Safety Evaluation of Sinusoidal Centerline Rumble Strips

Task 5: Supplemental Data Collection Procedures

Prepared by:

Eric T. Donnell
Professor

Vikash V. Gayah
Professor

Prakash Poudel
Doctoral student

Department of Civil and Environmental Engineering
The Pennsylvania State University
217 Sackett Building
University Park, PA 16802

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INTRODUCTION

The Montana Department of Transportation maintains crash data and several roadway inventory data elements in electronic datafiles which, when merged together, form the database to be used to evaluate the safety effectiveness of sinusoidal centerline rumble strips. However, several site-specific variables that have been shown in past research to be associated with crash frequency or severity are not included in the electronic roadway inventory files. As such, the research team proposes to supplement the existing roadway inventory data with additional data elements that are available via alternative sources.

The objective of this task is to describe the supplemental data collection plan, including the elements to be collected, the source(s) used to collect the elements, and the procedures for compiling each data element. Supplemental data elements will be added to the existing electronic data files to form a more robust database to evaluate the safety performance of sinusoidal centerline rumble strips in Montana.

SUPPLEMENTAL ROADWAY DATA ELEMENTS

The supplemental data elements are safety-influencing features that past research has indicated may be associated with crash frequency or severity. These variables were not included in Montana roadway inventory files and are proposed to be collected using alternative sources, such as video photologs or satellite imagery. The proposed supplemental data elements were identified in the Task 2 Data Collection and Analysis report. These data elements and the source/tools to be used for data collection purpose are summarized in Table 1.

Table 1. List of supplement data elements to be used for data collection

Data Element	Source	To be collected (Yes/No)
Shoulder type	MDT geodatabase file	Yes
Paved shoulder width	MDT geodatabase file	Yes
Curve length, radius and degree of curvature	ArcGIS Pro, Civil 3D, Google Earth Pro	Yes
Presence of centerline rumble strips	Google Earth Pro	Yes
No. of driveways	Google Earth Pro	Yes
Roadside Hazard Rating (RHR)	---	No
Presence of 'Curve Warning' sign	Pathpoints Videolog / Google Earth Pro	Yes
Presence of 'Stop Ahead' sign	---	No
Presence of 'Signal Ahead' sign	---	No
Presence of 'Turn Lane'	---	No

A process to collect each of these data elements was reviewed and discussed with the MDT project panel on July 8, 2024. During this meeting, the panel recommended collecting current paved shoulder width data using a supplemental electronic file, which MDT provided. The panel also recommended omitting the RHR variable from the supplemental data collection process due to its subjectivity. In addition, the presence of "Stop Ahead" or "Signal Ahead" signs and the presence of turn lanes will not be collected because these signs and turn lanes are typically located near intersections where sinusoidal centerline rumble strips are typically not present or are in segments that may be classified as urban areas or locations with posted speed limits of 45 mph or lower.

The following sections describe the sources used to collect the supplemental data, the elements collected using each source, and offer illustrative examples of the data collection procedure. The supplemental data elements will be appended to existing crash and roadway inventory data, to form the safety analysis database for the sinusoidal centerline rumble strips evaluation.

Source: MDT Geospatial Data Files

Data on the presence of shoulder rumble strips will be extracted from the MDT geodatabase file. The information on paved shoulder width was provided by MDT in .csv format, which was extracted from the 'route segment plan' data file. For the purposes of this project, it will be assumed that the paved shoulder width remained unchanged throughout the analysis period. The rumble strip and shoulder width data files contain milepost information corresponding to the start and end points of the rumble strip or shoulder widths. These files will be merged with other roadway inventory data provided by MDT using the route ID and milepost details.

Source: ArcGIS Pro and Civil 3D

Horizontal curve geometry information will be obtained by extracting geospatial data from shapefiles of Montana roadways using ArcGIS Pro and Civil 3D software. Both the radius (or degree of curvature) and the length of each horizontal curve will be collected at the segment level. If a segment has no curve or the entire curve falls within it, this will be noted in the analysis files. For curves that cross into other segments, the length of the curve within each segment will be recorded in the analysis database.

Simple circular curves connect two tangent road segments with an arc of constant radius. Spiral curves, also known as transition curves, connect tangents to simple circular curves, but the spiral curves on either end of the simple curve have a continuously-changing radius, in order to provide a smooth transition between the tangent and simple curve segments. Figure 1 illustrates the difference between a simple circular curve and a spiral curve. Equations 1 and 2 illustrate how the "degree of curvature" is calculated when no spirals are present and when they are present.

For simple circular curves:

$$\text{Degree of curvature} = 100 * {|\Delta_i|}/{Lc_i} \tag{1}$$

For curves with spirals:

$$\text{Degree of curvature} = 100 * {|\Delta_i|}/{(2 * L_{s,i} + Lc'_i)} \tag{2}$$

where:
Δ_i is the deflection angle for curve i
Lc_i is the length of the single circular curve (shown by black broken line in figure 1)
Lc'_i is the length of the circular curve between the spirals
$L_{s,i}$ is the length of the spiral on either side of the circular curve

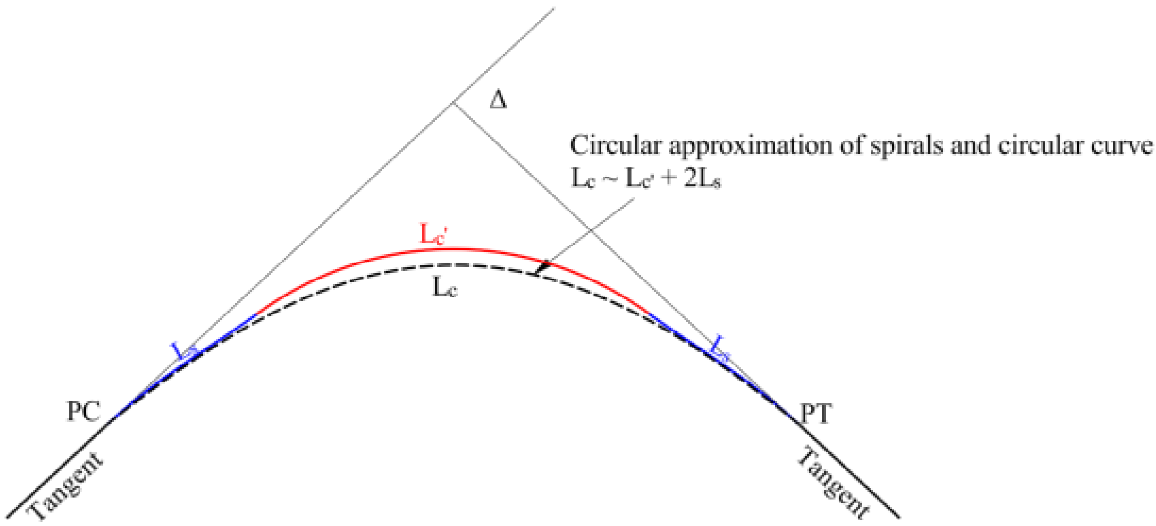


Figure 1. Horizontal curve with spirals + circular curve combination and circular approximation of the same

As shown in Figure 1, the deflection angle in both cases will be the same. Although the length of the spirals plus the circular curve is slightly longer than a single circular curve, the difference is small when the deflection angle is small. For the current project, we approximated the degree of curve or radius of curve near the mid-point of the simple or spiral curve, in order to measure the arc with a constant radius. The detailed process for extracting this information is described in Appendix A.

Using the length, radius and degree of curvature of horizontal curves, the following segment level data will also be collected described as follows:

1. Curve density = # curves in a segment / L
2. Average Radius = $\sum R_i / n$
3. Ratio of the curve length to the total length of the segment = $\sum Lc_i / L$
4. Degree of curvature per mile = $\frac{\sum|\Delta_i| / \sum Lc_i}{L} * 100$

Where:
L = length of segment in miles
R_i = Radius of curve 'i' in ft

n = number of horizontal curves in a road segment
Lc_i = length of curve for curve 'i' in miles

Δ_i = Deflection angle of curve 'i' in degrees

Source: Pathpoints

Pathpoints is a LiDAR-based tool that contains point cloud data, along with a videolog taken from the drivers perspective, of roads in Montana. The data are not publicly available and access to Pathpoints requires login credentials. The perspective images in Pathpoints display forward-facing and right-shoulder camera views. For the purpose of supplemental data collection, perspective images consisting of the videolog for 'Montana 2021 Roads' will be used. It will be assumed that the data elements collected using the year 2021 video information do not differ before and after SCLRS installation. For the roadway segments for which the videologs were not available, Google Earth Pro will be used to collect the required information. The information that will be collected using this method are as follows:

- Presence of centerline rumble strips: Presence of centerline rumble strips will be verified by running the roadway videolog from the 'Perspective Images' window (Figure 2).
- Presence of curve warning signs: After identifying curve locations from the previous section, the videolog for the corresponding roadway segment will be used to check for the presence of curve warning signs before the curve in both directions (Figure 3).

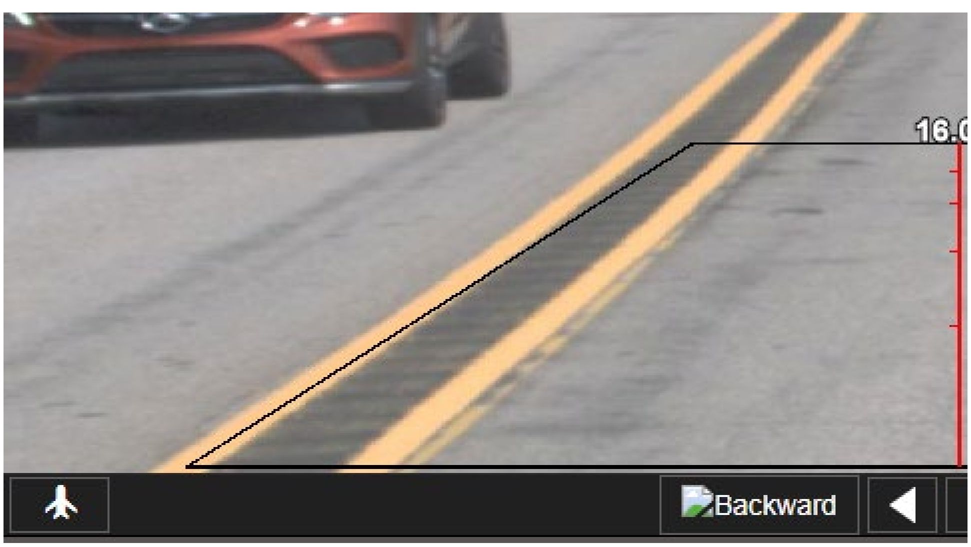


Figure 2. Screen capture of the Pathpoints window showing centerline rumble strips

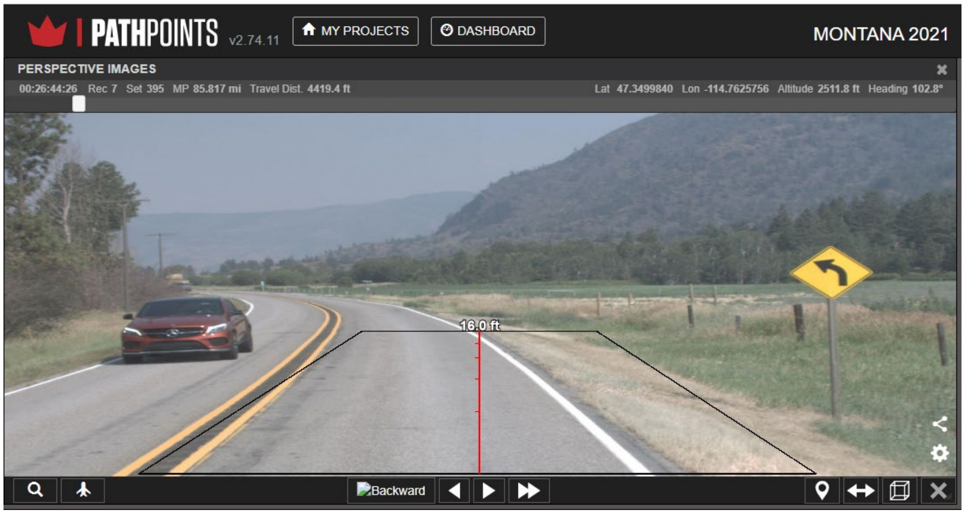


Figure 3. Screen capture of the Pathpoints window showing a horizontal curve warning sign

Source: Google Earth Pro

The Google Earth Pro tool provides high-quality satellite imagery of the roads and built-in functions to measure features to scale. This tool will be used to verify the presence of centerline rumble strips and calculate driveway density which is the number of access points (driveways) within a road segment divided by the length of the segment. The process for extracting this information is explained in Appendix B.

Appendix A: Horizontal Curve Data Collection

The process used to compute horizontal curve information for the present study is described below.

1. Importing Data: GIS shapefiles of each route were imported into AutoCAD Civil 3D. Routes were split into tiny elements approximately 25 ft in length. An example of state route C000060A is shown on the left side of Figure 4. Alternate segments are highlighted with blue dots to indicate the size of the segments relative to the features seen in the background imagery.
2. Change in Bearing Calculation: The absolute value of the change in bearing between consecutive elements was calculated. Elements with negligible differences (e.g., less than 0.1 degrees) were joined. The following distinctions were used:

   - Tangents: Successive elements have no or negligible change in bearing (say, $|\Delta| < 0.1$ degrees).
   - Curves: Successive elements exhibit a non-zero and nearly constant change in bearing.
   - Spirals: Successive elements have non-zero, varying (between 0 to the maximum value for the curves) changes in bearing.

   An illustration of this process of identification is shown in Figure 6.

3. Joining Segments and Identification of PC and PT Locations: Segments with negligible bearing differences were joined to form longer tangents, while keeping the curves and spirals unchanged. This will help identify the Point of Curvature (PC) and Point of Tangency (PT), as shown in Figure 5. These points represent the change going from tangents to curves, or tangents to spirals (if present).

Figure 4. Segments before joining (left) and after joined together (right) based on the change in bearings

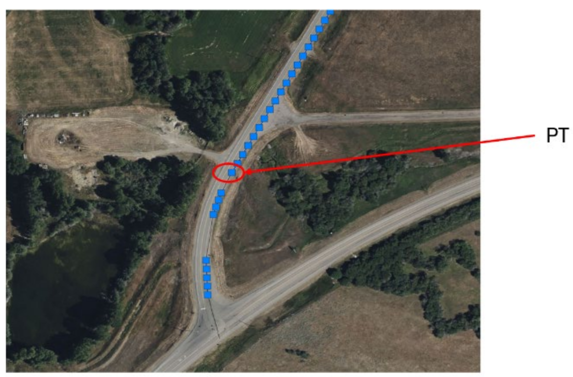
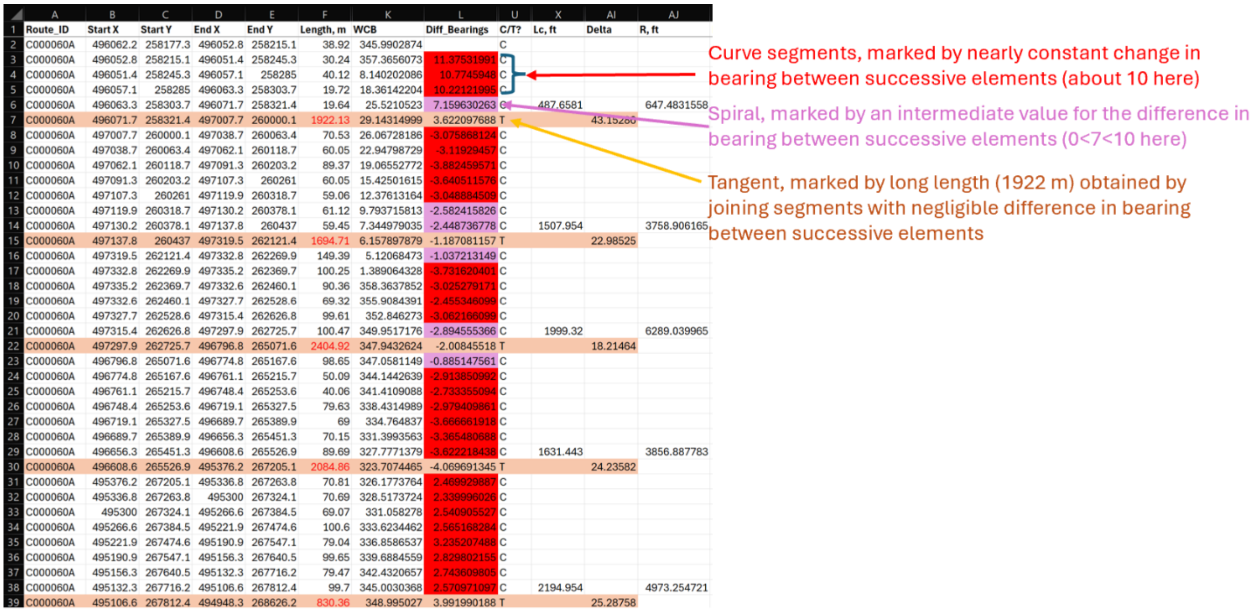


Figure 5. Point of tangency (PT) identified between the curve element and tangent element based on the difference in bearing of successive elements

Figure 6 shows the results in csv format, with column L showing the differences in bearings for consecutive elements. This difference in bearing is used to identify tangents, curves, and spirals. Spirals are generally observed in curves with small radii and short lengths as seen in the first couple of curves for the example shown in Figure 6.



	A	B	C	D	E	F	K	L	U	X	AI	AJ
1	Route_ID	Start X	Start Y	End X	End Y	Length, m	WCB	Diff_Bearings	C/T?	Lc, ft	Delta	R, ft
2	C000060A	496062.2	258177.3	496052.8	258215.1	38.92	345.9902874		C			
3	C000060A	496052.8	258215.1	496051.4	258245.3	30.24	357.3656073	11.37531991	C			
4	C000060A	496051.4	258245.3	496057.1	258285	40.12	8.140202086	10.7745948	C			
5	C000060A	496057.1	258285	496063.3	258303.7	19.72	18.36142204	10.22121995	C			
6	C000060A	496063.3	258303.7	496071.7	258321.4	19.64	25.5210523	7.159630263	C	487.6581		647.4831558
7	C000060A	496071.7	258321.4	497007.7	260000.1	1922.13	29.14314999	3.622097688	T		43.15280	
8	C000060A	497007.7	260000.1	497038.7	260063.4	70.53	26.06728186	-3.075868124	C			
9	C000060A	497038.7	260063.4	497062.1	260118.7	60.05	22.94798729	-3.11929457	C			
10	C000060A	497062.1	260118.7	497091.3	260203.2	89.37	19.06552772	-3.882459571	C			
11	C000060A	497091.3	260203.2	497107.3	260261	60.05	15.42501615	-3.640511576	C			
12	C000060A	497107.3	260261	497119.9	260318.7	59.06	12.37613164	-3.048884509	C			
13	C000060A	497119.9	260318.7	497130.2	260378.1	61.12	9.793715813	-2.582415826	C			
14	C000060A	497130.2	260378.1	497137.8	260437	59.45	7.344979035	-2.448736778	C	1507.954		3758.906165
15	C000060A	497137.8	260437	497319.5	262121.4	1694.71	6.157897879	-1.187081157	T		22.98525	
16	C000060A	497319.5	262121.4	497332.8	262269.9	149.39	5.12068473	-1.037213149	C			
17	C000060A	497332.8	262269.9	497335.2	262369.7	100.25	1.389064328	-3.731620401	C			
18	C000060A	497335.2	262369.7	497332.6	262460.1	90.36	358.3637852	-3.025279171	C			
19	C000060A	497332.6	262460.1	497327.7	262528.6	69.32	355.9084391	-2.455346099	C			
20	C000060A	497327.7	262528.6	497315.4	262626.8	99.61	352.846273	-3.062166099	C			
21	C000060A	497315.4	262626.8	497297.9	262725.7	100.47	349.9517176	-2.894555366	C	1999.32		6289.039965
22	C000060A	497297.9	262725.7	496796.8	265071.6	2404.92	347.9432624	-2.00845518	T		18.21464	
23	C000060A	496796.8	265071.6	496774.8	265167.6	98.65	347.0581149	-0.885147561	C			
24	C000060A	496774.8	265167.6	496761.1	265215.7	50.09	344.1442639	-2.913850992	C			
25	C000060A	496761.1	265215.7	496748.4	265253.6	40.06	341.4109088	-2.733355094	C			
26	C000060A	496748.4	265253.6	496719.1	265327.5	79.63	338.4314989	-2.979409861	C			
27	C000060A	496719.1	265327.5	496689.7	265389.9	69	334.764837	-3.666661918	C			
28	C000060A	496689.7	265389.9	496656.3	265451.3	70.15	331.3993563	-3.365480688	C			
29	C000060A	496656.3	265451.3	496608.6	265526.9	89.69	327.7771379	-3.622218438	C	1631.443		3856.887783
30	C000060A	496608.6	265526.9	495376.2	267205.1	2084.86	323.7074465	-4.069691345	T		24.23582	
31	C000060A	495376.2	267205.1	495336.8	267263.8	70.81	326.1773764	2.469929887	C			
32	C000060A	495336.8	267263.8	495300	267324.1	70.69	328.5173724	2.339996026	C			
33	C000060A	495300	267324.1	495266.6	267384.5	69.07	331.058278	2.540905527	C			
34	C000060A	495266.6	267384.5	495221.9	267474.6	100.6	333.6234462	2.565168284	C			
35	C000060A	495221.9	267474.6	495190.9	267547.1	79.04	336.8586537	3.235207488	C			
36	C000060A	495190.9	267547.1	495156.3	267640.5	99.65	339.6884559	2.829802155	C			
37	C000060A	495156.3	267640.5	495132.3	267716.2	79.47	342.4320657	2.743609805	C			
38	C000060A	495132.3	267716.2	495106.6	267812.4	99.7	345.0030368	2.570971097	C	2194.954		4973.254721
39	C000060A	495106.6	267812.4	494948.3	268626.2	830.36	348.995027	3.991990188	T		25.28758	

Figure 6. Output table calculation that identifies the curve, spiral and tangents based on difference in bearings between successive elements of a route

The deflection angle (Δ_i), for curve 'i', is calculated between the two tangent segments, in order to consider the degree of curvature due to the presence of spirals. The radius of the curve is then calculated by dividing the length of the curve and spirals (if present) by the deflection angle in radians.

$$R_i = \frac{(2*L_{s,i}+Lc\prime_i)}{\Delta_i} \tag{3}$$

Note that the length of the spirals and the curve will be obtained by adding the length of the segments between PC and PT stations of the curve.

Verification of results: Sample results were validated using images from AutoCAD Civil 3D's Geolocation feature. For example, the radius and curve lengths for the first five curves of route C000060A closely matched actual road geometry, as shown in Figure 7.

Figure 7. Verifying the radius and length of curves for route C000060A using Geolocation feature in Civil3D

Note: If a horizontal curve spans two segments, it should be split and recorded in both segments. In such case, the end point of the curve in the first segment will be assigned as PT for the curve in the first segment and PC for the subsequent segment.

APPENDIX B: ACCESS POINTS AND RUMBLE STRIPS PRESENCE USING GOOGLE EARTH PRO

Google Earth Pro is a free desktop application used to view, analyze, and create geospatial data using 3D terrain and roadway features. For this project, Google Earth Pro is primarily used to collect the number of access points within a roadway section, and also to verify the locations of the presence of rumble strips using Google Street View. The online Google Earth tool can be accessed using the following link: https://www.google.com/earth/about/. The following steps describe the procedure used to gather the access points information.

1. *Convert the coordinates of the mile post locations in DMS format*
   The northing and easting coordinates of the start mileposts for road segments in the provided geodatabase file will be converted to Degrees, Minutes, and Seconds (DMS) format for use in Google Earth. This can be accomplished with a simple R script. The final output will be a comma-separated (.csv) file containing columns for Name, Latitude, and Longitude. It's helpful to create the 'Name' column by combining the route ID with the milepost location corresponding to the latitude and longitude coordinates.

2. *Import the coordinates in Google Earth Pro*
   Once the coordinates are ready, open the Google Earth Pro application and import the coordinates of the mile post locations of the start and end points of the roadway segments. The mile post locations can be represented by pins as shown in **Figure 8**.

Figure 8. Screen capture from the Google Earth Pro interface showing the start and end points of a section, marked by yellow pins, between which the access points can be counted.

3. *Calculate access density*

   Count the number of access points between one set of start and end points. Access density for that roadway segment will be computed as follows:

   Access density, AD (number per mile) = Number of access points / Length of the segment in miles