, collect, and process this data.

Project team

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- Dr. Brad Putman
- Dr. Ronnie Chowdhury, P.E.
- Dr. W. Jeffrey Davis

Department of Civil Engineering
Clemson University

The Citadel

South Carolina Department of Transportation
Objectives

1. Perform technical and economic comparisons of the alternative mobile scanning technologies and conventional survey methods for cross slope verification

2. Establish a validation site that contains tangent and curve sections using traditional survey methods that may then be used to qualify mobile scanning vendors;

3. Establish SCDOT guidelines for testing procedures and data delivery for the vendor rodeo and ultimately statewide data collection; and

4. Provide a survey of the cross slope and other related geometric properties for the entire interstate system in South Carolina with the selected technology which is suitable for future reference on projects.
Typical Cross-slope

Relatively flat pavement cross-slopes of less than one percent (1%) are prone to creating unacceptable water depths. Cross slopes that are too steep can cause vehicles to drift and become unstable when crossing over the crown to change lanes.

A normal cross slope in South Carolina is 2.08 percent with some exceptions depending on the number of lanes.
Hydroplaning

- Hydroplaning is a phenomenon that occurs when a vehicle traveling at high speed basically floats on a film of water covering the roadway.

- When the tires lose contact with the road surface, the vehicle may not be controlled by the driver.

A water depth of 0.15 inches can lead to hydroplaning for a passenger vehicle.
Factors that contribute to hydroplaning:

- Driver
- Vehicle
- Environment
- Pavement Surface (geometry, condition, drainage)

Roadway factors affecting water depth accumulation on the road surface include:

- depth of compacted wheel tracks
- pavement micro texture
- pavement macro texture
- pavement cross-slope
- Grade
- width of pavement
- roadway curvature and longitudinal depressions.
• **Cross Slope**
  Facilitates / hampers drainage

• **Grade**
  Affects drainage path (DP)

• **Rutting**
  Increases water retention
Traditional Survey Methods for Collecting Cross slope

- Slow and labor intensive
- Expose crew to hazardous conditions
- Require traffic control
- Cause inconvenience to traveling public
- Costly
Automated Survey Methods

- Fast (highway speed)
- Safe (no traffic control required)
- Efficient (simultaneous data collection)
- Cost-Effective
The SCDOT’s cross slope verification specification is included in the Supplemental Specification updated on November 16, 2009

Contractor is responsible for obtaining the existing cross slope data
- collecting elevation data for the edge of each travel lane
  - Even 100-ft stations in tangents
  - Even 50-ft stations in curves.

Elevation data shall be recorded in accordance with the *SCDOT Preconstruction Survey Manual* (2012) to the nearest 0.01 ft.
The elevation data shall be collected at the edge of each travel lane at

1. minimum of one random location every 300 ft. in tangent sections

2. beginning and end of super elevation, flat cross slopes within the super elevation transition, and beginning and end of maximum super elevation

3. cross slopes at beginning and end of bridges.
The SCDOT has two acceptable tolerance levels for cross slopes:

✓ **Tolerance Level 1**: ± 0.00174 ft/ft (± ¼ in over 12 ft or ± 0.174%) of the design cross slope

✓ **Tolerance Level 2**: ± 0.00348 ft/ft (± ½ in over 12 ft or ± 0.348%) of the design cross slope

When final measurements is:

- **Within Tolerance Level 1**: no pay adjustments for the work.
- **Outside of Tolerance Level 1**: either corrective measures may be required at the contractor’s expense or a pay reduction will be assessed to the work.
- **outside of Tolerance Level 2**: the work will either be corrected at the contractor’s expense or work will be subject to a pay reduction.

**SCDOT's cross slope verification specification**

THE CITADEL
South Carolina Department of Transportation
These guide specifications provide a template that can be adopted by state DOTs when developing or modifying their pavement performance specification documents.

the SHRP2 guide specification includes a target value of \( \pm 0.2\% \) of the design value for the final measurement after project completion.
AASHTO PP70-10 recommend the following minimums:

- Interval between transverse profiles
  - < 10-ft for network-level collection
  - < 1.5-ft for project-level collection.

- The transverse profile width
  - > 13-ft for distress detection
  - > 14-ft if edge drop-off is desired.

- The data points in the transverse profile are to be no more than 0.4-in apart.
- The resolution of the vertical measurements is to be no greater than 0.04-in.
The cross slope specifications in many states are similar to those of the SCDOT with most having a single tolerance level of approximately 0.2% from the design cross slope. While the specifications may be similar, the methods used to measure the cross slope do vary.

<table>
<thead>
<tr>
<th>State</th>
<th>Method</th>
<th>Frequency</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>Electronic level with a length of 4-ft and accuracy of 0.1°</td>
<td>Tangents: 100-ft</td>
<td>± 0.2% (average deviation) and ± 0.4% (individual deviation) for tangent and superelevation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superelevation: 100-ft</td>
<td></td>
</tr>
<tr>
<td>Alabama</td>
<td>Straight edge 10-ft long</td>
<td>Not specified</td>
<td>± 0.3% for tangents and superelevations</td>
</tr>
</tbody>
</table>

**Note:**
- For tangents and superelevation in Florida, tolerances are given for both average and individual deviation.
- In Alabama, the tolerance is specified for both tangents and superelevations, but not in a table format.
Automated Survey Methods

Typical Components
Position and Orientation System (POS)

- Differential Global Positioning System (DGPS)
- Inertial Measurement Unit (IMU)
- Distance Measurement Indicator (DMI)
- POS Computer
Inertial Measurement Unit (IMU)

- Generates tilt, roll and yaw data
- 3 accelerometers
- 3 gyroscopes
Distance Measuring Indicator (DMI)

- Linear distance referencing
POS Computer

- Data storage and processing
Automated Mobile Transverse Profile Data Collection Methods

Stand Alone Gyroscope System
Vehicle mounted subsystem that utilizes a combination of gyroscopes that record vehicle pitch, roll, and heading at traffic speeds. The data collected from the gyroscopes can be interpreted by accompanying software to determine pavement cross slope at approximately 13-ft intervals.

Other systems combine sensitive gyroscopes and accelerometers to collect precise vehicle roll data. When this data is coupled with GPS and a supplemental distance measurement system, the transverse profile data can be used to determine the pavement cross slope at rod and level accuracy.
Benefits

1. SCDOT saves millions of dollars on interstate rehabilitation projects by adopting the mobile scanning technology instead of conventional surveying

2. **Preconstruction** – could accurately estimate material quantities for potential interstate rehabilitation

3. **Construction** – reduces potential disagreement between contractors and the Department

4. **Finance** – better cash flow projection with more accurate material quantities and project duration

5. **Surveyor** – no longer needs to step into interstate traffic

6. **Legal/Contracts** - reduce the risk of tort liabilities of SCDOT arising from non-standard cross-slopes

7. **All** - Provides data for other uses such as safety analysis, drainage modeling, pavement design
Multi-Purpose Survey Vehicle (MPSV)

- Inertial Profiling System
- Position and Orientation System (POS)
Inertial Profiling System

- Three height laser sensors
- Two accelerometers
- Distance Measurement Indicator (DMI)
- Automatic Trigger System
Automated Cross-Slope Analysis Program (ACAP)

- Imports MPSV data
- Calculates cross-slope, grade, rutting, distance
- Calculates drainage path length
- Generates outputs (tabular and graphical)
MPSV Cross-Slope Precision

- Repeatability: 0.06%
- Accuracy: ± 0.13 %
Short-Term Preventive Action
Short-Term Preventive Action
Short-Term Solution
Holgado-Barco et.al. (2014) extracted road geometric parameter through the automatic processing of mobile LIDAR system (MLS) point cloud.

Their methodology was carried out in different steps.
1. data capturing.
2. segmentation, which is to simplify the point cloud to extract the road platform.
3. Applying principal component analysis (PCA)-based on orthogonal regression to fit the best plane on points.
4. extracting vertical and cross section geometric parameter and analysis.

The experiment results validate the method within relative accuracies under 3.5%
Tsai et al. (2013) proposed mobile cross slope measurement method, which used emerging mobile LIDAR technology.

The proposed method instruments:

- Emerging mobile LIDAR system
  - (Reigl LMS-Q 120i)
- High resolution video camera
  - (Point Grey Gras-50S5C)
- Accurate positioning system
  - (Applanix LV 210PP) composed of Global Positioning System (GPS), an inertial measurement unit, and distance measurement instrument.
Data Acquisition with LIDAR

Region of Interest Extraction

Tsai et al. (2013)
The results showed the proposed method achieved desirable accuracy:

- Maximum difference of 0.28% cross slope (0.17°)
- Average difference of less than 0.13% cross slope (0.08°) from the digital auto level measurement.
- Standard deviations within 0.05% (0.03°) at 15 benchmarked locations in three runs.

The acceptable accuracy is typically 0.2% (or 0.1°) during construction quality control.

The case study on I-285 demonstrated that the proposed method can efficiently conduct network-level analysis. The GIS-based cross slope measurement map of the 3-miles section of studied roadway can be derived in fewer than 2 person hours with use of the collected raw LIDAR data. Front pointing laser is multi-purpose.

Tsai et.al. (2013)
Sourleyrette et al. (2003) attempted to collect grade and cross slope from LIDAR data on tangent highway sections.

The measurements were compared against autolevel data collection for 10 test sections along Iowa Highway 1.

The physical boundaries of shoulders and lanes were determined by visual inspection from (a) 6-in resolution ortho-photos

(b) 12-in ortho-photo by Iowa DOT

(c) triangular irregular network (TIN) from LIDAR.
Multi linear regression analysis was taken to fit the plane to the LIDAR data corresponded to each analysis section.

- Grade on pavement surface was calculated to within 0.5% for most sections, and within 0.87% for all sections.

- On shoulder sections, grade was calculated within 1% of the surveyed value.

- Cross slope estimation from LIDAR was deviated from field measurement by 0.72% to 1.65%. model.
Zhang and Frey (2012) tried to model the road grade using LIDAR to estimate the vehicles emissions.

- The LIDAR data have been used to fit a plane using regression techniques.
- The pilot case study was divided in different segments, which slope is constant.
- A plane fit to the roadway surface on each roadway section using bivariate linear regression.
Jaakkola et al. (2008) discussed that laser-based mobile mapping is necessary for transportation study due to the huge amount of data produced.

- The data was collected with the Finnish Geodetic Institute (FGI) Roamer mobile mapping system (MMS).

Part of the point cloud
The authors classified the points belonging to the painted marking on the road, then they found the curbstones from the height of the image.

Finally, they modeled the pavement as a TIN.

The proposed method was able to find most curbstones, parking spaces, and zebra crossing.

Due to intensity image, it was often unclear where the edge should be, therefore part of the error could be caused by the ambiguousness of the line edges in the reference data.
Awuah-Baffour et al. (1997) applied GPS to conduct high-speed surveys of roadway alignment, grade, and cross slope. Predecessor to LIDAR.

- Only a single lane of data can be collected at a time.
- Sensitive to roadway imperfections because of the high center of gravity.
- Problems with bridges.
- Data collected at 1 second intervals.
Gathering precise positional data is corresponded to
- roadway measurement
- differential correction with GPS base station at fixed points.

Large volume data can be collected in a short period of time while a data collection vehicle travel in the highways

Comparison of GPS and surveying grade data collection
All of the data collected were compared with a standard data set collected using conventional surveying.

The cross slopes were collected in 50’ intervals, and the accuracy was at +/-1%.
Potential Benefit Over LIDAR is that extensive post-processing is not required to acquire cross slope data.

Problem with using a dual RTK GPS system is loss of lock when traveling under bridges.

An inertial device doesn’t have this problem.

LIDAR can collect data over multiple lanes with a single pass.
Clemson’s Mobile Laboratory
Clemson’s Mobile Laboratory

Before there was Street View
Clemson’s Mobile Laboratory

Where are we?
Clemson’s Mobile Laboratory

Hint
LIDAR vs. Field Survey

GeoDigital LIDAR data on all restricted access roads around the state.
GeoDigital LIDAR data collection on US 123
LIDAR
Field surveying cross slope data collection

13 ft
## LIDAR vs. Field Survey

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<th>Point ID</th>
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<th>FS</th>
<th>Height (Vertical Distance)</th>
<th>Slope Distance</th>
<th>Horizontal Distance</th>
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LIDAR vs. Field Survey

LIDAR DATA

FIELD SURVEY
LIDAR vs. Field Survey
## LIDAR vs. Field Survey

### Clemson - Easley

Sign 1 - Guide Sign - Station 34+31

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### LIDAR

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**Field Survey**

-3.0%  
-3.17%  
-0.67%  
1.83%  
1.17%  
0.5%

**LIDAR**

-2.08%  
1.3%
### Clemson - Easley

**Sign 2 - SPEED LIMIT - Station 38+51.71**

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### LIDAR

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**LIDAR vs. Field Survey**

**CL**

-3.0%  -1.33%  -0.5%  -1.17%  -9%

-0.92%  -1.75%

**Field Survey**

**LIDAR**

-1.08%  -1.91%
## LIDAR vs. Field Survey

### Clemson - Easley

**Sign 3 - MILE POST - Station 44+19.98**

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### LIDAR

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### Field Survey

- **CL**
  - -4%
  - -1.5%
  - -0.83%
  - -2.5%
  - -4%

### LIDAR

- **CL**
  - -1.33%
  - -2.17%
## Field Survey vs. LIDAR

### Clemson - Easley

**Sign 4 - Guide Sign - Station 44+68.43**

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<tr>
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### LIDAR

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**LIDAR vs. Field Survey**

- **CL:**
  - Field Survey: -3%  -1.5%  -1.0%  -1.83%  -2.5%  -3%
  - LIDAR: -1.42%  2.25%

---

**Images:**

- The Citadel
- South Carolina Department of Transportation
- Clemson University
### LIDAR vs. Field Survey

#### Clemson - Easley

**Sign 5 - SPEED LIMIT - Station 45+92.41**

<table>
<thead>
<tr>
<th></th>
<th>TAPE</th>
<th>ROD</th>
<th>HEIGHT</th>
<th>SLOPE (6 FT)</th>
<th>SLOPE (12 FT)</th>
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<tbody>
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<tr>
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<tr>
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<tr>
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<tr>
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#### LIDAR

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</tbody>
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**Field Survey**

- CL: -3.0% -1.5% -0.33% -1.5% -2.3% -3.5%

**LIDAR**

- CL: -1.16% -2.0%
## LIDAR vs. Field Survey

### Clemson - Easley

**Sign 6A - GUIDE SIGN - Station 57+39.43**

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**LIDAR**

<table>
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### Field Survey vs. LIDAR

**Diagram:**

- **Field Survey:**
  - CL: 4.5%, 6.5%, 8.0%
  - SLOPE: -8.2%, -9.0%, -10.4%

- **LIDAR:**
  - CL: 6.41%, -8.08%
Potential Rodeo Site
LIDAR has great potential for Asset Management activities.

- Horizontal and vertical alignment of highways
- Cross section details (besides cross slope)
- Guard rail, cable rail, barrier, clear zone and other safety aspects.
- Bridge characteristics
- Curb and gutter
- Signs
- *Pavement marking retroreflectivity*
How does it work?

- Influencing factors – size, shape, embedment, wearing, etc.
30 Meter Observation Distance Geometry
LIDAR has great potential
Is it too much of a good thing?

• Processing point clouds is tedious and time consuming
• Intensity/amplitude attribute information is critical for extracting useful information in an efficient (and possibly automated manner)
• Breaklines are needed for preconstruction and major rehab projects
Thank you