US 67 CORRIDOR MASTER PLAN

APPENDIX L

FEBRUARY 2020

US 67 CORRIDOR
MASTER PLAN

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Memorandum

To: *Rebecca Reyes, TxDOT Project Manager*
Christopher Weber, TxDOT Alpine Area Engineer

From: *CDM Smith*

Date: *February 2020*

Subject: *US 67 Corridor Master Plan Mobile LiDAR Survey Procedure and Findings*

1.0 Introduction

The purpose of this technical memorandum is to describe the Mobile Light Detection and Ranging (LiDAR) field survey methodology performed along the US 67 study corridor. This memorandum summarizes the field activities and Mobile LiDAR survey findings.

The US 67 corridor stretches 142 miles from Interstate 10 (I-10) west of Fort Stockton to the Presidio/Ojinaga Port of Entry (POE) on the United States (U.S.)/Mexico border. **Figure 1** shows the study corridor.

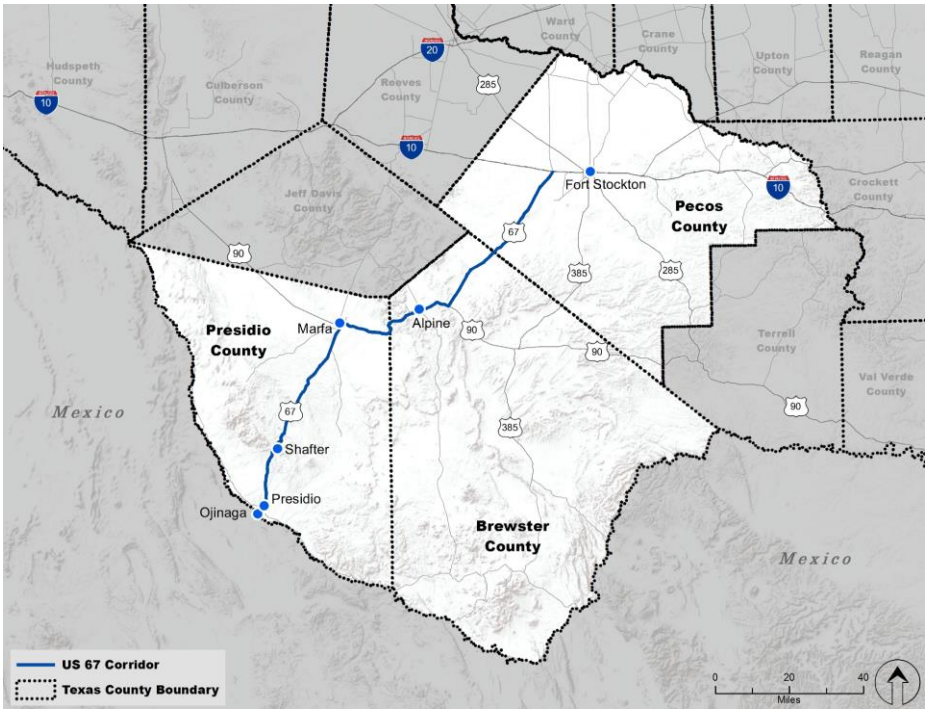

Figure 1: US 67 Corridor Master Plan Study Corridor

This rural area has experienced traffic growth in recent years driven by many factors including tourism growth, international commerce, and Permian Basin oil field development. In response to these trends, the Texas Department of Transportation (TxDOT), in partnership with communities, is developing a Corridor Master Plan for US 67 to help determine current and future corridor transportation needs.

The study objectives are focused on enhancing efficiency, safety, and mobility along the corridor by recommending transportation projects and strategies for short-, mid-, and long-term implementation.

LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system— generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.[1] The Mobile LiDAR is an innovative mobile mapping solution that is safe and an ideal tool for the collection of transportation corridor infrastructure requiring an extraordinary level of detail and accuracy.

The Mobile LiDAR system incorporates a state-of-the-art LiDAR sensor, capable of 1.1 million points per second, and eight video cameras to provide full 360° coverage. Two of the eight cameras include a downward-facing camera focused on pavement, and one upward-facing camera to collect information beneath bridge decks and other overhead structures. All mobile imagery was georeferenced to the point cloud and used in combination with the Mobile LiDAR for accurate asset identification. Together, the Mobile LiDAR sensor, eight cameras, and high precision positional/navigational equipment collect rich data for asset inventories and design-grade mapping—at highway speeds.

The Mobile LiDAR technology used on this project produces a LiDAR point cloud containing up to 4,000 points per square meter, compared to aerial LiDAR containing approximately 20-25 points per square meter. This enhanced point density enables LiDAR technicians to accurately extract crown and edge of pavement information – used in calculating guardrail, cross slope, and superelevation information.

The remainder of this document is divided into the following sections:

- **Section 2** – Mobile LiDAR Survey Methodology
- **Section 3** – Mobile LiDAR Survey Findings

[1] National Oceanic and Atmospheric Administration. National Ocean Service. *What is LiDAR?*. Retrieved July 2019 from https://oceanservice.noaa.gov/facts/lidar.html

2.0 Mobile LiDAR Survey Methodology

The Mobile LiDAR data acquisition procedure consisted of the following steps described below:

- Mission planning
- Mobile LiDAR data acquisition
- LiDAR data processing
- LiDAR data extraction
- Quality Assurance and Quality Control (QA/QC)

2.1 Mission Planning

Gorrondona & Associates, Inc. (G&AI) (a Study Team firm) Mobile LiDAR manager reviewed the US 67 study corridor and determined the most optimal location for setting the Global Positioning System (GPS) Continuous Operating Reference Stations to support data processing. Weather conditions were also observed to ensure that precipitation was not present on the roadway, which could cause voids in the data. Using a Mobile LiDAR data collection van, the LiDAR data was collected in April 2019.

2.2 Mobile LiDAR Data Acquisition

The G&AI Mobile Lidar collection team compiled LiDAR data along the 142-mile US 67 corridor. LiDAR data was captured in both directions utilizing a Leica Pegasus: Two – 3D Laser Mapping (3DLM) System, which includes a Z+F Profiler 9012 Laser Scanner collecting 1.1 million points at 200 rps (revolutions per second). The Mobile LiDAR system uses eight digital cameras of which the frame rate is adjustable. During Mobile LiDAR data acquisition, one GPS Continuous Operating Reference Station, within 18 miles of the data compilation location, was recorded at a minimum of five-second epochs to provide supplemental GPS needed for LiDAR data processing. The mobile LiDAR system captured data at the posted speed limits. The data was compiled over a three-day period initially for the whole US 67 study corridor. G&AI returned to the study site for a fourth day due to the identification of poor data from the initial data acquisition near Presidio.

2.3 LiDAR Data Processing

Once LiDAR data was acquired, it was processed from the system and converted to .las files. LiDAR data was transferred upon review and post-field processing for further processing. Further steps taken to process the LiDAR data include:

1. Extract Inertial Measurement Unit (IMU) data and .las files
2. Review .las files for completeness
3. Calibrate the Point Cloud data
4. Verify the Point Cloud data to a relative control within LiDAR Point Cloud

5. Translate all data to the required coordinate system
6. Georeference images to the point cloud
7. Reclassify the data to combine the LiDAR data
8. Finally, the required feature line elements are extracted to a MicroStation (.dgn) file format.

2.4 LiDAR Data Extraction

The .dgn file obtained from LiDAR data processing was utilized to extract guard fence, guardrail end treatments, and cross slope data at 100-feet intervals along the US 67 study corridor. The cross slope data was extracted from road centerline to 12-feet out on each direction and to the edge of the pavement. **Figure 2** illustrates the cross slope data extracted from the Mobile LiDAR data acquisition process. All the .dgn files were converted to shapefiles and placed into a geodatabase (gdb).

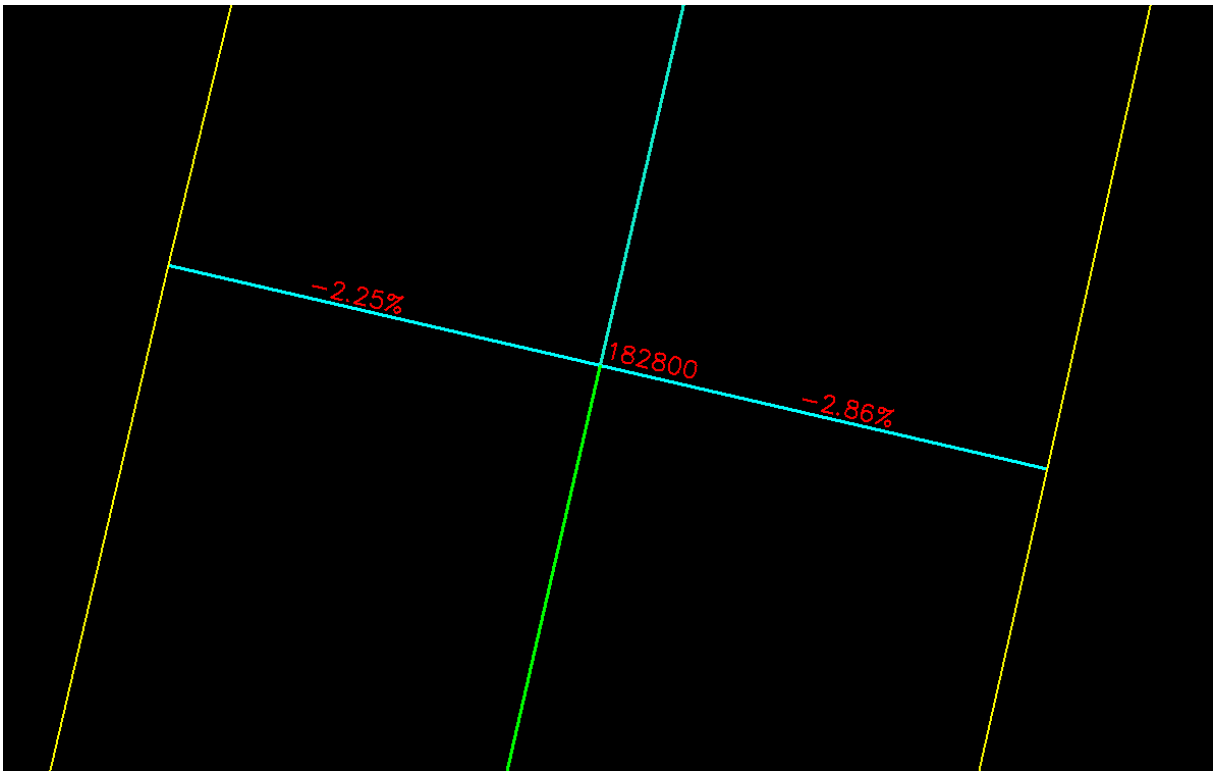

Figure 2: Typical Cross Slope with Stations

2.5 Quality Assurance and Quality Control (QA/QC)

In order to review the cross slope and superelevation rates, contours were used as a visual reference. **Figure 3** and **Figure 4** represents the contours used for the quality assurance process. The different

colors illustrated in **Figure 3** and **Figure 4** represent the contour elevations at every one-foot interval. The 142-mile corridor dataset was reviewed to determine any anomalies.

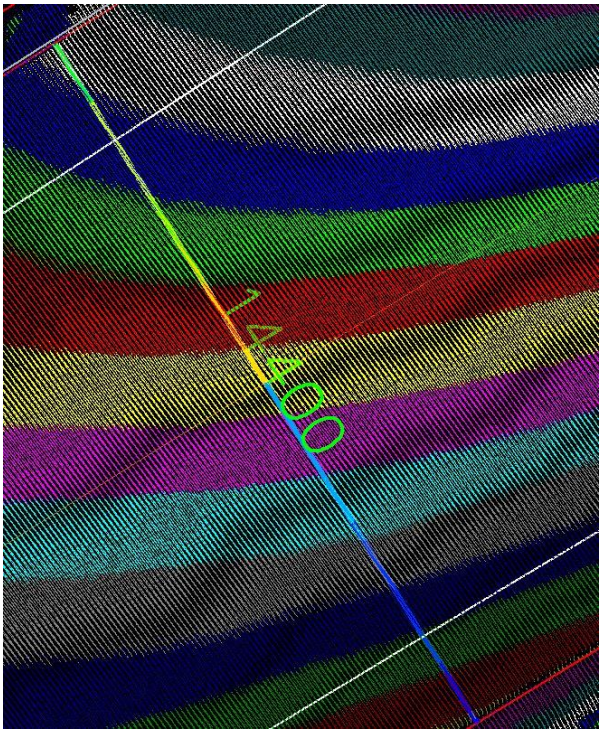

Figure 3: Typical Contours for QA/QC

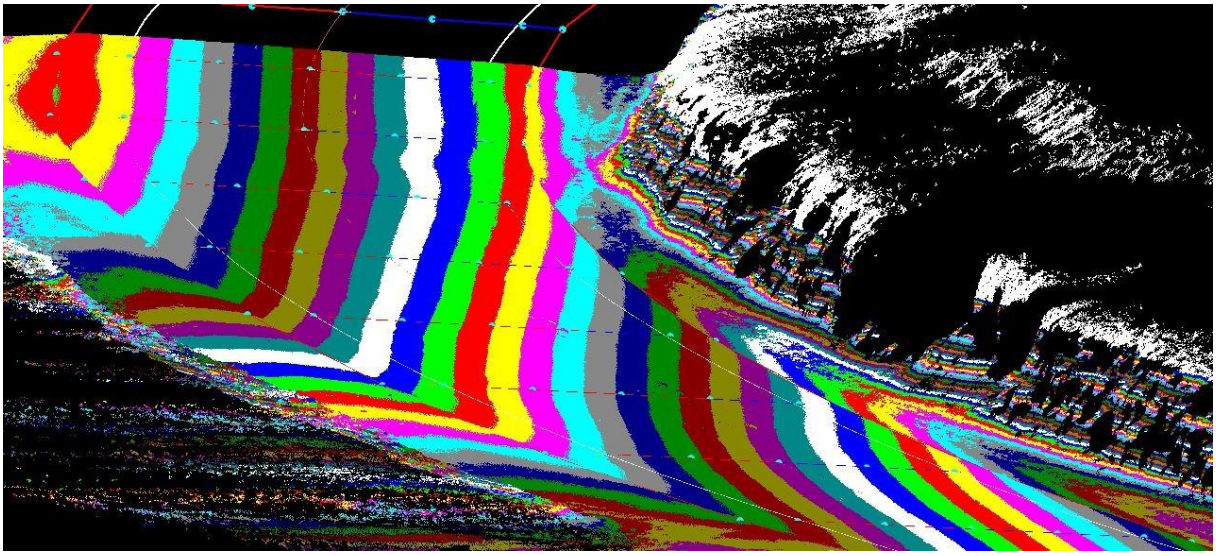

Figure 4: Typical Contours for QA/QC

3.0 Mobile LiDAR Survey Findings

The .dgn file extracted from LiDAR data processing was used to review guardrail, cross slope, and superelevation information for the US 67 corridor. They are discussed in detail in the following sections.

3.1 Guardrail Analysis

Based on the Mobile LiDAR survey data, the US 67 corridor has a total guardrail length of 82,261 feet. There are 370 guardrail end treatments installed along bridges, culverts, steep side slopes, and rocky edge risks. There are 210 Sequential Kinking Terminal (SKT) 350, 99 ET Plus, 54 Turndown, 3 Driveway Terminal Anchor Sections, and 4 Downstream Anchor Terminal guardrail end treatments along the corridor. An electronic copy of the ArcGIS shapefiles was provided to TxDOT including the guard fence and guardrail end treatments located along the US 67 corridor.

3.2 Cross Slope Analysis

The Mobile LiDAR survey reported cross slopes along the US 67 study corridor at 100-feet intervals. The locations of cross slopes with less than 2 percent grades were identified using ArcGIS shapefiles following two-step process described below:

Step 1:
Data were selected from ArcGIS shapefile using the following location criterion:

1. Segment slope value > 2.25 percent or < 2.25 percent
   Segment slope value attribute in the shapefile represents pavement cross slope at each station (100-feet interval). The scope of work required identifying locations where pavement cross slope is steeper than a normal crown of 2 percent. A tolerance of 0.25 percent was used based on engineering judgment to eliminate any inaccuracies during the LiDAR data acquisition process.
2. Segment length (Shape_Length in shapefile) > 10 feet
   Each station in shapefile has at least four cross slope segments. Typically, the width of a single travel lane is 12 feet. The 10 feet criterion was used to exclude shoulders and other small segments from the LiDAR data.
3. The curves along the US 67 study corridor were identified from the as-builts provided by TxDOT. Cross slopes within the curve were excluded from cross slope analysis.
4. The cross slope segments that met the above criteria were then exported to an excel spreadsheet.

Step 2:
For cross slope analysis, using engineering judgment, at least five continuous stations (500 feet) with cross slope described in **Step 1** were selected from the excel spreadsheet.

The following assumptions were used in the process:

- Each selected station has at least one segment with cross slope described in Step 1.
- If all of the selected segments at a station were located on the shoulder, they were excluded.
- In general, segments were excluded if they are in or near the existing curves to avoid superelevation transition and superelevation grades.

Using **Steps 1** and **2**, the locations with deficient cross slopes were identified. The locations with deficient cross slope are mentioned below in this memo by their corresponding station number shown in ArcGIS shapefile. The US 67 study corridor segmentation shown in **Figure 5** was used to present the deficient cross slope locations in this tech memo. It should be noted that the segments mentioned above (at each station) are different from the overall segments 1 to 7 described in **Figure 5**. An electronic copy of the ArcGIS shapefiles provided to TxDOT includes deficient cross slope locations.

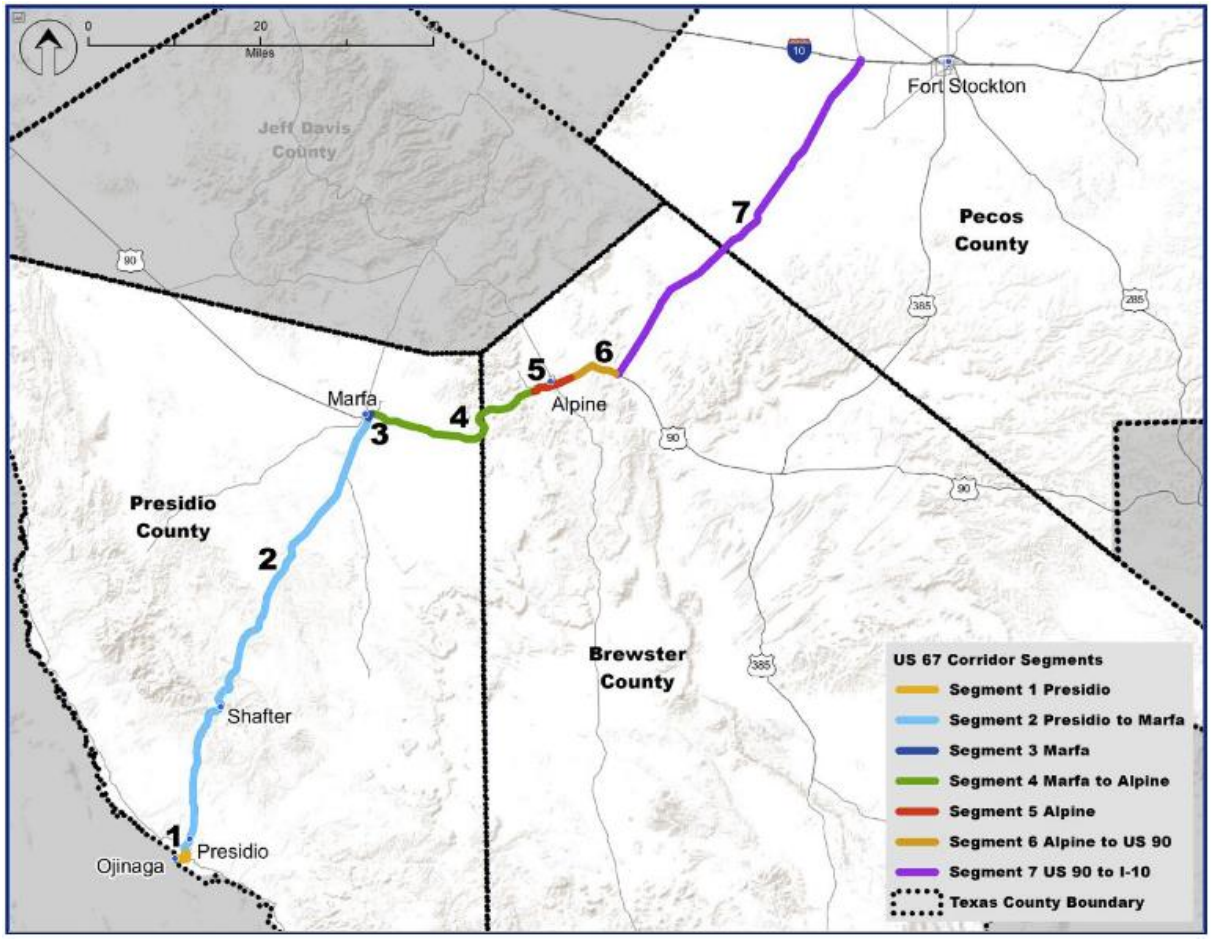

Figure 5: US 67 Corridor Segments

3.2.1 Segment 1 Presidio: (US 67 within Presidio city limits)

Based on the criteria in **Steps 1** and **2**, no qualifying stations are present in this segment, as the deficient cross slopes are either located on shoulders, or the continuous deficient cross slope stations are less than 500 feet.

3.2.2 Segment 2 Presidio to Marfa: (US 67 between Presidio city limits and Marfa city limits)

The stations with deficient cross slopes are listed in **Table 1**.

Table 1: Stations with deficient cross slope in Segment 2

From Station	To Station	Length (feet)
20+00	**26+00**	600
1916+00	**1924+00**	800
1931+00	**1936+00**	500
2759+00	**2771+00**	1,200

3.2.3 Segment 3 Marfa: (US 67 within Marfa city limits)

Based on the criteria in **Steps 1** and **2**, no qualifying stations are present in this segment, as the deficient cross slopes are either located on shoulders, or the continuous deficient cross slope stations are less than 500 feet.

3.2.4 Segment 4 Marfa to Alpine: (US 67 between Marfa city limits and Alpine city limits)

The stations with deficient cross slopes are listed in **Table 2**.

Table 2: Stations with deficient cross slopes in Segment 4

From Station	To Station	Length (feet)
243+00	**249+00**	600
277+00	**283+00**	600
1196+00	**1208+00**	1,200

3.2.5 Segment 5 Alpine: (US 67 within Alpine city limits)

The stations with deficient cross slopes are listed in **Table 3**.

Table 3: Stations with deficient cross slopes in Segment 5

From Station	To Station	Length (feet)
6+00	**33+00**	2,700
78+00	**90+00**	1,200
201+00	**248+00**	4,700

3.2.6 Segment 6 Alpine to US 90: (US 67 between Alpine city limits and the east US 90/US 67 interchange)

The stations with deficient cross slopes are listed in **Table 4**.

Table 4: Stations with deficient cross slopes in Segment 6

From Station	To Station	Length (feet)
64+00	**72+00**	800
304+00	**310+00**	600

3.2.7 Segment 7 US 90 to I-10: (US 67 from US 90/US 67 interchange east of Alpine to I-10)

The stations with deficient cross slopes are listed in **Table 5**.

Table 5: Stations with deficient cross slopes in Segment 7

From Station	To Station	Length (feet)
106+00	**111+00**	500
417+00	**429+00**	1,200
646+00	**670+00**	2,400
1242+00	**1248+00**	600
2058+00	**2143+00**	8,500

3.3 Superelevation Analysis

Superelevation analysis was performed for 112 horizontal curves along the US 67 study corridor to identify the curves that do not meet the present minimum required superelevation rate based on the TxDOT Roadway Design Manual, April 2018.

Superelevation is the amount of cross slope provided on a horizontal curve to counterbalance, in combination with the side friction, the centrifugal force of a vehicle driving through the curve. As a vehicle drives through a horizontal curve, centrifugal force is counter-balanced by the vehicle weight due to roadway superelevation and by the side friction between tires and road surface. There are practical limits to superelevation. Too much superelevation can create steering problems for drivers traveling at lower speeds, particularly during ice or snow conditions. According to the TxDOT Roadway Design Manual, for urban freeways and rural highways, maximum superelevation rates of 6 to 8 percent are generally used and serve as the basis for the superelevation analysis along the corridor.

The superelevation rates along the curves within the project were obtained from the following two sources:

1. Mobile LiDAR Survey data

2. TxDOT provided TIN file

The data from the above two sources were compared with e_{max} = 8 percent presented in the TxDOT Roadway Design Manual, Table 2-7.

The LiDAR data presented the rate of superelevation on the curve on an ArcGIS shapefile to the left and right side of the centerline of the roadway. These two values were averaged, and that value was used to compare with the minimum required superelevation from TxDOT Roadway Design Manual.

Based on the above criteria, and review of the LiDAR data, it was concluded that out of the 112 curves, 89 curves do not meet the minimum required superelevation standards and can be considered for potential improvements.

As noted in the US 67 Corridor Master Plan Safety Analysis Technical Memorandum (**Appendix D – Safety Analysis**), superelevation analysis was performed for the 112 curves based on the TxDOT provided TIN file, curve radius, and speed. It was concluded that out of the 112 curves, 88 curves do not meet the minimum required superelevation standards and can be considered for potential improvements.

Out of the 88 curves identified in the Safety Analysis Technical Memorandum, 85 curves match with the curves identified on the LiDAR superelevation analysis that do not meet the minimum superelevation requirements.

Table 6 presents the 89 curves that do not meet the minimum superelevation requirements from LiDAR superelevation analysis. An electronic copy of the ArcGIS shapefiles provided to TxDOT includes the 89 curves that do not meet the minimum superelevation requirements based on the LiDAR data superelevation analysis.

Table 6: Curves with Deficient Superelevation from LiDAR data Superelevation Analysis

			A	B	C=(A+B)/2	D	E=C-D
Curves	**Radius[2] (feet)**	**Length[2] (feet)**	**Existing Super LHS[3,4]**	**Existing Super RHS[4,5]**	**Average Super[6]**	**Min. Super Req.[7] (emax = 8%)**	**Difference**
0104-06-C2	5,730	1,400	2.70%	3.30%	3.00%	3.60%	-0.60%
0104-06-C3	5,730	2,350	3.40%	3.10%	3.30%	3.60%	-0.30%

[2] Curve Radius and Curve Length are obtained from TxDOT provided as-builts.

[3] Existing Superelevation of the curve on the Left-Hand Side (LHS) of the road centerline.

[4] The roadbed side (LHS/RHS) is based on traveling on US 67 corridor from Presidio/Ojinaga Port of Entry (POE) on the United Stated (U.S.)/Mexico border to the Interstate 10 (I-10) west of Fort Stockton.

[5] Existing Superelevation of the curve on the Right-Hand Side (RHS) of the road centerline.

[6] Average Superelevation of the curve.

[7] Minimum Superelevation Required on the curved based on TxDOT Roadway Design Manual Table 2-7.

Table 6: Curves with Deficient Superelevation from LiDAR data Superelevation Analysis (continued)

			A	B	C=(A+B)/2	D	E=C-D
Curves	Radius[2] (feet)	Length[2] (feet)	Existing Super LHS[3,4]	Existing Super RHS[4,5]	Average Super[6]	Min. Super Req.[7] (emax = 8%)	Difference
0104-07-C1	5,730	1,453	3.00%	3.40%	3.20%	3.60%	-0.40%
0104-07-C2	2,865	1,252	5.50%	5.20%	5.30%	6.40%	-1.10%
0104-07-C3	1,433	900	6.20%	8.60%	7.40%	8.00%	-0.60%
0104-07-C4	1,433	1,273	8.20%	7.10%	7.60%	8.00%	-0.40%
0104-07-C5	1,910	781	6.30%	5.90%	6.10%	8.00%	-1.90%
0104-07-C6	1,433	435	4.80%	5.90%	5.30%	8.00%	-2.70%
0104-07-C7	2,865	923	4.40%	4.70%	4.50%	6.40%	-1.90%
0104-07-C8	2,865	772	3.90%	4.10%	4.00%	6.40%	-2.40%
0104-07-C9	5,730	952	3.50%	2.80%	3.10%	3.60%	-0.50%
0104-07-C12	1,433	660	5.80%	6.10%	6.00%	8.00%	-2.00%
0104-07-C13	2,865	817	4.70%	5.60%	5.10%	6.40%	-1.30%
0104-07-C14	2,865	1,028	5.20%	5.20%	5.20%	6.40%	-1.20%
0104-07-C15	2,292	2,362	6.10%	5.50%	5.80%	7.40%	-1.60%
0104-07-C17	5,730	572	2.80%	3.60%	3.20%	3.60%	-0.40%
0104-07-C18	1,433	651	6.00%	6.40%	6.20%	8.00%	-1.80%
0104-08-C1	5,730	875	2.80%	3.40%	3.10%	3.60%	-0.50%
0104-08-C2	1,146	840	7.30%	5.40%	6.30%	8.00%	-1.70%
0104-08-C3	1,910	1,185	5.50%	5.70%	5.60%	8.00%	-2.40%
0104-08-C4	2,865	612	4.30%	4.50%	4.40%	6.40%	-2.00%
0104-08-C5	1,146	629	5.50%	5.70%	5.60%	8.00%	-2.40%
0104-08-C6	1,433	688	5.50%	5.70%	5.60%	8.00%	-2.40%
0104-08-C7	1,146	1,917	5.90%	5.70%	5.80%	8.00%	-2.20%
0104-08-C8	1,910	554	6.20%	6.20%	6.20%	8.00%	-1.80%
0104-08-C9	1,433	750	5.90%	6.60%	6.30%	8.00%	-1.70%
0104-08-C10	1,146	879	6.60%	6.60%	6.60%	8.00%	-1.40%
0104-08-C11	1,274	793	5.90%	6.60%	6.20%	8.00%	-1.80%
0104-08-C12	1,274	778	6.10%	6.40%	6.30%	8.00%	-1.70%
0104-08-C13	1,274	453	5.60%	5.90%	5.80%	8.00%	-2.20%
0104-08-C14	1,146	813	6.10%	6.30%	6.20%	8.00%	-1.80%
0104-08-C15	1,433	346	6.80%	5.60%	6.20%	8.00%	-1.80%

Table 6: Curves with Deficient Superelevation from LiDAR data Superelevation Analysis (continued)

			A	B	C=(A+B)/2	D	E=C-D
Curves	Radius[2] (feet)	Length[2] (feet)	Existing Super LHS[3,4]	Existing Super RHS[4,5]	Average Super[6]	Min. Super Req.[7] (emax = 8%)	Difference
0104-08-C17	1,910	1,236	6.10%	6.20%	6.10%	8.00%	-1.90%
0104-08-C18	1,146	1,238	6.80%	6.00%	6.40%	8.00%	-1.60%
0104-08-C19	1,274	524	6.70%	6.00%	6.40%	8.00%	-1.60%
0104-08-C20	1,433	626	5.90%	4.90%	5.40%	8.00%	-2.60%
0104-08-C21	1,433	377	6.30%	6.10%	6.20%	8.00%	-1.80%
0104-08-C22	1,433	514	5.70%	6.00%	5.80%	8.00%	-2.20%
0104-08-C23	1,274	880	6.10%	5.30%	5.70%	8.00%	-2.30%
0104-08-C24	1,433	548	6.10%	5.70%	5.90%	8.00%	-2.10%
0104-08-C25	1,146	709	6.20%	5.60%	5.90%	8.00%	-2.10%
0104-08-C26	1,433	1,007	6.40%	5.60%	6.00%	8.00%	-2.00%
0104-08-C27	2,865	314	4.00%	4.50%	4.20%	6.40%	-2.20%
0104-08-C28	2,865	719	4.00%	4.10%	4.00%	6.40%	-2.40%
0104-08-C29	1,910	1,014	5.60%	5.70%	5.60%	8.00%	-2.40%
0104-08-C30	2,865	674	4.20%	3.60%	3.90%	6.40%	-2.50%
0104-08-C31	2,865	1,055	3.50%	3.90%	3.70%	6.40%	-2.70%
0104-08-C32	1,274	995	5.40%	5.70%	5.60%	8.00%	-2.40%
0104-08-C33	1,910	1,583	5.20%	6.50%	5.80%	8.00%	-2.20%
0104-08-C34	1,433	542	5.60%	5.90%	5.80%	8.00%	-2.20%
0104-09-C1	1,433	703	5.00%	6.20%	5.60%	8.00%	-2.40%
0104-09-C2	5,730	875	3.30%	2.30%	2.80%	3.60%	-0.80%
0104-09-C3	1,433	675	5.60%	5.80%	5.70%	8.00%	-2.30%
0104-09-C4	1,910	492	5.60%	5.50%	5.50%	8.00%	-2.50%
0104-09-C5	1,433	613	6.10%	6.10%	6.10%	8.00%	-1.90%
0104-09-C6	2,865	700	5.00%	4.60%	4.80%	6.40%	-1.60%
0104-09-C7	5,730	717	2.80%	3.20%	3.00%	3.60%	-0.60%
0104-09-C8	5,730	1,425	3.20%	3.30%	3.20%	3.60%	-0.40%
0104-09-C9	5,730	1,642	2.40%	3.30%	2.80%	3.60%	-0.80%
0104-09-C10	5,730	1,677	3.30%	2.80%	3.00%	3.60%	-0.60%
0104-09-C11	5,730	1,612	2.20%	1.60%	1.90%	3.60%	-1.70%
0104-09-C12	1,910	1,111	6.20%	6.50%	6.30%	8.00%	-1.70%
0104-09-C14	1,910	1,947	6.00%	6.00%	6.00%	8.00%	-2.00%
0020-08-C1	2,651	187	5.60%	5.70%	5.70%	6.80%	-1.10%
0020-08-C2	2,901	1,025	6.00%	6.20%	6.10%	6.40%	-0.30%

Table 6: Curves with Deficient Superelevation from LiDAR data Superelevation Analysis (continued)

			A	B	C=(A+B)/2	D	E=C-D
Curves	**Radius[2] (feet)**	**Length[2] (feet)**	**Existing Super LHS[3,4]**	**Existing Super RHS[4,5]**	**Average Super[6]**	**Min. Super Req.[7] (emax = 8%)**	**Difference**
0020-08-C3	2,881	1,826	6.10%	6.10%	6.10%	6.40%	-0.30%
0020-08-C4	2,892	1,154	2.50%	3.40%	3.00%	6.40%	-3.40%
0020-08-C6	2,865	1,457	2.00%	2.00%	2.00%	6.40%	-4.40%
0020-08-C8	2,972	489	5.20%	6.00%	5.60%	6.20%	-0.60%
0020-08-C10	2,547	1,459	7.00%	5.70%	6.30%	7.00%	-0.70%
0020-08-C11	2,868	1,026	5.10%	5.90%	5.50%	6.40%	-0.90%
0020-08-C12	2,855	1,716	3.50%	4.00%	3.80%	6.40%	-2.60%
0020-08-C13	3,234	1,897	3.50%	4.50%	4.00%	5.80%	-1.80%
0020-09-C1	1,910	2,311	6.90%	8.10%	7.50%	8.00%	-0.50%
0020-11-C1	3,820	3,059	4.20%	3.40%	3.80%	5.20%	-1.40%
0020-11-C2	2,865	639	5.90%	5.80%	5.80%	6.40%	-0.60%
0020-11-C3	6,876	3,480	2.00%	1.80%	1.90%	3.00%	-1.10%
0020-11-C4	5,730	995	2.70%	3.40%	3.10%	3.60%	-0.50%
0020-11-C6	2,865	1,572	5.60%	5.40%	5.50%	6.40%	-0.90%
0020-11-C7	5,730	892	1.90%	2.60%	2.30%	3.60%	-1.30%
0075-01-C1	5,730	1,469	3.20%	2.20%	2.70%	3.60%	-0.90%
0075-01-C2	2,865	1,254	4.40%	5.40%	4.90%	6.40%	-1.50%
0075-01-C3	2,865	790	4.10%	4.90%	4.50%	6.40%	-1.90%
0075-01-C4	5,730	977	3.20%	2.90%	3.10%	3.60%	-0.50%
0075-01-C5	5,730	344	3.60%	2.00%	2.80%	3.60%	-0.80%
0075-02-C4	2,865	2,839	6.20%	6.30%	6.30%	6.40%	-0.10%
0075-02-C5	2,865	2,037	5.50%	6.10%	5.80%	6.40%	-0.60%
0075-03-C5	5,730	1,802	3.40%	3.40%	3.40%	3.60%	-0.20%
0075-03-C7	5,730	848	2.40%	2.40%	2.40%	3.60%	-1.20%

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