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Highway & Traffic Engineering

HIGHWAY GEOMETRIC DESIGN – VERTICAL ALIGNMENT

by

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Chapter Description

- Aims
  - Understand basic principles of vertical alignment, understand the variables of vertical alignment and produces vertical alignment design.

- Expected Outcomes
  - Students should be able to understand principles of vertical alignment.
  - Students should be able to illustrates variables of vertical alignment
  - Students will be able to perform vertical alignment design.

- References
  - Highway Engineering, Paul H. Wright / Karen K. Dixon
  - Images are taken from other related websites

INTRODUCTION

- Vertical alignment constitute one of the most important features of highway design.
- Vertical alignment consist of straight profile connected with **vertical parabolic curves** and ended with straight profile again.
- This profile lines known as *'profile grade line'*

Vertical alignment in real world

https://theconstructor.org/transportation/vertical-alignment-of-highways/11266/

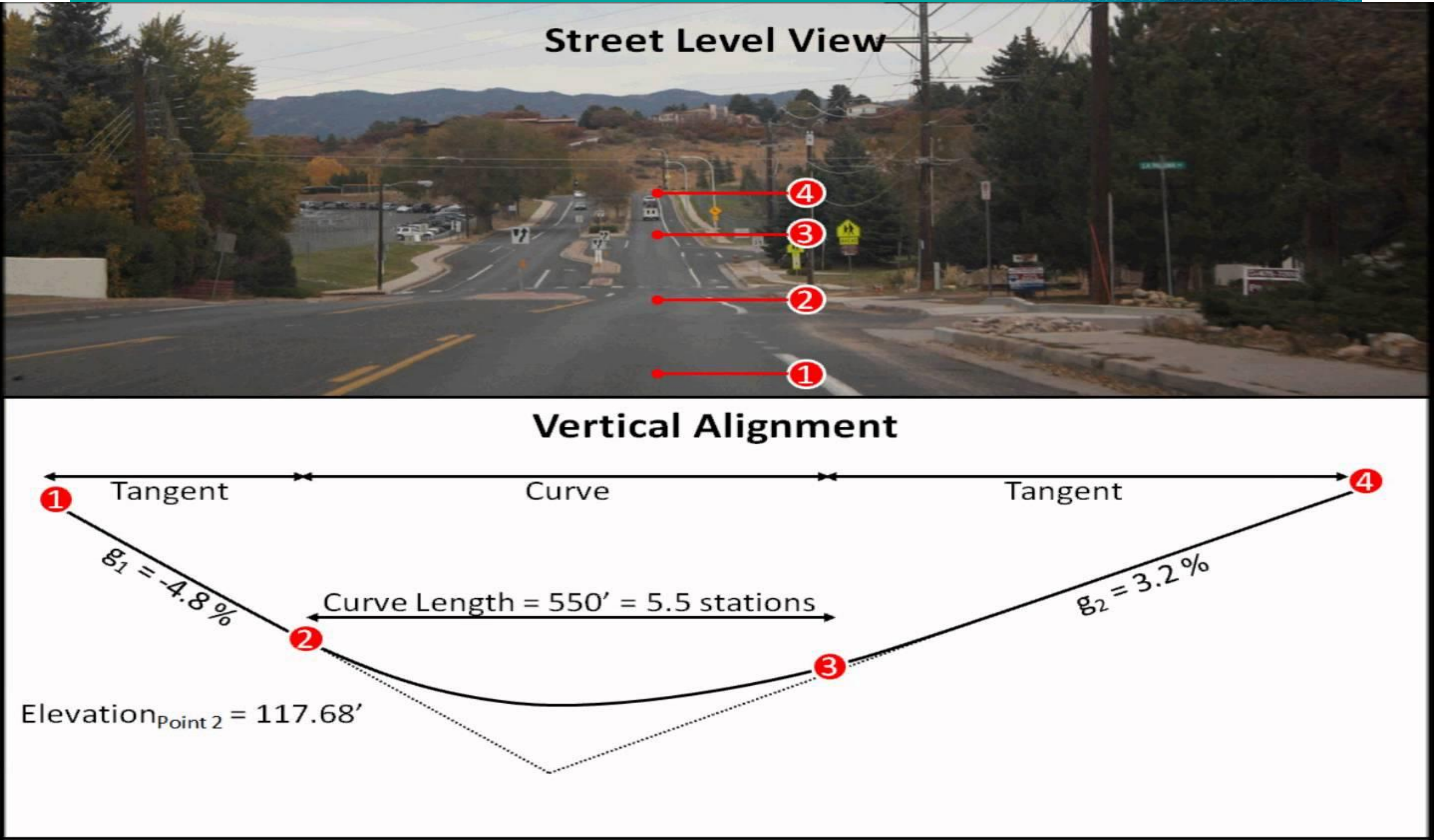
- When a profile grade line increasing from flat alignment to a parabolic curves, it is referred as positive or plus grade.
- When the grade is decreasing from curves to flat alignment, it is referred as negative or minus grade.
- The changes in grade profile will effect the change in centerline profile of roadway.

- Ideal grade should follow natural terrain with very limited cut and fill works.
- If any cut and fill, the quantity should be balanced.(+ → - = cut, - → + = fill)
- Ideal grade should have long distance between point of intersection (between flat and curve) to provide smooth and good visibility riding.

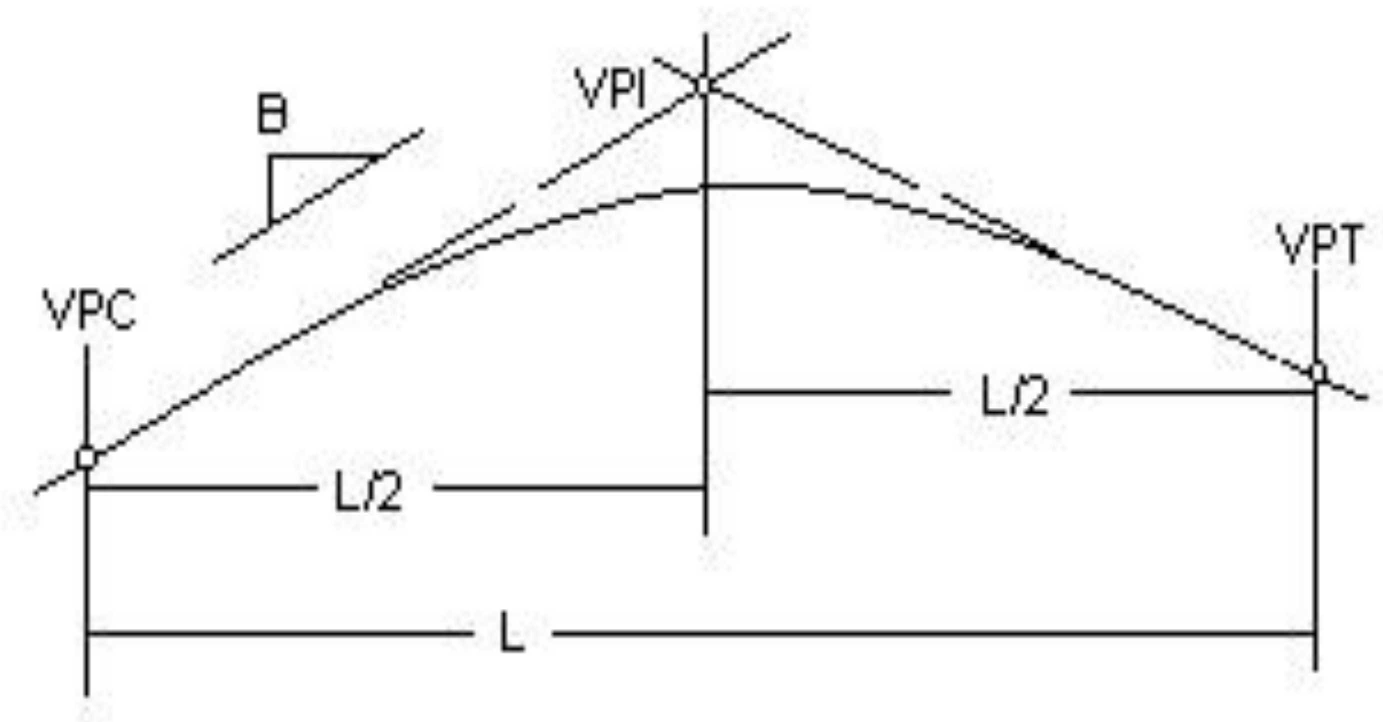
- If the upgrade project, it is recommended to adjust the grade that meets the existing condition to reuse of existing utilities.
- Maximum grades allow depends on the design speed of the road.
- For design speed of 110km/h, maximum grades will be 5%.
- For design speed of 50km/h, maximum grades are range from 7% - 12%.

Vertical Curves

- The parabolic curves used in connecting profile grade tangent (straight line) to curves.
- The curves is used in which the vertical offsets can be computed, smooth transition are created from tangent to curves back to tangent.
- When vertical curves connecting positive grade with negative grade it’s call crest curve.
- When vertical curves connecting negative curve with positive curve it’s call sag curve.

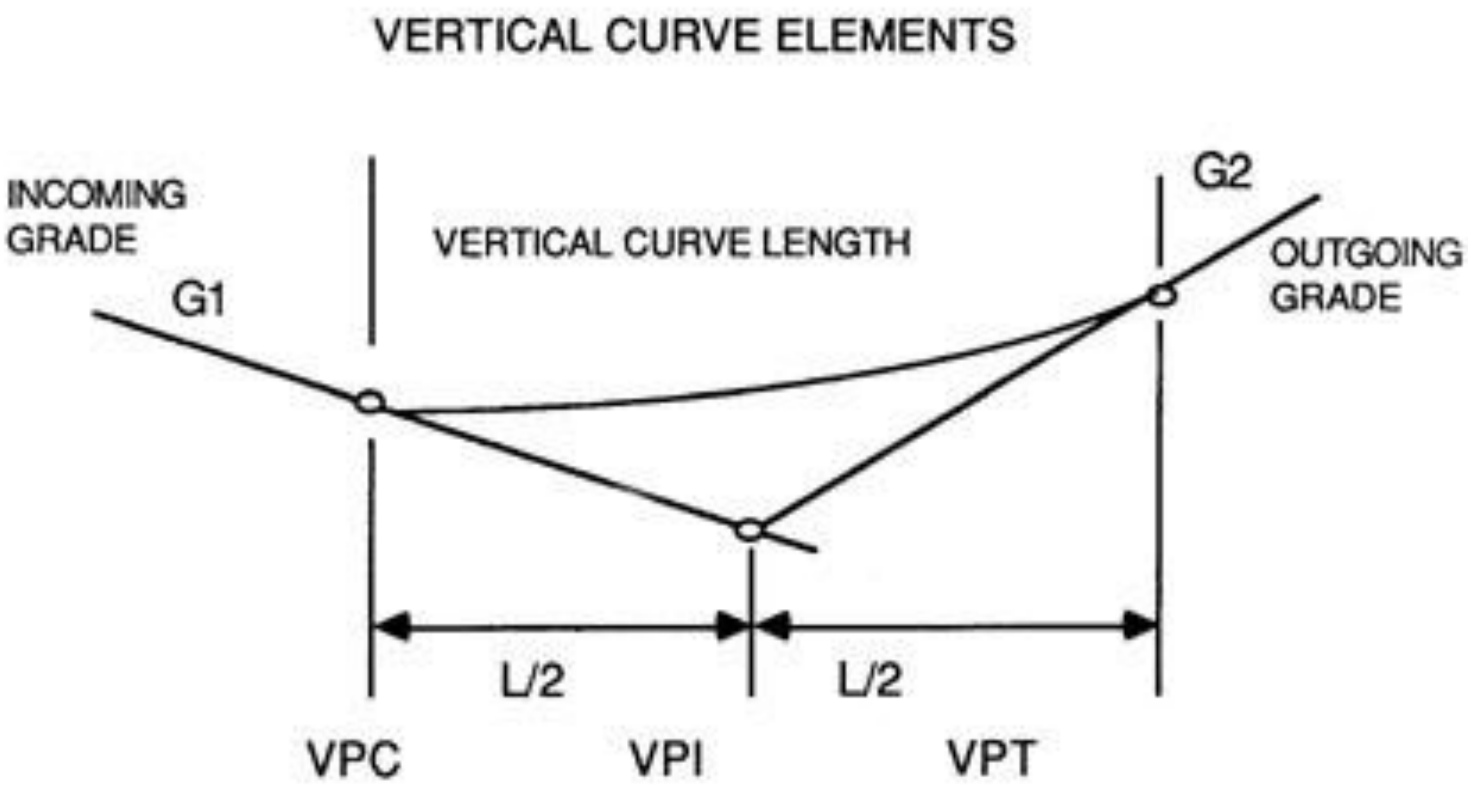

Street Level View
4
3
2
1
Vertical Alignment
Tangent
Curve
Tangent
1
4
g1 = -4.8 %
Curve Length = 550' = 5.5 stations
g2 = 3.2 %
2
3
ElevationPoint 2 = 117.68'

Crest Curves



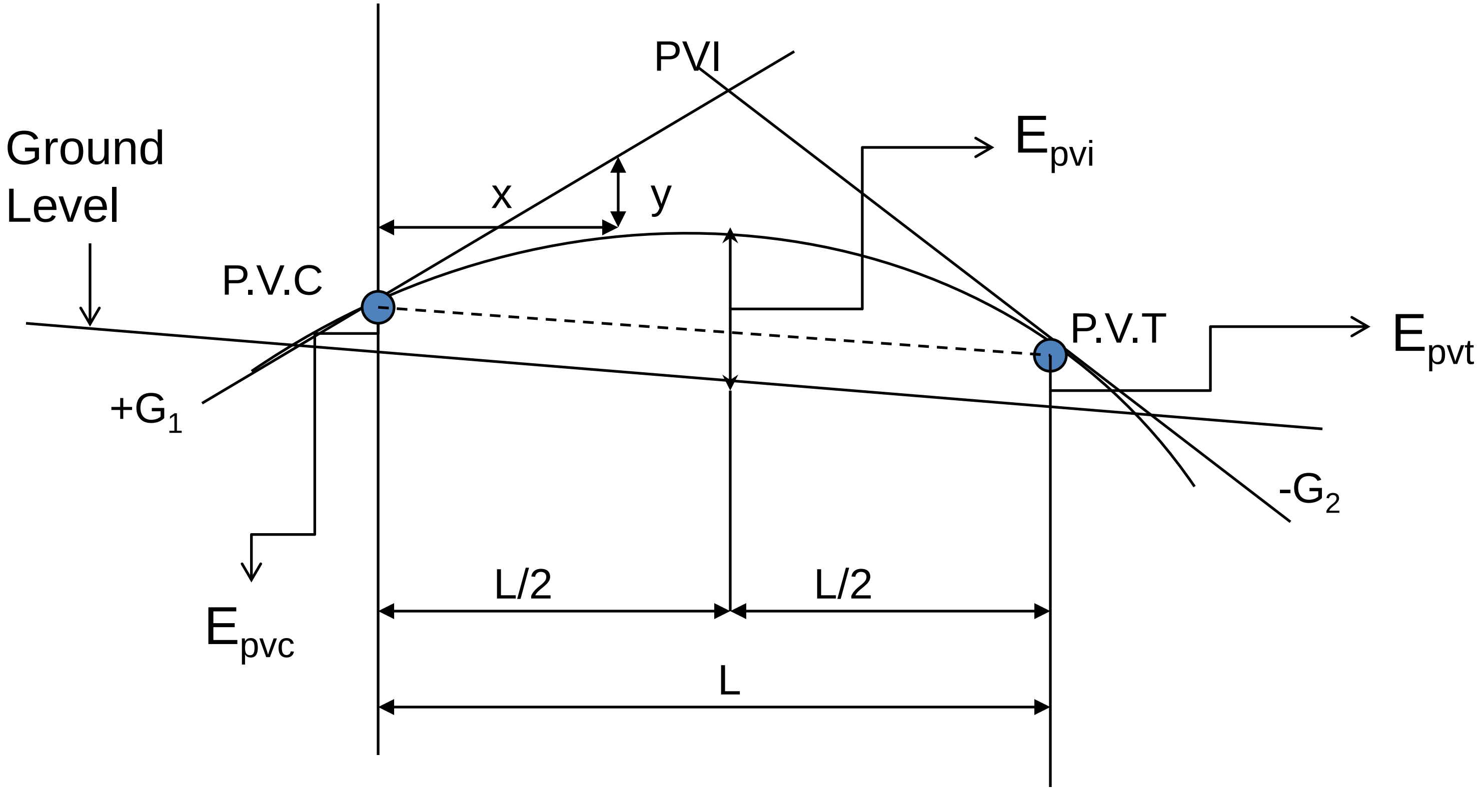
http://www.fao.org/docrep/006/t0099e/T0099e03.htm

Sag Curves



http://www.fao.org/docrep/006/t0099e/T0099e03.htm

Vertical Curves Variables



Variables

- PVI = Point of vertical intersection
- PVC = Point of vertical curvature
- PVT = Point of vertical tangency
- G_1 = Grade of initial tangent (%)
- G_2 = Grade of final tangent (%)
- L = Length of vertical curve
- A = algebraic different in grade between G1 and G2.
- K = Vertical curve length coeffient (as in stopping sight distance)
- x = horizontal distance to point on curve from PVC

- E_x = Elevation of point on curve located at distance x from PVC
- x_m = Location of min/max point on curve from PVC
- E_m = Elevation of min/max point on curve at distance x_m from PVC.
- y = Offset of curve from initial grade line

Vertical Curve Equations

- A $= G_2 - G_1$
- K $= L / A$
- x_m $= |G_1 L / A|$
- y $= x^2 / 200K$
- Ex $= E_{pvc} + (G_1/100)x + [(G_2 - G_1)x^2 / 200L]$
- E_{PVC} $= E_{PVI} - |G_1/100|(L/2)$
- E_{PVT} $= E_{PVI} - |G_2/100|(L/2)$
- E on initial tangent $= E_{PVC} + (G_1/100)x$

Vertical Curve Properties

- This equation can only be used for the symmetrical parabolic curve.
- Other necessary point on curve should also be calculated in order to ensure proper drainage, clearance and connection to side streets.

Worked Example

- A plus 3% grade intersects a minus 2.0% grade at station 3+20 and at elevation of 320.40ft. Given that a 180-ft length of curve is utilized, determine the station and elevation of the PVC and PVT. Calculate elevations at every 25-ft station and locate the station and elevation of the high point of the curve. Sketch the given condition.

Sight distance

- Sufficient distance for drivers of clear vision ahead so they can avoid hitting expected obstacles and can pass slower vehicles without danger.
- Sight distance = length of road/highway that visible ahead to the drivers of a vehicles
- 2 types of sight distance :
  - Stopping sight distance
  - Passing sight distance

Stopping sight distance

- Minimum distance required to stop a vehicles that travelling near design speed before it reach stationary object.
- Sight distance at any point must as long as possible but in a situation where long distance cannot be provided, the distance cannot less than minimum stopping distance.
- Phases in stopping distance:
  - Distance travelled from object sighted until brakes applied
  - Distance required for stopping the vehicles after brakes is applied.

Stopping distance

First phase:

- Depend on speed of the vehicles
- The perception reaction time
- The brake reaction time

Second phase:

- Speed of the vehicles
- The deceleration rate of vehicles
- The road alignment
- The grade of the highway

Effect of grade on stopping distance

- For 2-way roads, sight distance for downgrades –G, is longer than sight distance for upgrades +G.
- The sight distance is depends on :
  - fundamental characteristics of the curve (crest or sag curve)
  - the algebraic difference in grades (A)
  - the length of curves (L).

Measuring stopping distance

- **Crest Curve**
- **S < L**
- **$L = AS^2 / 658$**
- **S > L**
- **$L = 2S – (658/A)$**
- Where,
- L = Length of crest vertical curve
- A = Algebraic difference in grades (%)
- S = Sight distance available over crest curve

Measuring stopping distance

Example 1

Calculate a stopping sight distance for a crest curve having curve length of 400m, a plus grade of 4.5% and an minus grade of 3.2%. The sight distance is restricted to be shorter than the length of curve.

Measuring stopping distance

Example 2

Calculate a stopping sight distance over the crest of the curve with plus grade of 5.8 and a minus grade of 3.9. The minimum length of curve is designed to be 400m.

Conclusion of The Chapter

- Conclusion #1
  - Definition of sag and crest curve and the profile grade lines are very important to understand the concept of vertical alignment.
- Conclusion #2
  - Vertical alignment's variables must be fully understandable by the students before designing the alignment.
- Conclusion #3
  - Design of the vertical alignment must be accompanied with sketches of the whole curves for a better understanding of the final results.

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