Chapter 1220 Geometric Profile Elements

1220.01 General

Vertical alignment (roadway profile) consists of a series of gradients connected by vertical curves. It is mainly controlled by the following:

- Topography
- Class of highway
- Horizontal alignment
- Safety
- Sight distance
- Construction costs
- Drainage
- Adjacent land use
- Vehicular characteristics
- Aesthetics

This chapter provides guidance for the design of vertical alignment. For additional information, see the following chapters:

Chapter	Subject
Chapter 1103	Design controls, terrain
Chapter 1210	Horizontal alignment
Chapter 1260	Sight distance
Chapter 1310	Grades at intersections
Chapter 1360	Maximum grade for ramps

1220.02 Vertical Alignment

1220.02(1) Design Principles

The following are general principles for developing vertical alignment (also see Exhibit 1220-4 through Exhibit 1220-7):

- Use a smooth grade line with gradual changes, consistent with the context identification and character of terrain. Avoid numerous breaks and short grades.
- Avoid “roller coaster” or “hidden dip” profiles by use of gradual grades made possible by heavier cuts and fills or by introducing some horizontal curvature in conjunction with the vertical curvature.
- Avoid grades that affect truck speeds and, therefore, traffic operations.
- Avoid broken back grade lines with short tangents between two vertical curves.
- Use long vertical curves to flatten grades near the top of long, steep grades.
- Where at-grade intersections occur on roadways with moderate to steep grades, it is desirable to flatten or reduce the grade through the intersection.
- Establish the subgrade at least 1 foot above the high water table (real or potential), or as recommended by the Region Materials Engineer. Consider the low side of superelevated roadways.
- When a vertical curve takes place partly or wholly in a horizontal curve, coordinate the two as discussed in Section 1220.03.

1220.02(2) Minimum Length of Vertical Curves (Section rewritten September 2021)

The minimum length of a vertical curve is controlled by design speed, stopping sight distance, and the change in grade.

1220.02(2)(a) New Construction Projects

For new construction (building a street where one does not currently exist), the minimum length of the vertical curve must meet stopping sight distance (see Chapter 1260) or have a length at least three times the design speed, whichever is greater. For aesthetics, the desirable length of a vertical curve is two to three times the length needed for stopping sight distance.

1220.02(2)(b) Reconstruction Projects

On reconstruction projects, a zero-length vertical curve may be used as follows:

- Intermediate and Low Speeds: Algebraic difference of 1.0% or less
- High Speeds: Algebraic Difference of 0.5% or less

Zero-length vertical curves are meant for spot locations to accommodate small profile changes that match into existing profiles. For example, modifying the existing profile for an overlay or adjusting the profile to accommodate a fish passage structure. Do not use a series of zero-length vertical curves as a replacement for a properly designed vertical curve.

The minimum length of crest vertical curves shall be the same as new construction.

The minimum length of sag vertical curves is determined using Exhibit 1220-1. There are two minimum lengths listed in Exhibit 1220-1: minimum and desired minimum. Try to meet the desired minimum as it provides more sight distance for nighttime driving. If you are unable to meet the desired minimums and must drop to the minimum, document your decision in the Design Documentation Package. A spreadsheet is available on the Design Support website to calculate the minimum and desired minimum shown in Exhibit 1220-1.

Exhibit 1220-1 Minimum Length of Sag Vertical Curves

Sag Vertical Curve Minimum Length *** (Reconstruction Only)		
Design Speed	Minimum	Desired Minimum
≤ 30 mph	Use the equations for L in Exhibit 1260-7 with S equal to the SSD from Exhibit 1260-1*.	Same as Minimum*.
35 to 45 mph	Use the equations for L in Exhibit 1260-7 with S equal to 230'*.	Use the equations for L in Exhibit 1260-7 with S equal to the SSD from Exhibit 1260-1*.
≥ 50 mph	Use the equation for comfort: ** $L = \frac{AV^2}{46.5}$ $L =$ Curve length (ft) $A =$ Change in grade (%) $V =$ Design speed (mph)	Use the equations for L in Exhibit 1260-7 with S equal to the SSD from Exhibit 1260-1*.

* The calculated value of L cannot be less than what is required for comfort. Use the formula for comfort shown above. In this case, the comfort equation may be used within pedestrian crossings or intersections because sight distance is not restricted by the sag vertical curve.

** The comfort equation cannot be applied when the curve is within an intersection or a pedestrian crossing. In these situations, the minimum sag vertical curve must meet stopping sight distance.

*** All values for SSD used in this table must be adjusted for grade per Section 1260.03(2).

1220.02(3) Maximum Grades

Analyze grades for their effect on traffic operation because they may result in undesirable truck speeds. Maximum grades are controlled by terrain type and design speed (see Exhibit 1220-4 and Section 1360.03(3) for ramp grades).

Exhibit 1220-2 Maximum Grades

Table 1 Maximum Grades for Rural Contexts

Type of Terrain	Design Speed (mph)											
	25	30	35	40	45	50	55	60	65	70	75	80
Level	<u>5</u>	<u>5</u>	<u>5</u>	5	5	4	4	3	3	3	3	3
Rolling	8	7	7	6	6	5	5	4	4	4	4	4
Mountainous	<u>10</u>	<u>9</u>	8	8	7	7	6	6	5	5	5	5

Table 2 Maximum Grades for Suburban and Urban Contexts

Type of Terrain	Design Speed (mph)								
	20	25	30	35	40	45	50	55	60
Level	8	<u>7</u>	<u>7</u>	7	7	6	6	5	5
Rolling	<u>10</u>	<u>10</u>	9	8	8	7	7	6	6
Mountainous	13	12	11	10	10	9	9	8	8

Table 3 Maximum Grades for Interstate and Full Limited Access Control Facilities

Type of Terrain	Design Speed (mph)						
	50	55	60	65	70	75	80
Level	4	4	3	3	3	3	3
Rolling	5	5	4	4	4	4	4
Mountainous	6	6	6	<u>5</u>	5	5	5

<u>Grades 1 percent steeper than the value shown may be used in urban areas.</u>

1220.02(4) Minimum Grades

Minimum grades are used to meet drainage requirements. Avoid selecting a "roller coaster" or "hidden dip" profile merely to accommodate drainage.

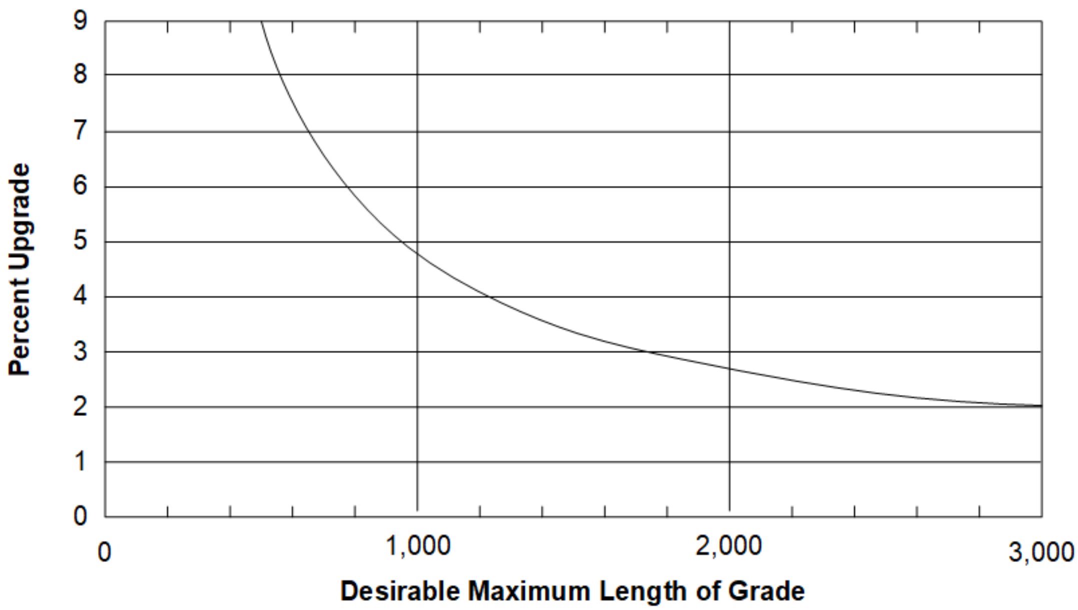
Minimum ditch gradients of 0.3% on paved materials and 0.5% on earth can be obtained independently of roadway grade. Medians, long sag vertical curves, and relatively flat terrain are examples of areas where independent ditch design may be justified. A closed drainage system may be needed as part of an independent ditch design.

1220.02(5) Length of Grade

The desirable maximum length of grade is the maximum length on an upgrade at which a loaded truck will operate without a 10 mph reduction. Exhibit 1220-3 gives the desirable maximum length for a given percent of grade. When grades longer than the desirable maximum are unavoidable, consider an auxiliary climbing lane (see Chapter 1270). For grades that are not at a constant percent, use the average.

When long, steep downgrades are unavoidable, consider an emergency escape ramp, and for grades longer than indicated, consider an auxiliary climbing lane (see Chapter 1270).

Exhibit 1220-3 Grade Length



For grades longer than indicated, consider an auxiliary climbing lane (see Chapter 1270).

1220.02(6) Grade and Speed Considerations

Grades can affect the operating performance of the vehicles negotiating them. The bicycle, transit, and freight modes are most affected by grades, while passenger cars can readily negotiate grades as steep as 5% without appreciable loss of operating speed. Steep downgrades can also impact operating speeds, particularly for heavy trucks, which display up to a 5% increase in speed on downgrades. Consider the selected performance for a location and corridor before making a determination on grade selection, to avoid unnecessary cuts or fills required for a vertical alignment. Exhibit 1220-3 provides the maximum grades based on the context, terrain classification, and targeted speed.

1220.02(7) Alignment on Structures

Where practicable, avoid high skew, vertical curvature, horizontal curvature, and superelevation on structures, but do not sacrifice safe roadway alignment to achieve this.

1220.03 Coordination of Vertical and Horizontal Alignments

Do not design horizontal and vertical alignments independently. Coordinate them to obtain uniform speed, pleasing appearance, and efficient traffic operation. Coordination can be achieved by plotting the location of the horizontal curves on the working profile to help visualize the highway in three dimensions. Perspective plots will also give a view of the proposed alignment. Exhibit 1220-4 and Exhibit 1220-5 show sketches of desirable and undesirable coordination of horizontal and vertical alignment.

Guides for the coordination of the vertical and horizontal alignment are as follows:

- Balance curvature and grades. Using steep grades to achieve long tangents and flat curves or excessive curvature to achieve flat grades are both poor designs.
- Vertical curvature superimposed on horizontal curvature generally results in a more pleasing facility. Successive changes in profile not in combination with horizontal curvature may result in a series of dips not visible to the driver.
- Do not begin or end a horizontal curve at or near the top of a crest vertical curve. A driver may not recognize the beginning or ending of the horizontal curve, especially at night. An alignment where the horizontal curve leads the vertical curve and is longer than the vertical curve in both directions is desirable.
- To maintain drainage, design vertical and horizontal curves so that the flat profile of a vertical curve is not located near the flat cross slope of the superelevation transition.
- Do not introduce a sharp horizontal curve at or near the low point of a pronounced sag vertical curve. The road ahead is foreshortened and any horizontal curve that is not flat assumes an undesirably distorted appearance. Further, vehicular speeds, particularly of trucks, often are high at the bottom of grades and erratic operation may result, especially at night.
- On two-lane roads, the need for passing sections (at frequent intervals and for an appreciable percentage of the length of the roadway) often supersedes the general desirability for the combination of horizontal and vertical alignment. Work toward long tangent sections to secure sufficient passing sight distance.
- On divided highways, consider variation in the width of medians and the use of independent alignments to derive the design and operational advantages of one-way roadways.
- Make the horizontal curvature and profile as flat as practicable at intersections where sight distance along both roads is important and vehicles may have to slow or stop.
- In residential areas, design the alignment to minimize nuisance factors to the neighborhood. Generally, a depressed facility makes a highway less visible and less noisy to adjacent residents. Minor horizontal adjustments can sometimes be made to increase the buffer zone between the highway and clusters of homes.
- Design the alignment to enhance attractive scenic views of the natural and constructed environment, such as rivers, rock formations, parks, and outstanding buildings.

When superelevation transitions fall within the limits of a vertical curve, plot profiles of the edges of pavement and check for smooth transitions.

1220.04 Airport Clearance

Contact the airport authorities early for proposed highway construction or alteration in the vicinity of a public or military airport, so that advance planning and design work can proceed within the required Federal Aviation Administration (FAA) regulations (see the *Environmental Manual*).

1220.05 Railroad Crossings

When a highway crosses a railroad at grade, design the highway grade to prevent low-hung vehicles from damaging the rails or getting hung up on the tracks. Exhibit 1220-8 gives guidance on designing highway grades at railroad crossings. For more information on railroad-highway crossings, see Chapter 1350.

1220.06 Procedures

When the project modifies the vertical alignment, develop vertical alignment plans for inclusion in the Plans, Specifications, and Estimates (PS&E) to a scale suitable for showing vertical alignment for all proposed roadways, including ground line, grades, vertical curves, and superelevation. (See the *Plans Preparation Manual* for guidance.) When justifying any modification to the vertical alignment, include the reasons for the change, alternatives addressed (if any) and why the selected alternative was chosen.

When the profile is a result of new horizontal alignment, develop vertical and horizontal alignments together, and include the profile with the horizontal alignment justification.

1220.07 References

1220.07(1) Federal/State Laws and Codes

Washington Administrative Code (WAC) 468-18-040, Design standards for rearranged county roads, frontage roads, access roads, intersections, ramps and crossings

1220.07(2) Design Guidance

Local Agency Guidelines (LAG), M 36-63, WSDOT

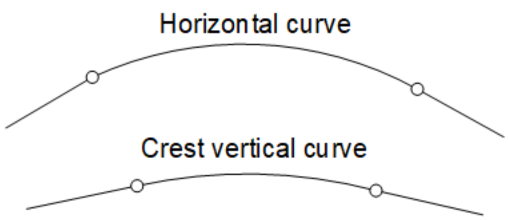
Manual on Uniform Traffic Control Devices for Streets and Highways, USDOT, FHWA; as adopted and modified by Chapter 468-95 WAC "Manual on uniform traffic control devices for streets and highways" (MUTCD)

Plans Preparation Manual, M 22-31, WSDOT

1220.07(3) Supporting Information

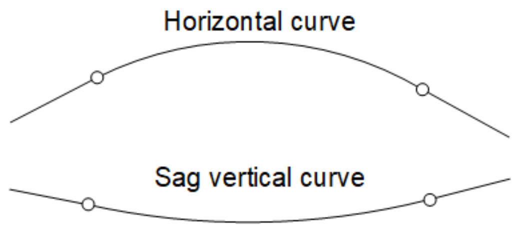
A Policy on Geometric Design of Highways and Streets (Green Book), AASHTO, current edition

Exhibit 1220-4 Coordination of Horizontal and Vertical Alignments



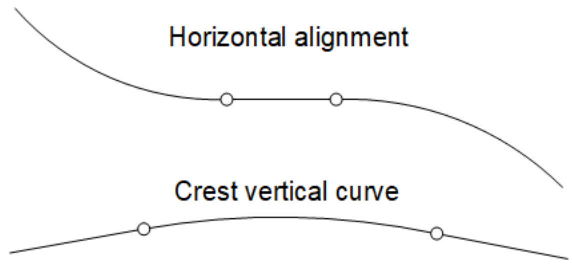
Coinciding Horizontal and Crest Vertical Curves

When horizontal and crest vertical curves coincide, a satisfactory appearance results.



Coinciding Horizontal and Sag Vertical Curves

When horizontal and sag vertical curves coincide, a satisfactory appearance results.

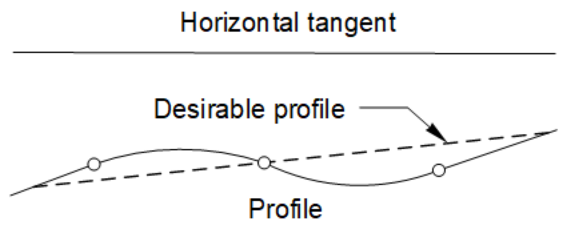


Short Tangent on a Crest Between Two Horizontal Curves

This combination is deficient for several reasons:

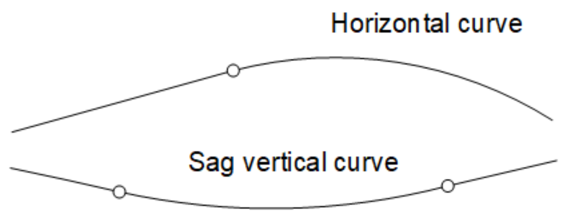
- The curve reversal is on a crest, making the second curve less visible.
- The tangent is too short for the superelevation transition.
- The flat area of the superelevation transition will be near the flat grade in the crest.

Exhibit 1220-5 Coordination of Horizontal and Vertical Alignments



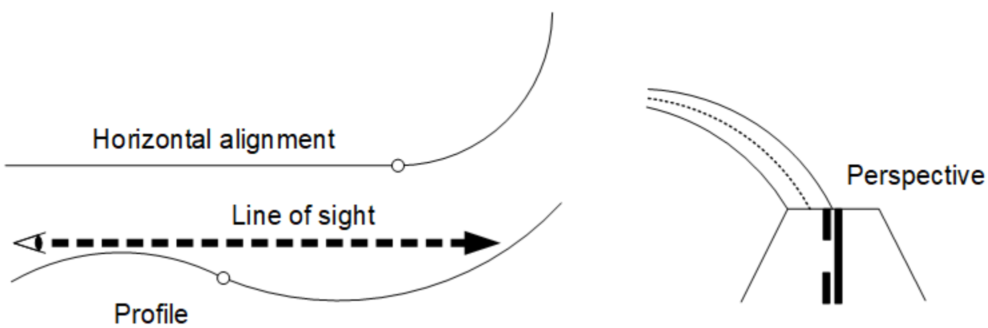
Profile with Tangent Alignment

Avoid designing dips on an otherwise long uniform grade.



Sharp Angle Appearance

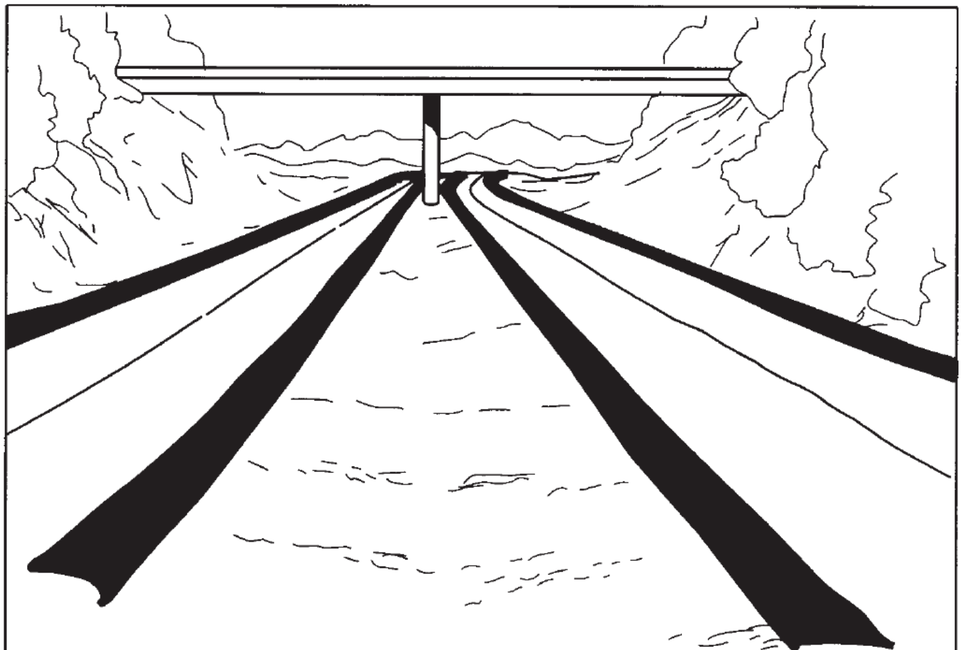
This combination presents a poor appearance. The horizontal curve looks like a sharp angle.



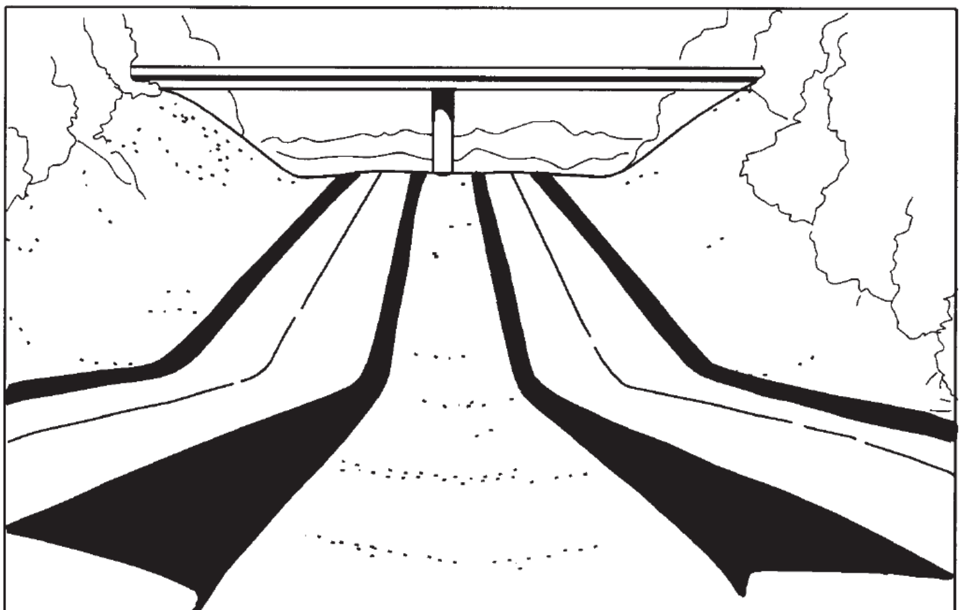
Disjointed Effect

A disjointed effect occurs when the beginning of a horizontal curve is hidden by an intervening crest while the continuation of the curve is visible in the distance beyond the intervening crest.

Exhibit 1220-6 Alignment Examples

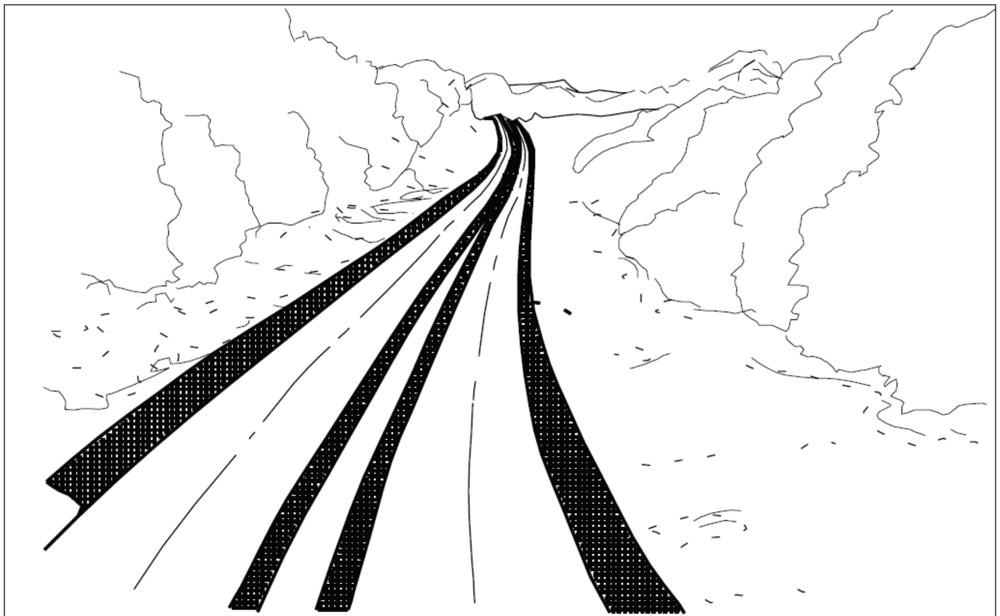


Desirable - Vertical Curves Lengthened

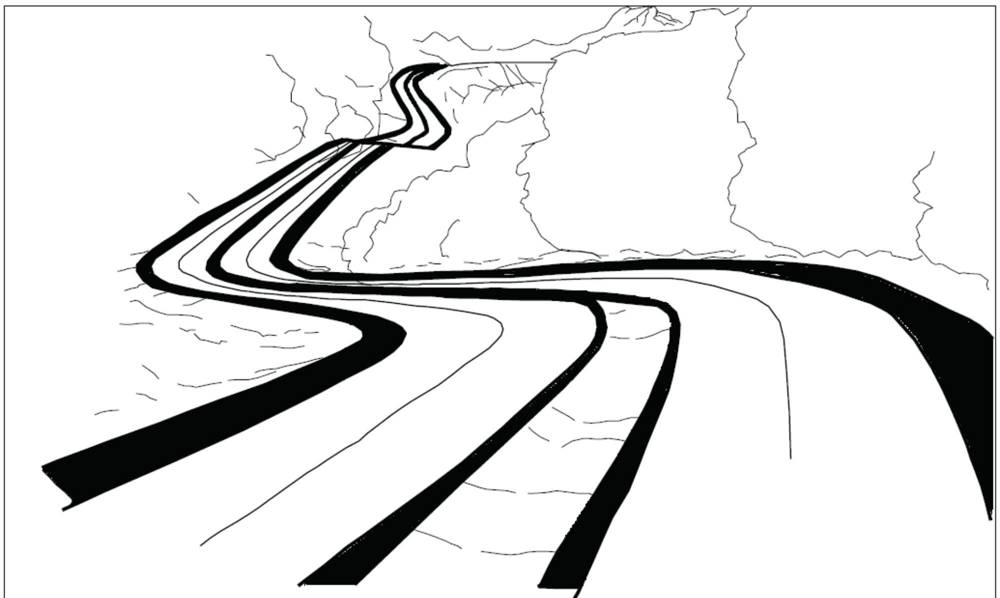


Undesirable - Minimum Vertical Curves Used

Exhibit 1220-7 Coordination of Horizontal and Vertical Alignments



Desirable Coordination of Vertical and Horizontal Curves and the Use of Flowing Alignment



Undesirable - Vertical and Horizontal Curves Not Coordinated and Using Minimums

Exhibit 1220-8 Grading at Railroad Crossings