

# HIGHWAY GEOMETRIC DESIGN

Instructors:

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# Purpose

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- To introduce new highway designers and design technicians to the concepts needed for highway geometric design.
- To familiarize class participant with the Engineering Policy Guide (EPG), Standard Drawings for Construction, and the AASHTO Green Book.

# Materials

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- Roadway Geometric Design Notes (For you to keep)
- Engineering Policy Guide (Searchable Electronic Document)
- AASHTO Green Book Material

# Agenda

- Section 1: Design Controls & Criteria
  - Roadway Design Resources
  - Definitions
  - Highway Capacity
  - Facility Selection
  - Typical Section Elements
  - Access Management
- Section 2: Horizontal Alignment
  - Definitions
  - Geometric Elements
  - Design Controls & Guidelines
  - Superelevation and Widening of Curves

# Agenda

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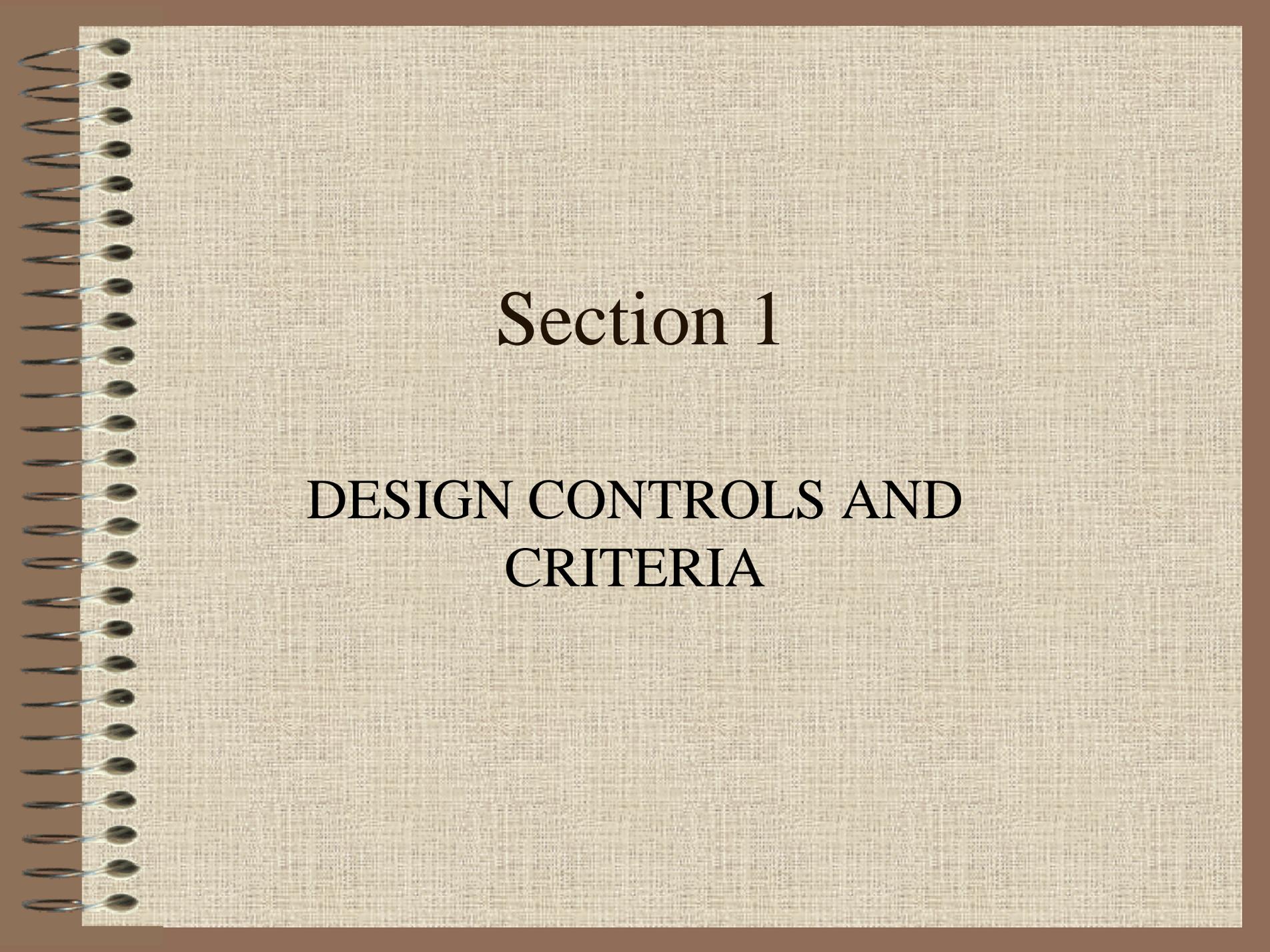
- Section 3: Geopak Classical COGO
  - Pull Down Menus
  - Creating & Editing Horizontal Geometry Elements
  - Individual Exercise

# Agenda

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- Section 4: Sight Distance and Vertical Alignment
  - Definitions
  - Stopping Sight Distance
  - Decision Sight Distance
  - Passing Sight Distance
  - Vertical Geometric Elements
  - SSD and Vertical Curves
  - Design Controls & Guidelines



The image shows the cover of a spiral-bound notebook. The cover is a light beige or tan color with a fine, woven fabric texture. On the left side, there is a silver metal spiral binding. The text is centered on the cover in a black, serif font.

# Section 1

## DESIGN CONTROLS AND CRITERIA

# Roadway Design Resources

## MoDOT Resources for Roadway Design:

- Roadway Geometric Design Notes (For you to keep)
- Engineering Policy Guide (Searchable Electronic Document)  
<http://epg.modot.org>
- Design Standard Plans for Highway Construction (Std. Drawings)

## MoDOT Standard Plans for Highway Construction

Standard Drawings show details on how to construct certain work items. Last hard copy of the standard plans issued was in July 2004. These Plans are also available electronically and are located in PW. Plans are in Microstation format and they're placed in folders according to effective date.

pwname://MoDOT/Documents/CADD\_Standards/Standard Plans for Highway Construction/

# Roadway Design Resources

## OTHER NON-MODOT RESOURCES

- AASHTO's A Policy on Geometric Design of Highways and Streets (a.k.a The Green Book)
- AASHTO's Roadside Guide Design Manual
- Highway Capacity Manual
- The Manual on Uniform Traffic Control Devices
- Other AASHTO, and FHWA publications
- Other publications on specific topics.

# Definitions: Traffic/Design Terms

## Volume

**AADT** or Annual Average Daily Traffic is the number of cars that travel a road in a 24-hr consecutive period averaged over 365 days.

**Peak-Hour Traffic** – traffic volume collected in a time shorter than one day (e.g. rush hour volume). Peak-hour traffic is used to determine the design hourly volume (DHV), which is often expressed as a percentage of the AADT.

- New roadway projects should not be based on the current traffic volumes, instead a design volume of a distant future should be obtained.
- Future traffic volumes are hard to accurately be predicted. Through years of research, highway engineers have found that a maximum design period is in the range of 15-24 years.
- At MoDOT we use a 20-year design volume for new construction. According to AASHTO, for reconstruction/rehabilitation projects, a period of 5-10 years may be chosen. 3R projects use a 10-yr design volume. 3R stands for resurfacing, restoration, and rehabilitation.

# Definitions: Traffic/Design Terms

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## Traffic Composition

Truck traffic volume is collected and determined in percentages to be used in the design.

For this purpose, trucks are normally defined as those vehicles having a gross vehicle weight (GVW) of 9,000 lbs and having dual tires on at least one rear axle

## Speed

*Design Speed* – is used as a parameter in the design. This is the maximum safe speed that can be maintained on a section of roadway for specific design features.

# Definitions: Traffic/Design Terms

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## Design Vehicle

The design vehicle characteristics are used to establish roadway design controls. This vehicle represents the weight, dimensions and operation characteristics for what the roadway is designed.

## Classification of Design Vehicles

- Passenger cars – cars, SUV's, mini-vans and vans, and pickup trucks
- Buses – inter-city (motor coaches), city transit, and school buses.
- Trucks – single unit trucks and tractor semi-trailer combinations.
- Recreational vehicles

AASHTO Green Book Exhibit 2-1 shows design vehicle dimensions and Exhibit 2-2 shows minimum turning radii. Exhibits 2-3 through 2-23 show the minimum turning path for the various different design vehicles.

# Definitions: Traffic/Design Terms

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## Vehicle Performance and Pollution

Acceleration/deceleration rates are a measure of vehicle performance and are important factors for proper design of ramps, climbing/passing lanes, and turnout bays for buses.

Vehicular pollution refers to air pollution from car emissions as well as noise pollution.

# Definitions: Traffic/Design Terms

How do drivers interact with the highway and information system presented to them?

## The Driving Task

This consists of a series of actions required to complete the journey. The task is based on many inter-related activities, which are classified as follow:

- Control – steering, speed control, shifting, etc.
- Guidance – following road signs
- Navigation – trip planning in general, looking at a map, etc.

Designers should keep designs simple and provide continuity in their roadway design to make it easier on the driver to complete the driving task.

# Definitions: Traffic/Design Terms

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## The Driver and the Information System

Drivers handle information through a short and complex process. This process happens in a short amount of time (reaction time) and includes three steps:

- Acknowledgment – recognize a situation exists
- Decision making – what should I do?
- Reaction – taking action

# Definitions: Traffic/Design Terms

## Reaction Time

Time it takes a driver to react to a situation, and it increases depending on the complexity of the situation and amount of information processed.

The longer the reaction time, the greater the chance for error.

For expected situation, average reaction times range from 0.6 sec up to 2 sec. However, for unexpected events, the reaction time increases up to 35%, taking 2.6 sec or more time for simple decision-making and action.

## How do drivers react to different situations?

Drivers react to situations based on the concepts of primacy and expectancy. Primacy refers to “how important is to my safety to respond”, and expectancy refers to continuity or familiarity of the roadway.

# Definitions: Traffic/Design Terms

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## Driver Error

There are two types of driver errors:

- Due to situation demands – careful planning and design can prevent these types of errors.
- Due to driver deficiencies – lack of driver experience, influence of alcohol and drugs, and advancing age.

# Highway Capacity

## Highway Capacity Manual (HCM)

The HCM is used to determine or assess roadway capacities. Highway capacity is the maximum hourly rate at which vehicles can reasonably travel a particular section of roadway during a given time under normal roadway and traffic conditions.

Always consult with district traffic studies engineers when assessing roadway capacities.

## Levels of Service (LOS)

Levels of service is a subjective way to define the roadway capacity.

A – Free flow

B – Reasonable free flow

C – Stable flow

D – Approaching unstable flow

E – Unstable flow

F – Forced or breakdown flow

# Facility Selection

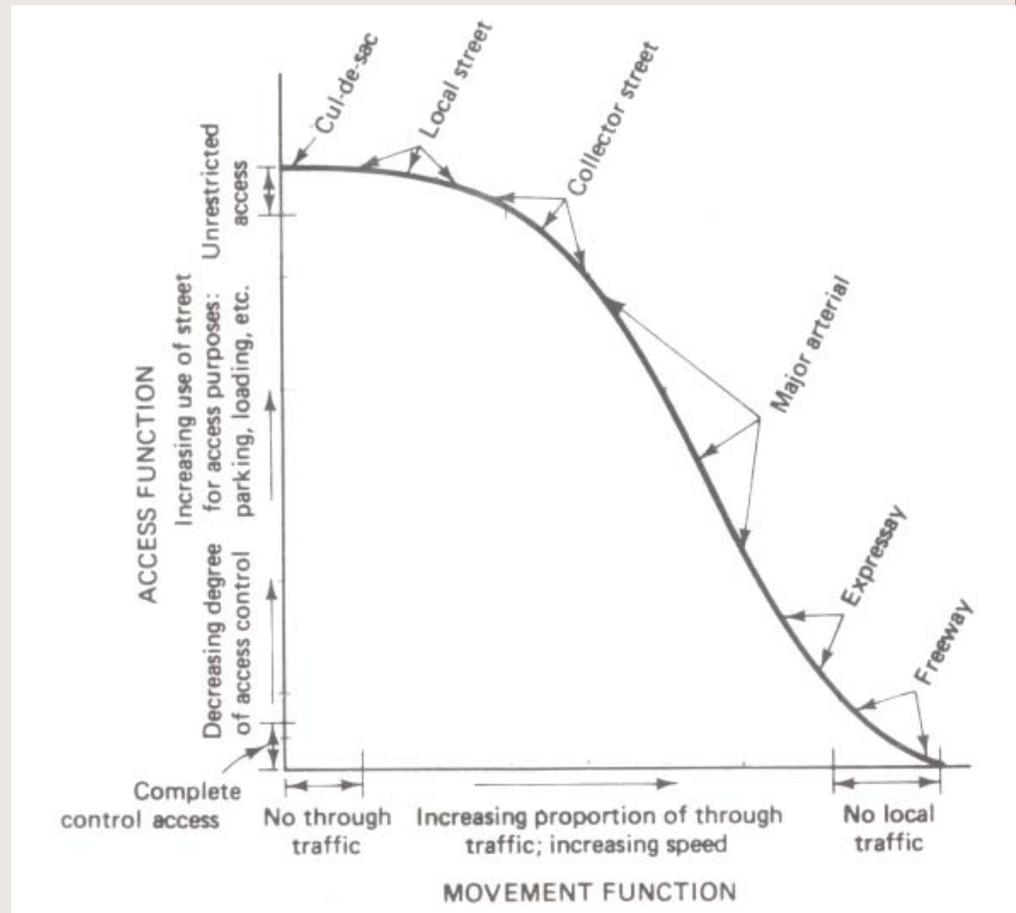
EPG Category: 232

## Mobility vs. Access?

Roadways are classified based on travel mobility and access to property.

The faster traffic moves, the less access it has to adjacent property.

Roadway classification determines the type of criteria used for the design.



# Facility Selection

EPG Category: 232

## The Rural Roadway System consists of:

- Rural Principal Arterials – freeways and other principal arterials, which provide relatively high travel speed. These roads carry state and interstate traffic, and movements between urban areas. Examples: interstate highways, and some US routes.
- Rural Minor Arterials – provide linkage for cities or larger towns, integrated interstate and intercounty travel.
- Rural Collectors – primarily carries intracounty traffic rather than statewide.
- Rural Local Roads – include all rural roads not classified as any of the above. These roads provide direct access to adjacent property.

# Facility Selection

EPG Category: 232

## The Urban Roadway System consists of:

- Urban Principal Arterials – freeways and other principal arterials, which provide relatively high travel speed. These roads carry movements entering and exiting urban areas or movements bypassing the central city.
- Urban Minor Arterials – arterials not classified as principal. This system provides intra-community travel and may include bus routes. This system does not enter neighborhoods.
- Urban Collectors – provide both land access and traffic circulation within neighborhoods, commercial and industrial areas, and it also carry local bus routes.
- Urban Local Roads – provide direct access to adjacent property and has the lowest level of mobility. These roads do not carry bus routes.

# Facility Selection

EPG Category: 232

## MoDOT Roadway Classification:

- Major Highways – Principal Arterials (and above) in the state, which include all NHS routes and Interstate as well as some other routes which are not on the NHS.
- Non-Major Highways – All minor arterials (and below).

# Facility Selection

EPG Category: 232

## Primary Design Guidance:

Roadway design will be based on the following criteria:

1. Design Speed = Posted Speed
2. Level of Service
  - Rural – 20 yr peak hourly traffic at LOS D and off-peak at LOS C
  - Urban - 20 yr peak hourly traffic at LOS E and off-peak at LOS D
3. System Continuity
4. Access vs. Mobility
5. Expressway vs. Freeway
6. Two Way Left Turn Lanes
7. Passing Lanes

# Section Elements for Roadway

EPG Category: 231

## Lane Widths

- Major Roadways = 12 ft wide
- Minor Roadways = 10 –12 ft wide
- Auxiliary lanes are to be as wide as the through-traffic lanes.
- For very low volume local/collector roads and streets carrying < 400 veh/day, use guidance in the AASHTO Green Book section for Geometric Design of Very Low Volume Local Roads.

# Section Elements for Roadway

EPG Category: 231

## Shoulder Widths

- Never eliminate shoulders altogether. Motorists expect them.
- Shoulders on major roadways = 4-10 ft wide.
- Shoulders on rural minor roadways = 2-4 ft wide.
- Shoulders will not be provided on urban roads with no access control if ample turning opportunities exist for a vehicle to leave the roadway. (No U2 paved shoulders).
- An earthen shoulder will be provided behind a mountable curb.

# Section Elements for Roadway

EPG Category: 231

## Median Widths

- 60-ft depressed median is preferred for expressways and freeways.
- Narrower than 60-ft median may be used with a barrier on expressways and freeways.

# Section Elements for Roadway

EPG Category: 231

## Side Slopes

- In-slopes should be designed based on the geotechnical report recommendations as well as the AASHTO Roadside Design Guide to meet a safe clear zone.
- Backslope grade should be designed based on the geotechnical report recommendations including benching design. When good quality rock is present, you can use a 1:1 backslope from the back of the ditch to establish theoretical slope limits for determining R/W limits.

# Section Elements for Roadway

EPG Category: 231

## Roadside Ditches

- The purpose of a ditch is to provide adequate drainage for the design storm event and also to prevent seepage under the pavement through a permeable base.
- The geometry selected for ditches are based on hydraulic capacity. Keep the side slope requirements based on clear zone principles and/or soil conditions.
- When using pavement edge drains, make sure the ditch is of sufficient depth.
- Min. ditch grades are based on the drainage velocities needed to avoid sedimentation as max. ditch grades are based on a tolerable velocity for vegetation and shear on soil types.
- Use the appropriate erosion control methods to reduce or withstand the flow velocity.

# Access Management

EPG Category: 940

## Control Access vs. Access Management

Control access refers to simply regulating access while access management is the proper planning and design of access to the public roadway system that helps ensure traffic flow more smoothly and with fewer crashes.

# Access Management

EPG Category: 940

## Why should we control access

Roadways with full access control consistently experience much lower crash rates than those without any access control.

To achieve an acceptable access management design, one should:

- Limit direct access to roads with higher functional classifications.
- Locate traffic signals to emphasize through traffic movements.
- Locate driveways and major entrances to minimize interference with traffic operations.
- Use curbed medians and locate median openings to manage access movements and minimize conflicts.

# Pedestrian Facilities

EPG Category: 642

## Resources for design of pedestrian traffic:

- Engineering Policy Guide
- *The American with Disabilities Act Accessibility Guidelines (ADAAG)*
- *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities.*
- *FHWA: Designing Sidewalks and Trails for Access.*
- Technical assistance available on case-by-case from either the Missouri office of the U.S. Access Board or the MoDOT's Non-Motorized Transportation Engineer.

# Pedestrian Facilities

EPG Category: 642

## When do we provide sidewalks?

- The local jurisdiction has a comprehensive pedestrian policy in the area of proposed improvement.
- There is public support through local planning organizations.
- There is evidence of pedestrian traffic along proposed improvement.
- Pedestrian traffic generators are located near the proposed project.
- The route provides access across a natural or man-made barrier.
- Existing sidewalks are disturbed by construction.

# Pedestrian Facilities

EPG Category: 642

## MoDOT Sidewalk Design Criteria:

- In developed areas, separate the sidewalks from the traveled way (barrier curb).
- No sidewalks on paved shoulders behind mountable curbs (NO U2 SHOULDERS).
- Provide paved shoulders in rural areas to accommodate pedestrian movements.
- Designated sidewalks or pedestrian paths must be accessible according to ADA guidelines.
- Min. width = 5ft and min. depth = 4 in thick. (Okay to reduce min. width = 4 ft, which is the min. allowed by ADA guidelines).

# Pedestrian Facilities

EPG Category: 642

## Walking Speeds

Average speeds for pedestrians range from 2.5-6 ft/sec. The MUTCD uses an average of 4 ft/sec as a design control.

## Some intersection guidelines include:

- Design should provide adequate storage area for those waiting to cross intersection.
- Crosswalks should be wide enough to accommodate pedestrian flow in both directions within the duration of the pedestrian signal phase.
- Avoid designing extremely wide streets as this provides too long of a pedestrian crosswalk.
- If wide street intersection is unavoidable, provide islands or medians at which the pedestrians can safely await to continue crossing the intersection.

# Pedestrian Facilities

EPG Category: 642

## Some intersection guidelines include:

- Eliminate left and/or right turns
- Prohibit right turn on red
- Convert from two-way to one-way street operation
- Provide separate signal phases for pedestrians
- Provide for pedestrian separations

# Bicycle Facilities

EPG Category: 641

## When do we provide bicycle facilities?

- Design and installation of bicycle facilities is at the sole discretion of the director or the district engineer.
- All decisions regarding bicycle facilities must be properly documented.
- Dedicated Bicycle facilities WILL NOT be provided on interstate roadways.
- If local jurisdiction is willing to assume the cost of the bicycle facility and R/W associated with it, the design should consider inclusion of bicycle lanes.
- Existing bicycle facilities disturbed by any MoDOT improvement will be replaced at MoDOT's expense.

# Right-of-Way

EPG Category: 236

## R/W Considerations

R/W is classified according to the type of access given to a roadway. The R/W type related to access control and the limits of such control is indicated on the plans and on the title sheet by proper legend.

## Minimum R/W width

- Acquire only the minimum R/W width needed to build and maintain the facility.
- Attempt to minimize breaks in R/W line.
- Take into account utilities corridors, easements, future improvements, and maintenance of the facility.

# Right-of-Way

EPG Category: 236

## Types of R/W

**Normal** – Allows entrances to the road wherever necessary to access a property.

**Controlled access** – (limited access) Limits the points of access to specific locations, types and dimensions.

**Fully controlled access** – Allows access only at interchanges thru extensive outer or service roadways.

**Partial controlled access** – Controls access at intersections at all state roads and side roads which intersect a state route carrying an ADT > 1700

**No R/W access** – Prohibits access to side roads near the interchanges.

# Right-of-Way

EPG Category: 236

## R/W Takings

R/W takings are based on the survey baseline. This survey centerline or baseline may not necessarily be in the “center” of the roadway pavement.

**NEVER** move a survey baseline that surveyors pick up.

## EPG Category 235: Preliminary Plans

235.2 The district prepares preliminary plans. The preliminary plan is prepared once horizontal and vertical alignment and tentative right of way limits have been established. Where the horizontal alignment is to tie into existing roadways or alignments, the tie location is based on field survey measures and verifications.

## EPG Category 238: Surveying Activities

238.3.1.1 A survey is made to physically establish a location in the field. It includes the location of all man-made features in relation to the established roadway centerline in such a manner that these features can be accurately indicated on the plans. The survey also includes elevations on National Geodetic Survey (NGS) or United States Geodetic Survey (USGS) datum necessary to locate grades, culverts, bridges, and to compute excavation quantities.

238.3.1.16 Before beginning a survey, the district survey party chief is furnished a copy of the location study. They become familiar with the type of proposed improvement, the plan for improving or relocating intersections, the location and type of interchanges, and all other information necessary to complete the survey.



# SECTION 2

## ELEMENTS OF DESIGN

Horizontal Alignment and Superelevation

EPG Category: 200 Geometrics

230: Alignments of the Roadway

230.1: Horizontal Alignments

AASHTO Green Book Chapter 3

# Elements of Design

EPG Category 230.1: Horizontal Alignment

A roadway design should provide safe, continuous operation at a speed at which most of the traffic travels under normal conditions while being economically practical.

Geometric elements allow the designer to provide such balanced design.

These geometric elements are known as horizontal and vertical alignments.

# Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

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## What is it?

*Horizontal alignment* is the physical location of a roadway baseline composed of geometric elements such as points, lines, and curves. This horizontal alignment is known as a “chain”.

Users can create these elements using GEOPAK traditional Coordinate Geometry (cogo), graphical cogo or/and horizontal alignment tools.

# Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

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Chains are expressed in terms of bearings, distances, curvature, transitions, stations, and offsets.

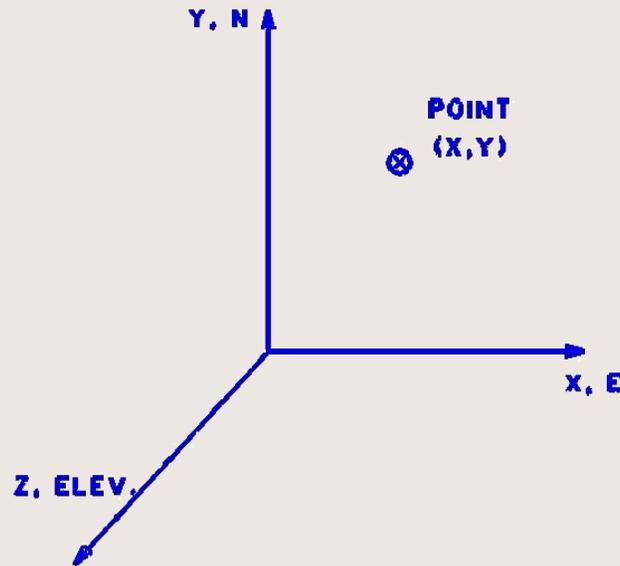
Typically, the alignment dimensions and distances are tabulated in a manner that facilitates construction staking as conducted by a field surveying crew. *EPG Table 237.1.1*

# Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

## Coordinate Geometry Definitions:

**Points** – are defined by a single set of coordinates. Each point has an X and Y coordinate. If an elevation is defined, the point may also have a Z coordinate.



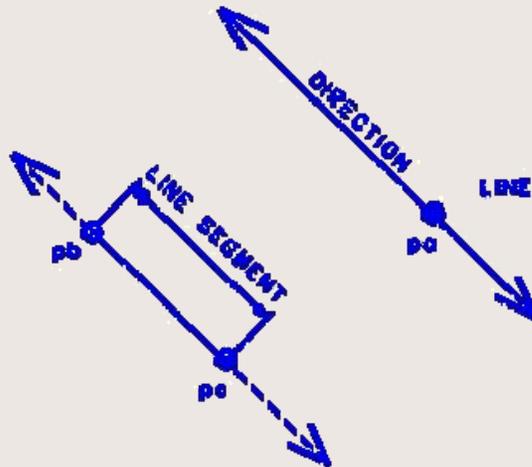
# Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

## Coordinate Geometry Definitions:

**Lines** – are defined by a location point and a direction, and are infinite in length.

**Line segments** - are a portion of a line that is defined by a beginning and an ending point.



# Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

## Coordinate Geometry Definitions:

**Curves** – are a segment of a circular arc.

**Types of curves** – simple, spirals, reversed, and compound curves

**Simple Curves** – Most commonly used in highway design.

MoDOT uses simple curves unless project parameters meet the requirements for a spiral curve.

**Reverse Curves** – are only suitable for low speed roads such as a temporary bypass.

**Compound Curves** – Typically used for low-speed turning roadways at intersections.

# Elements of Design: Horizontal Alignment

## EPG Category 230.1: Horizontal Alignment

**Spiral Curves** – Provide a gradual change from the tangent section to the circular curve and vice versa.

### Advantages:

1. A properly designed transition curve will provide a natural and smooth path, and will minimize encroachment on adjoining traffic.
2. Transition curve length provide a suitable location for Superelevation runoff length.
3. Spirals facilitate the transition in width where widening of the pavement is needed.
4. Appearance of highway is enhanced, a transition curve can avoid noticeable breaks in alignments or “kinks”.

# Elements of Design: Horizontal Alignment

## EPG Category 230.1: Horizontal Alignment

### Coordinate Geometry Definitions:

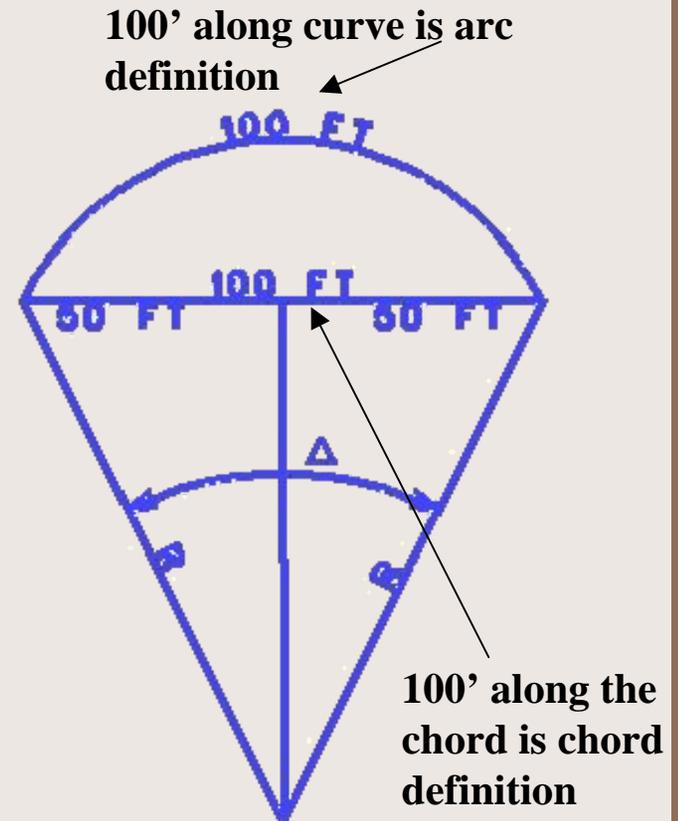
**Simple Curves** – are defined by degree of curvature in the traditional U.S. unit system and by radius in the metric system.

**Degree of Curvature** – Arc definition or Chord definition.

**Arc definition\*** – central angle subtended by an arc of 100 ft.

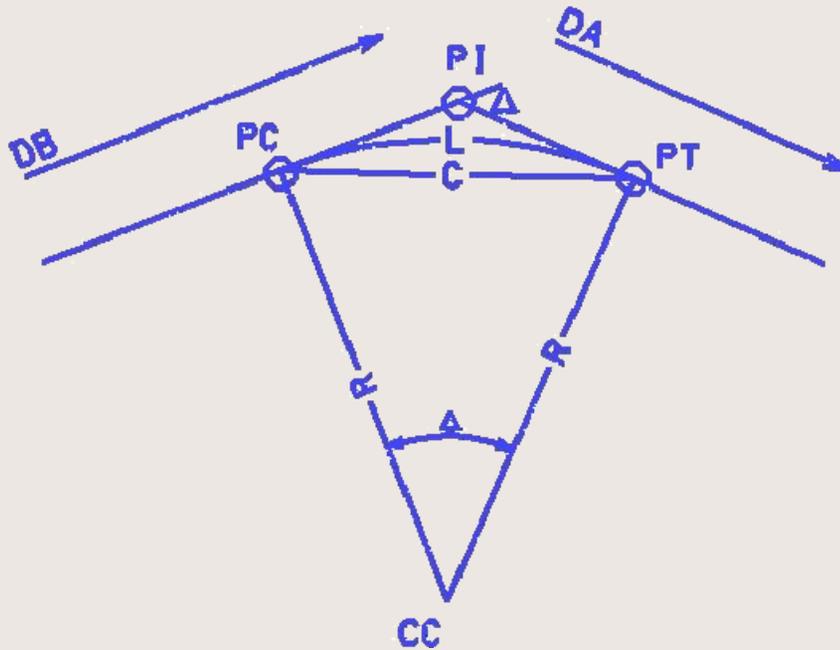
**Chord definition** – central angle subtended by a chord of 100 ft.

\* Arc definition is used for new alignments.



# Elements of Design: Horizontal Alignment

## Simple Curve Geometry



PC=Point of curvature  
 PT=Point of tangency  
 PI=Point of intersection  
 Δ=Central angle  
 L=Length of curvature  
 D=Degree of curvature  
 R=Radius of curve  
 C=Chord length  
 T=Tangent length

$$L = \frac{\pi R \Delta}{180}$$

$$\text{(Arc Def.) } \frac{2\pi R}{360} = \frac{100 \text{ ft}}{D} \text{ or } R = 5729.58/D$$

$$T = R \tan (\Delta/2)$$

$$\text{(Chord Def.) } R = 50/\sin (\Delta/2)$$

$$C = 2R \sin (\Delta/2)$$

# Elements of Design: Horizontal Alignment

## EPG Category 230.1: Horizontal Alignment

### MoDOT Criteria for Curves:

- ✓Arc definition should be used for all new alignment
- ✓Chord definition ONLY used when an existing curve is utilized in the alignment

### Approximate Length of curvature:

- ✓For design speeds  $\leq 60$  mph,  $L=15 \times$  design speed
- ✓For design speeds  $> 60$  mph,  $L=30 \times$  design speed

### For small deflection angles:

- ✓For roadways with less than 400 vehicles/day, no curves are required for central angles of 1 degree or less
- ✓L must be at least 500 ft for a central angle of 5 degrees
- ✓L must increase 100 ft for 1 decrease in the central angle

# Elements of Design: Horizontal Alignment

## EPG Category 230.1: Horizontal Alignment

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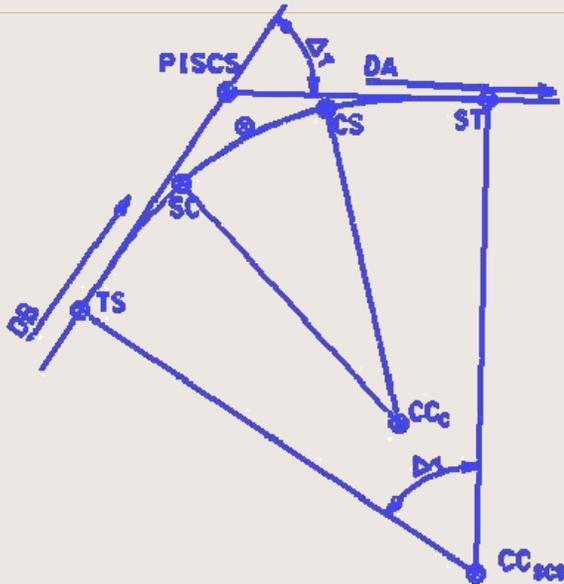
### When do we use spiral curve combinations?

If project data meets all three of the following MoDOT guidelines:

1.  $ADT > 400$
2.  $V > 50$  mph
3.  $Radius < 2865$  ft

# Elements of Design: Horizontal Alignment

## Spiral Curve Geometry



**TS=Tangent to Spiral Point**

**SC=Spiral to Curve Point**

**CS=Curve to Spiral Point**

**ST=Spiral to Tangent Point**

**PISCS=Overall PI**

**Δ<sub>T</sub>=Total Central Angle (degrees)**

**L<sub>s</sub>=Length of Spiral (ft)**

**L<sub>c</sub>=Length of Curve (ft)**

**D=Degree of Curvature (degrees)**

**T<sub>s</sub>=Tangent Length of SCS (ft)**

**R=Radius (ft)**

$$T_s = R \tan \Delta_T / 2$$

$$\text{(Arc Def.) } R = \frac{5729.6}{D}$$

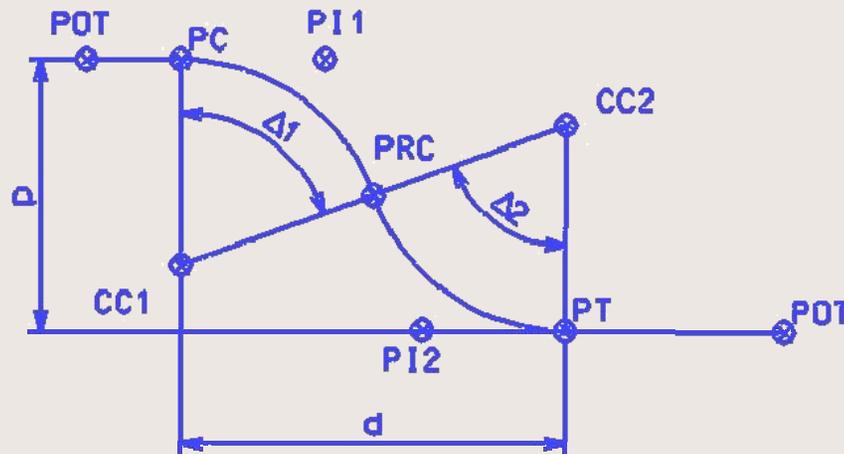
$$\text{(Chord Def.) } R = 50 / \sin \Delta / 2$$

L<sub>s</sub> = L in Standard Plans 203.20 & 203.21

Also see AASHTO Green Book Superelevation tables

# Elements of Design: Horizontal Alignment

## Reverse Curve Geometry



POT=Point on a Tangent

PC=Point of Curvature

PI=Point of Intersection

PT=Point of Tangency

PRC=Point of Reverse Curve

$R_1, R_2$ =Radius for C1 & C2 (ft)

$\Delta$ =Central angle (Same for both curves) units are degrees

p=Offset Distance (ft)

d=Tangent Distance (ft)

Equations:

$$p=(R_1 + R_2)(1-\cos \Delta)$$

$$d=(R_1 + R_2)(\sin \Delta)$$

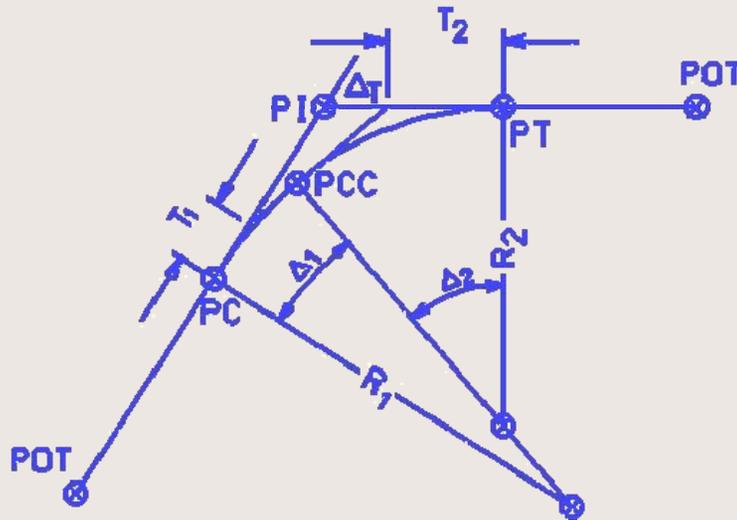
If  $R_1 = R_2$

$$p=2R(1-\cos \Delta) \quad p/d = \tan (\Delta/2)$$

$$d =2R\sin \Delta$$

# Elements of Design: Horizontal Alignment

## Compound Curve Geometry



PC=Point of Curvature

PI=Point of Intersection

PT=Point of Tangency

PCC=Point of Compound Curve

$R_1, R_2$  =Radius for C1 & C2 (ft)

$\Delta_1, \Delta_2$  =Central Angle for C1 & C2 (degrees)

$T_1, T_2$  =Tangent for C1 & C2 (ft)

$\Delta_T$  =Total Central Angle (degrees)

Equations:

$$\Delta_T = \Delta_1 + \Delta_2$$

$$T_1 = R_1 \tan \Delta_1 / 2$$

$$T_2 = R_2 \tan \Delta_2 / 2$$

# Elements of Design: Horizontal Alignment

## Chains

Chains are a combination of other elements such as points, curves, spirals, or other chains.

Chains have stationing associated with them. Locations along a chain can be determined by the stationing. Sometimes stations equations are used.

**What are Stations?** Stations are points along a chain which describe a distance from a reference point, usually the beginning of the project.

Conventional stationing proceeds North-South or West-East

One station = 100 ft (English)

One station = 1 km (Metric)

# Elements of Design: Horizontal Alignment

## Finding stationing at critical points:

### Simple Curves:

$$\text{PI station} = \text{PC station} + T$$

$$\text{PT station} = \text{PC station} + L$$

### SCS Combinations:

$$\text{SC station} = \text{TS station} + L_s$$

$$\text{CS station} = \text{SC station} + L_c$$

$$\text{ST station} = \text{CS station} + L_s$$

### Compound Curves:

$$\text{PCC station} = \text{PC station} + \text{Length of Curve 1}$$

$$\text{PT station} = \text{PCC station} + \text{Length of Curve 2}$$

### Reverse Curves:

$$\text{PRC station} = \text{PC station} + \text{Length of Curve 1}$$

$$\text{PT station} = \text{PRC station} + \text{Length of Curve 2}$$

# Elements of Design: Horizontal Alignment

## Curve Data for Plans Preparation

- PI, PC, and PT Stations
- Central Angle,  $\Delta$
- Degree of Curvature, D
- Length of Curvature, L
- Tangent Length, T
- Radius of Curve, R
- Superelevation, SE
- Bearings
- Overall PI for SCS combinations

### Geopak

```

CURVE RTE15
TOTAL PI 4+91.93
SC 0+00.00
CS 6+17.88
TOTAL  $\Delta$  37° 31' 23.0" (RT)
D 4° 46' 28.7"
Lc 617.88'
Ls 168.00'
Ts 491.93'
R 1,200.00'
Gs 4° 00' 38.5"
Xs 167.92'
Ys 3.92'

CURVE C6
PI 2+60.10
PC 0+00.00
PT 8+08.92
 $\Delta$  29° 09' 33.1" (RT)
D 5° 43' 46.5"
L 508.92'
T 250.10'
R 1,000.00'
    
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### Settings Manager

# Elements of Design: Horizontal Alignment

## EPG Category 230.1: Horizontal Alignment

### **MoDOT Guidelines for stationing chains**

- ✓ Centerline of median is generally used as the survey base line for divided pavement improvements
- ✓ If median  $> 100$  ft or is not parallel, then consideration should be given to using the inside edge of traveled way of each lane for individual alignment
- ✓ For undivided pavements, the survey base line is at the “center” of the pavement
- ✓ Use existing centerlines when practical
- ✓ Conventional stationing proceeds from N-S or W-E
- ✓ Crossroad stationing of intersected roadways is based on the existing stationing, if it exists
- ✓ If there is no existing stationing on a crossroad, then stationing proceeds from the left side of the intersection to the right side.

# Elements of Design: Horizontal Alignment

## EPG Category 230.1: Horizontal Alignment

### **MoDOT Guidelines for stationing chains**

- ✓ New stationing for intersections is chosen such that a five station increment occurs at the intersection with the main roadway
- ✓ For ramps, the base line is located along the right edge of the traveled way relative to the direction of traffic
- ✓ Stationing for ramps is carried in the direction of traffic, except for diamond interchange ramps
- ✓ Diamond interchange ramps are stationed in the same direction as the main line
- ✓ Ramp base lines are equated to the main roadway or cross road at the termini

# Elements of Design: Superelevation

## EPG Category 230.1: Horizontal Alignment

Regardless of the type of curve being designed, their design should be based on an appropriate relationship between design speed, curvature or radius, “superelevation”, and side friction or pavement friction.

### What is SuperElevation (SE)?

Superelevation is simply when we “tilt” a curve towards its inner side in order to keep vehicles from slipping due to the centrifugal forces acting upon them.

A vehicle moving on a circular path experience a centripetal acceleration which acts towards the center of curvature.

This acceleration is prolonged either by the weight of the vehicle related to the SE, the side friction between the vehicle tires and pavement, or by a combination of the two.

# Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

## Design Considerations

Maximum SE rates are used to determine minimum curvature for the design speed chosen.

The 4 factors controlling maximum SE rates are:

1. Climate conditions (frequency and amounts of ice/snow)
2. Terrain conditions (flat, rolling, mountainous)
3. Type of area (rural vs. urban)
4. Frequency of very slow moving vehicles

# Elements of Design: Superelevation

## EPG Category 230.1: Horizontal Alignment

Certain limiting values for maximum SE rate  $e_{\max}$  and side friction  $f_{\max}$  have been determined through extensive research and are used to determine the minimum radius of curve for a particular design speed.

Limiting values for  $e_{\max}$  and  $f_{\max}$  are found in AASHTO Green Book.

The equation below shows the relationship between SE, friction and radius of curve.

$$R_{\min} = \frac{V^2}{15(0.01e_{\max} + f_{\max})}$$

This equation is used to determine the values in the SE tables in Std. Plans [203.20](#) & [203.21](#) and AASHTO Green Book Superelevation tables.

# Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

## Transitioning Superelevation

Transitioning refers to going from normal crown to  $e_{\max}$  as well as going from tangent section to curve and vice-versa.

## SE Transition sections

- Superelevation transition runoff (L)– length of roadway needed to accomplish the change in outside lane cross slope from flat (zero) to full SE and vice-versa.
- Superelevation tangent runout (x) – length of roadway needed to accomplish the change in outside lane cross slope from normal crown to flat (zero) slope.

# Elements of Design: Superelevation

## EPG Category 230.1: Horizontal Alignment

### Runoff Calculations

For MoDOT designs, the runoff length  $L_{\text{runoff}}$  is already calculated for specific lane widths and design SE rates. See Standard Drawings 203.20 & 203.21 or AASHTO Green Book Exhibits Superelevation tables and graphs.

### Tangent Runout Calculations, $x$

Minimum Runout Length – determined by the amount of adverse cross slope to be removed and the rate at which it is removed.

$$x = \frac{\text{NC}(\%)}{e(\%)} \times L_{\text{runoff}}$$

$x$  – runout (AASHTO Green Book calls this  $L_t$ )

$L_{\text{runoff}}$  – runoff

$e$  – max. SE rate\*

\* From Std Drawing [203.20](#) & [203.21](#) or AASHTO Green Book Superelevation tables.

# Elements of Design: Superelevation

## EPG Category 230.1: Horizontal Alignment

### AASHTO Recommendations on SE rates:

1. A maximum of 12% should be used for rural situations.
2. Any SE rates  $> 8\%$  should only be used where no ice/snow conditions exist.
3. For urban design, 4%-6% SE rates are recommended.
4. SE can be omitted on low-speed urban design areas.

Because there is no single maximum SE rate that is universal, the transportation industry uses a range of SE rates for various criteria.

At MoDOT, these SE rates are listed in Standard Drawings [203.20](#) & [203.21](#). AASHTO Green Book Superelevation tables and graphs can also be used.

# Elements of Design: Superelevation

## EPG Category 230.1: Horizontal Alignment

### MoDOT Guidelines:

MoDOT's maximum SE rates tables are found in Standard Drawings [203.20](#) & [203.21](#)

1. Maximum of 8% SE rate for rural design ([203.20](#) Pg. 2/5; [203.21](#) Pg. 3/5).
2. Maximum of 4% SE rate for urban design ([203.20](#) Pg. 2/5; [203.21](#) Pg. 3/5).

Look up design speed column and find the corresponding e% for the appropriate radius of curve. Use the nearest value if not found in table.

$L_{\text{runoff}}$  = Length of Superelevation Runoff

NC – Normal Cross Slope

RC – Remove Adverse Cross Slope (reversed crown)

w = Amount of widening required

# Elements of Design: Superelevation

## EPG Category 230.1: Horizontal Alignment

### Methods of attaining SE for undivided highways (Std. Plan [203.20](#))

Case 1: Rotating about the centerline (Page 3/5).

Case 2: Rotating about the inside edge (Page 4/5).

Case 3: Rotating about the outside edge (Page 5/5).

### Methods of attaining SE for divided highways (Std. Plan [203.21](#))

SE for divided highways is attained by rotating about the inside edge of pavement.

### How SE should be shown on plans

When using SE rates specified in the guidelines; only SE max. rate and widening are required on plans. However, construction likes to see the station and SE transition slopes on the cross sections.

*If not using SE rates specified in the guidelines, complete details of all transitions are required on plans.*

# Elements of Design: Widening

## EPG Category 230.1: Horizontal Alignment

### Application of Widening on Curves

With the introduction of Practical Design, narrower traveled ways are being designed. Some curves may not provide adequate width to fit the paths of the vehicles entering or leaving the curve.

### Guidelines on widening (AASHTO)

- On unspiraled curves, apply the widening to the inside edge of traveled way only.
- On spiraled curves, you may apply the widening to the inside edge of traveled way OR divided equally on either side of the centerline.
- Widening should transition over the superelevation runoff length when practical, but shorter lengths are sometimes used.
- Widening transition should be a smooth, graceful curve. A tangent transition should be avoided.

# Elements of Design: Widening

EPG Category 230.1: Horizontal Alignment

## How much widening to apply?

The amount of widening is based on the curve radius, speed, design vehicle and width of lane width.

Amount of widening is tabulated on MoDOT Std. Plans [203.20](#) and [203.21](#) These values are for a WB-50 AASHTO designation design vehicle (intermediate semi-trailer) and 2-lane roadways.

Designers can always refer to the AASHTO Green Book widening tables.



# Section 3

**INTRODUCTION TO GEOPAK  
CLASSICAL COGO**

# Geopak COGO

## Geopak Coordinate Geometry

COGO is a method of using XYZ coordinates to store geometric elements such as points, lines, curves, spirals, chains, parcels and profiles.

The Geopak COGO tools are dialog and key-in driven.

The file in which Geopak stores all the geometry is called a “GPK file” and it is a binary database can only be viewed through Geopak.

# Storing Elements in COGO

## The Coordinate System

The coordinate system is defined with XYZ coordinates. The X and Y coordinates define a horizontal plane, while the Z coordinate defines the vertical dimension. The XYZ coordinates can also be referred to as Northing (N), Easting (E), and Elevations (Z) coordinates.

Northing = Y; Easting = X, and Elevation = Z

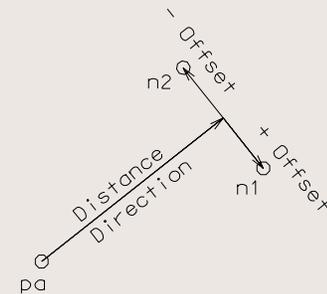
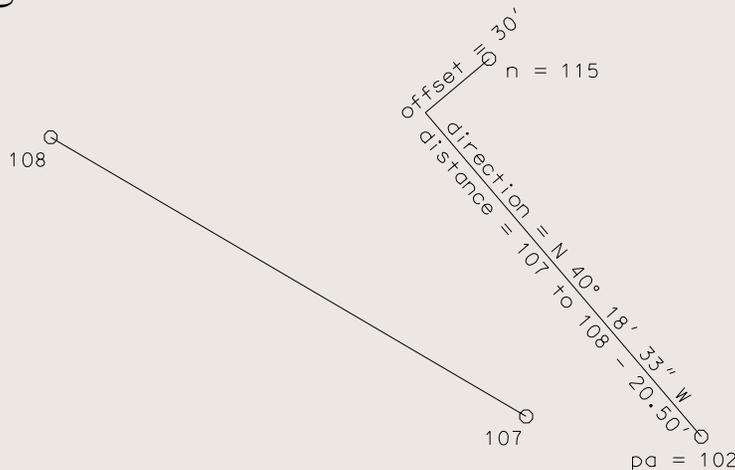
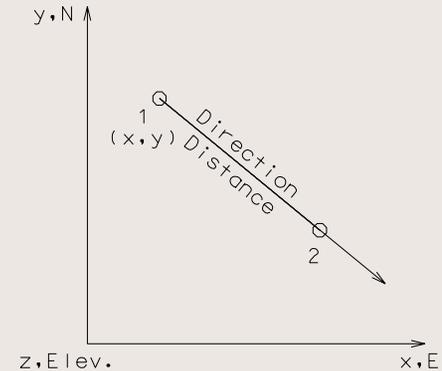
## Storing Elements

- All element names can be alpha-numeric. Alphabetic characters must be used before the numeric characters.
- Names can be up to 9 characters in length. Recommend up to 8
- Can use a number of tools to store elements

# Storing Elements in COGO

## Points

- Defined by single set of coordinates (X, Y).
- May have a Z coordinate if an elevation is defined.
- Names must contain at least 1 numeric character at the end of name.
- Stored from a set of coordinates, or located from existing elements.



loc 115 trav 102 dis 107 to 108 m 20.50 n 40 18 33 w off 30

# Storing Elements in COGO

## Curves and Spirals:

There are several ways to store curves, spirals and curve-spiral combination in Geopak.

The user must know some of the parameters prior to invoking any dialog boxes.

Depending on what parameters are available, the user may need to store points prior to selecting the most appropriate tool in Geopak.

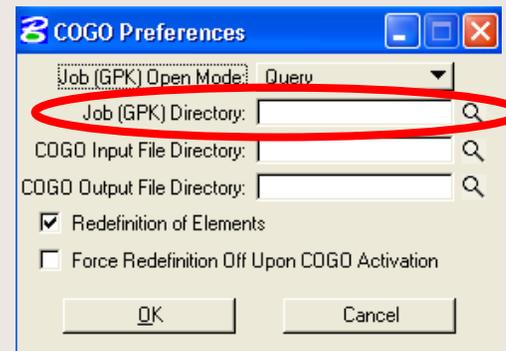
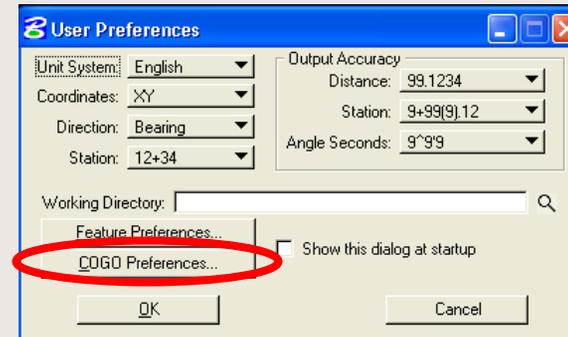
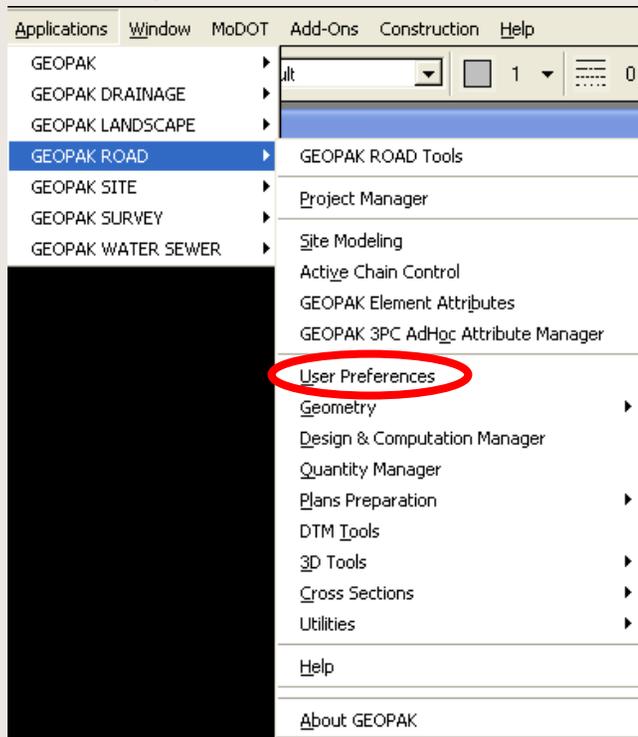
## Chains and Profiles:

Chains can be stored once the individual elements are stored in COGO.

The only kind of profile that can be stored directly from COGO is an “offset” profile. Existing and proposed profiles must be stored using another tool in Geopak.

# Accessing COGO

## Clearing User Preferences



Working Directory: Folder in ProjectWise where your Microstation files reside

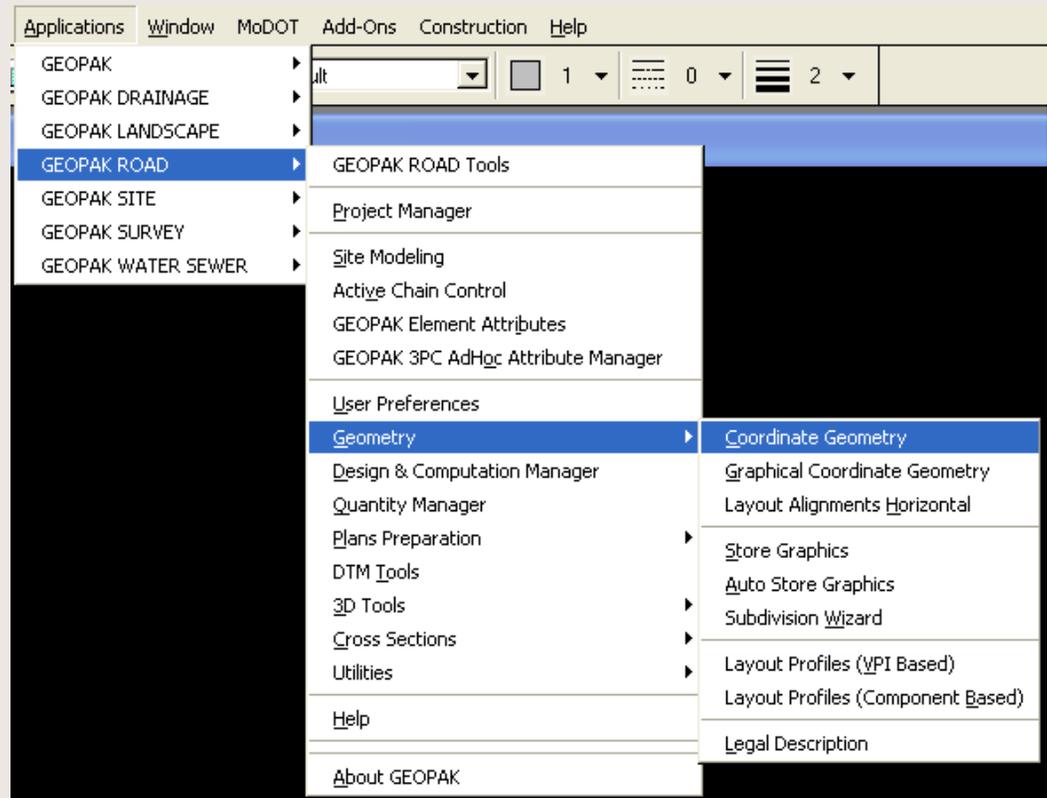
Job (GPK) Directory: Folder in the t-drive where your GPK file is stored

# Accessing COGO

From Geopak Road Tools:



From Geopak Road Pull Down Menu:



# Accessing COGO

## Cogo Dialog Boxes

**Coordinate Geometry**

Project Name:

Job:

Operator Code:

Subject:

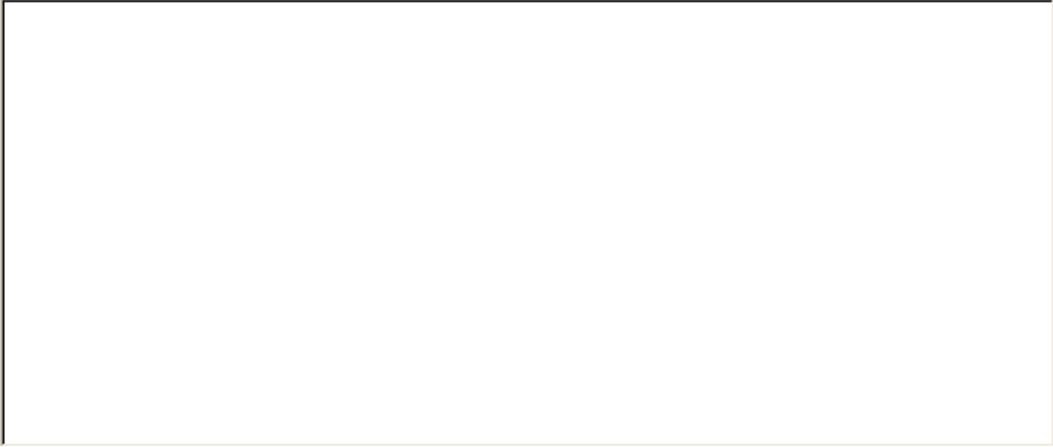
**Coordinate Geometry Job: 323 Operator: am**

File Edit Element View Tools

Redefine

9^99 << < > >>

COGO Key-in:





# Section 4

## ELEMENTS OF DESIGN

Sight Distance and Vertical Alignment

EPG Category 230: Geometrics

230: Alignments of the Roadways

230.2: Vertical Alignment

AASHTO Green Book Chapter 3

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

**Definition** – Sight distance is the length of roadway visible ahead to the driver of the vehicle.

## Types of Sight Distances

- Stopping Sight Distance (SSD)
- Decision Sight Distance (DSD)
- Passing Sight Distance (PSD)
- Operational Sight Distance (OSD)

# Elements of Design: Sight Distance

## EPG Category 230.1: Horizontal Alignment

Stopping Sight Distance (SSD) refers to both horizontal and vertical views.

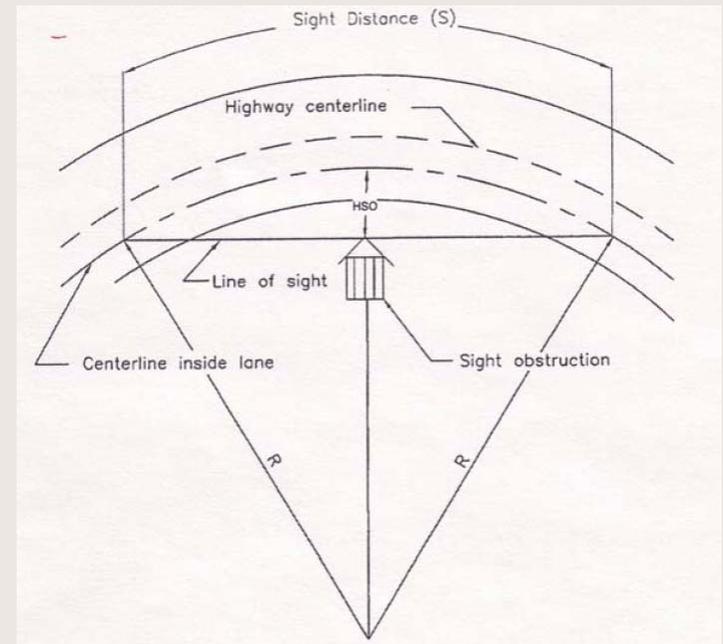
$$HSO = R \left[ 1 - \cos \frac{28.65S}{R} \right]$$

Where,

HSO= Horizontal sightline offset (ft)

R= Radius of Curve (ft)

S= Stopping Sight Distance (ft)



# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

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## Vertical SSD

By definition, SSD is the sum of two distances

1. *Break reaction distance*: the distance traversed by the vehicle during the time the driver takes to react.
2. *Breaking distance*: the distance needed to actually stop the vehicle.

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

## **Decision Sight Distance**

Decision sight distance is used when SSD is just not adequate to allow a reasonably competent driver the distance to react to potentially hazardous situations. If a situation that requires DSD arises, consult the AASHTO Green Book.

## **Operational Sight Distance**

Operational Sight Distance is not a design consideration for divided lane highways. OSD is based on the 85<sup>th</sup> percentile speed at which 85% of traffic travels at or less.

This speed is generally determined from speed studies made on a roadway after it has been opened to traffic.

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

## Passing Sight Distance

Passing sight distance is only a consideration for undivided highways. It is not practical nor desirable to design crest vertical curves based on PSD because of the excessive length of curves required.

### So, how do we get adequate PSD?

To obtain adequate PSD and still keep the length of curves to an acceptable length, vertical curves should be designed based on appropriate grades for the design speed and terrain.

However, if PSD needs to be calculated to determine the “no passing zone” striping. The AASHTO Green Book has formulas and tables to determine design passing sight distance in chapter 3.

# Elements of Design: Sight Distance

## EPG Category 230.2: Vertical Alignment

### Passing Sight Distance

Assumptions for calculating minimum PSD:

1. The overtaken vehicle travels at uniform speed.
2. The passing vehicle has reduced speed and trails the overtaken vehicle as it enters a passing section.
3. When the passing section is reached, the passing driver needs a short period of time to perceive the clear passing section and to react to start his/her maneuvers.
4. Passing is accomplished under what may be termed a delayed start and a hurried return in the face of opposing traffic. The passing vehicle accelerates during the maneuver, and its avg. speed while passing is 10 mph higher than that of the overtaken vehicle.
5. When passing vehicle returns to its lane, there is a suitable clearance length between it and an oncoming vehicle in the other lane.

# Elements of Design: Sight Distance

## EPG Category 230.2: Vertical Alignment

### Passing Sight Distance

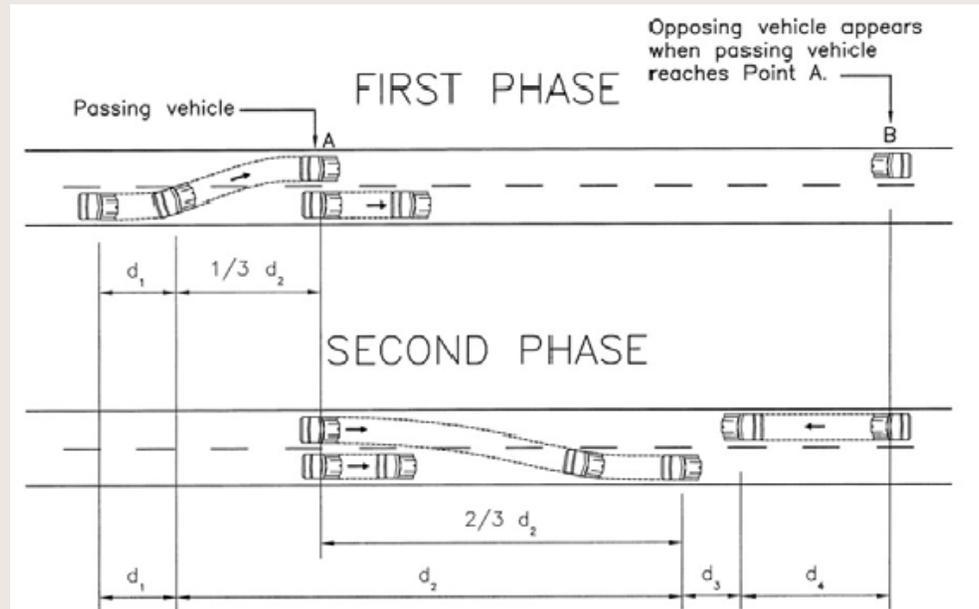
The minimum passing sight distance for 2-lane highways is determined as the sum of the following four distances:

$d_1$  – perception and reaction distance.

$d_2$  – distanced traveled while passing on the left lane.

$d_3$  – distance between the passing vehicle at the end of maneuver and the opposing vehicle.

$d_4 = 2/3 d_2$



Elements of Passing Sight Distance for 2-Lane Highways (Green Book)

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

## Passing Sight Distance

Component of passing maneuver	Metric				US Customary			
	Speed range (km/h)				Speed range (mph)			
	50-65	66-80	81-95	96-110	30-40	40-50	50-60	60-70
	Average passing speed (km/h)				Average passing speed (mph)			
	56.2	70.0	84.5	99.8	34.9	43.8	52.6	62.0
Initial maneuver:								
a = average acceleration <sup>a</sup>	2.25	2.30	2.37	2.41	1.40	1.43	1.47	1.50
t <sub>1</sub> = time (sec) <sup>a</sup>	3.6	4.0	4.3	4.5	3.6	4.0	4.3	4.5
d <sub>1</sub> = distance traveled	45	66	89	113	145	216	289	366
Occupation of left lane:								
t <sub>2</sub> = time (sec) <sup>a</sup>	9.3	10.0	10.7	11.3	9.3	10.0	10.7	11.3
d <sub>2</sub> = distance traveled	145	195	251	314	477	643	827	1030
Clearance length:								
d <sub>3</sub> = distance traveled <sup>a</sup>	30	55	75	90	100	180	250	300
Opposing vehicle:								
d <sub>4</sub> = distance traveled	97	130	168	209	318	429	552	687
<b>Total distance, d<sub>1</sub> + d<sub>2</sub> + d<sub>3</sub> + d<sub>4</sub></b>	<b>317</b>	<b>446</b>	<b>583</b>	<b>726</b>	<b>1040</b>	<b>1468</b>	<b>1918</b>	<b>2383</b>

<sup>a</sup> For consistent speed relation, observed values adjusted slightly.

Note: In the metric portion of the table, speed values are in km/h, acceleration rates in km/h/s, and distances are in meters. In the U.S. customary portion of the table, speed values are in mph, acceleration rates in mph/sec, and distances are in feet.

Exhibit 3-5. Elements of Safe Passing Sight Distance for Design of Two-Lane Highways

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

## Passing Sight Distance

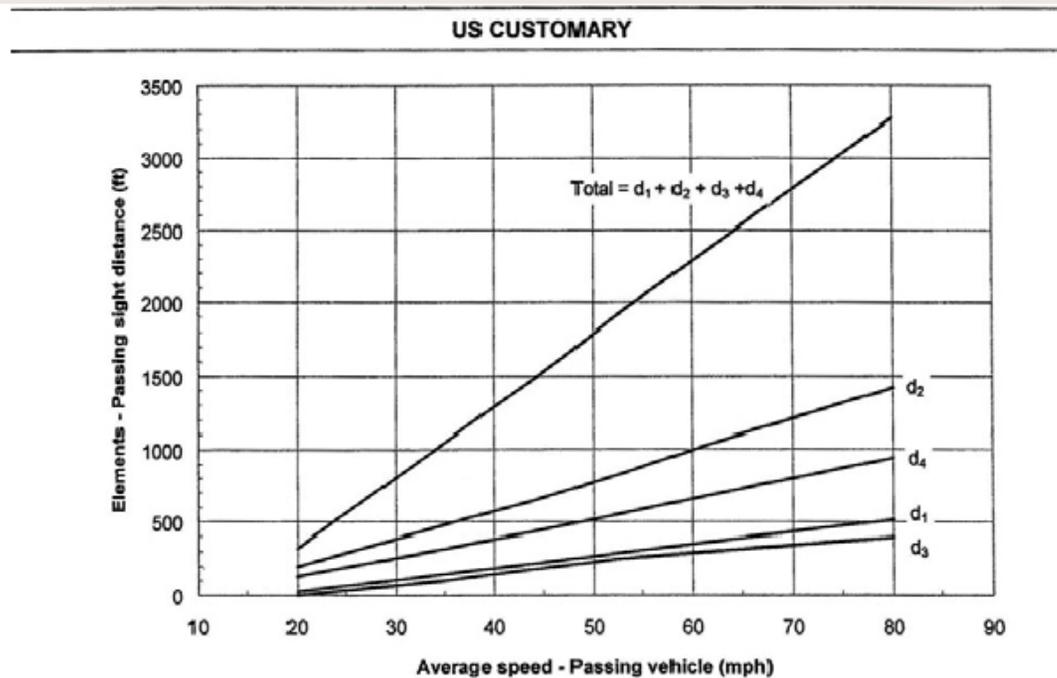


Exhibit 3-6. Total Passing Sight Distance and Its Components—Two-Lane Highways

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

## Passing Sight Distance

Metric					US Customary				
Design speed (km/h)	Assumed speeds (km/h)		Passing sight distance (m)		Design speed (mph)	Assumed speeds (mph)		Passing sight distance (ft)	
	Passed vehicle	Passing vehicle	From Exhibit 3-6	Rounded for design		Passed vehicle	Passing vehicle	From Exhibit 3-6	Rounded for design
30	29	44	200	200	20	18	28	706	710
40	36	51	266	270	25	22	32	897	900
50	44	59	341	345	30	26	36	1088	1090
60	51	66	407	410	35	30	40	1279	1280
70	59	74	482	485	40	34	44	1470	1470
80	65	80	538	540	45	37	47	1625	1625
90	73	88	613	615	50	41	51	1832	1835
100	79	94	670	670	55	44	54	1984	1985
110	85	100	727	730	60	47	57	2133	2135
120	90	105	774	775	65	50	60	2281	2285
130	94	109	812	815	70	54	64	2479	2480
					75	56	66	2578	2580
					80	58	68	2677	2680

Exhibit 3-7. Passing Sight Distance for Design of Two-Lane Highways

# Elements of Design: Sight Distance

EPG Category 230.2: Vertical Alignment

## Passing Sight Distance

### Frequency of Passing Sections

It's not practical to directly specify the frequency of passing sight distance areas. The designer should provide passing sight distance based on topography of the terrain, design speed, cost and spacing of entrances.

### Passing Lanes and 2+1 roadways

In some situations, it may be more practical to provide dedicated passing opportunities by adding a climbing/passing lanes. For more complex situations, a designer should consider a 2+1 roadway. These facilities provide a continuous third lane to offer alternating passing opportunity to either direction of travel.

Contact the Engineering Policy Group for policy guidance.

# Elements of Design: Vertical Alignment

EPG Category 230.2: Vertical Alignment

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## What is it?

Vertical alignment is a series of straight profile lines connected by vertical parabolic curves, and is referred as the “profile grade line” or PGL.

This PGL is based on the already established horizontal alignment.

Increasing PGL's = + grades

Decreasing PGL's = - grades

# Elements of Design: Vertical Alignment

EPG Category 230.2: Vertical Alignment

## Why is it important?

Vertical Alignment helps in the calculations of the amounts of cut and fill.

PGL is a key factor for proper drainage. In rock or in flood areas, the PGL should be higher than existing ground.

PGL sets the smoothness for the roadway. Drivers should feel comfortable when “riding” the roadway.

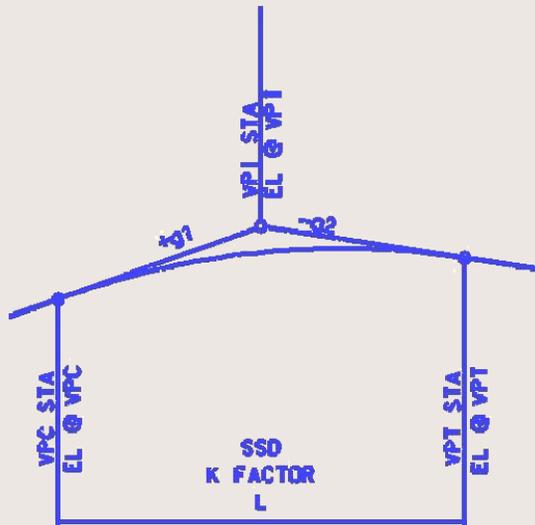
## How do we determine vertical alignment?

Vertical alignment is applied at the “design chain” trying to balance the hills and valleys so the beginning earthwork is close to balancing out. Please note that although the vertical alignment is well balanced, your earthwork may not be. Individual cross sections are used to accurately balance earthwork.

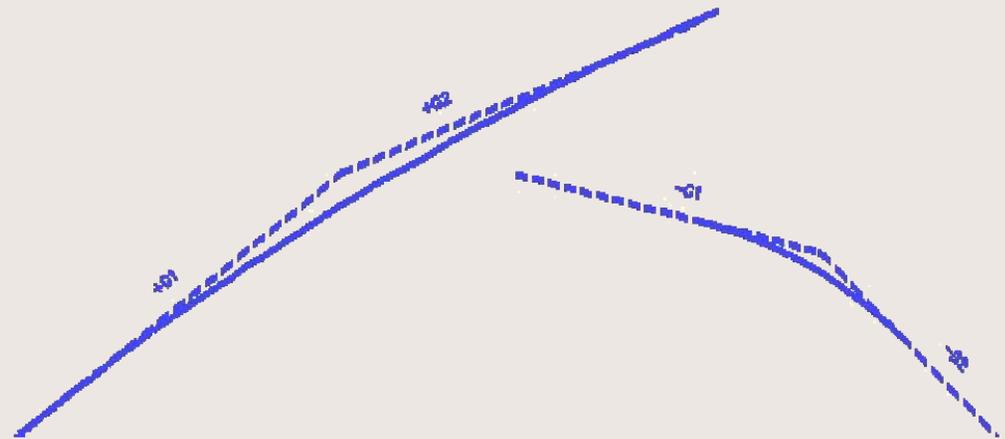
# Elements of Design: Vertical Alignment

EPG Category 230.2: Vertical Alignment

## Vertical Curve Geometry Crest Curves



Type I

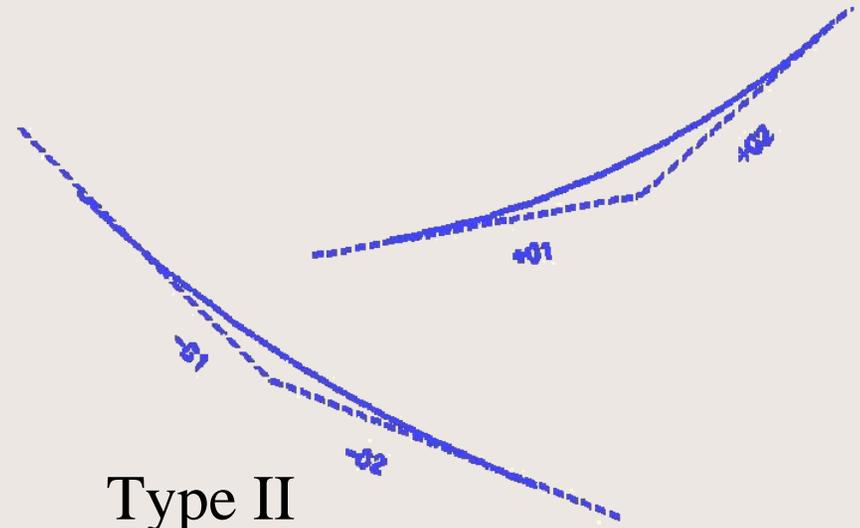
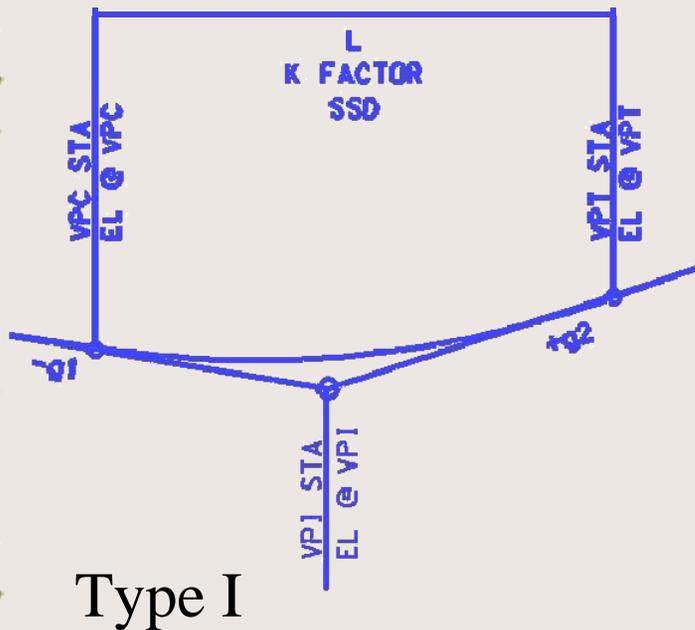


Type II

# Elements of Design: Vertical Alignment

EPG Category 230.2: Vertical Alignment

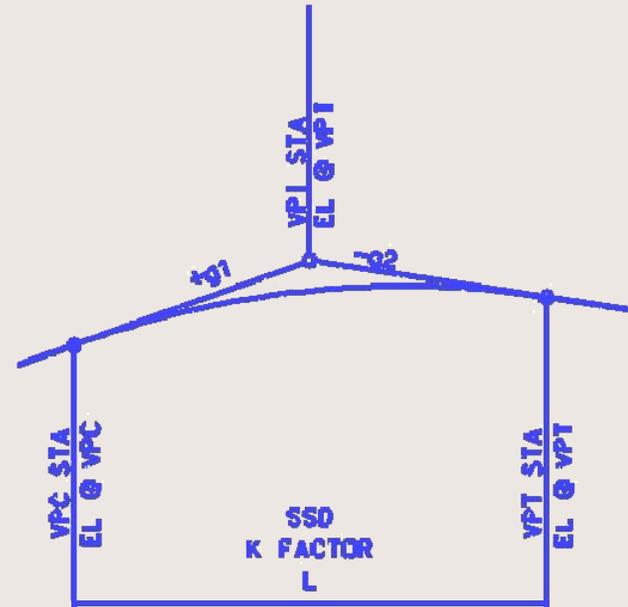
## Vertical Curve Geometry Sag Curves



# Elements of Design: Vertical Alignment

## Vertical Alignment Geometry

- VPI** Vertical Point of Intersection
- VPC** Vertical Point of Curvature
- VPT** Vertical Point of Tangency
- $g_1$  Grade of Initial Tangent in Percent
- $g_2$  Grade of Final Tangent in Percent
- L** Length of Vertical Curvature
- K** Vertical Curve Length Coefficient
- x** Distance to Point on Curve, from VPC
- $E_x$  Elevation of point on curve x from VPC
- $x_m$  Location of min/max point on curve from VPC



### Equations

$$K = L / |g_1 - g_2|$$

$$E_x = E_{PC} + g_1 x / 100 + x^2 / 200K$$

$$x_m = g_1 L / (g_2 - g_1)^{**}$$

(-) value = a low point,  
(+) value = a high point

$$\text{VPT Station} = \text{VPC station} + L$$

$$\text{VPI Station} = \text{VPC station} + L/2$$

$$\text{VPI Elevation} = \text{VPC Elev} + (g_1/100)(L/2)$$

OR

$$\text{VPI Elevation} = \text{VPT Elev} - (g_2/100)(L/2)$$

\*\*This equation only works for type I crest and sag vertical curves

# Elements of Design: Vertical Alignment

EPG Category 230.2: Vertical Alignment

## Calculating Vertical Curve Lengths

Crest curve lengths are based on SSD.

Sag curve lengths are based on: headlight sight distance, passenger comfort, drainage control and general appearance.

AASHTO Green Book shows the controls, equations and graphs to assist in determining SSD for either crest or sag curves.

There are three ways to calculate SSD:

1. Using equations.
2. Using graphs.
3. Using tables.

# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

Calculating length of vertical curves based on stopping sight distance using equations.

$$\text{When } S < L, L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2} \quad \begin{array}{l} h_1 = 3.5 \text{ ft} \\ h_2 = 2.0 \text{ ft} \end{array}$$

$$L = AS^2/2158$$

$$\text{When } S > L, L = \frac{2S - \frac{200(\sqrt{2h_1} + \sqrt{2h_2})^2}{A}}{A}$$

$$L = 2S - (2158/A)$$

**L=Length of Vertical Curve (ft)**

**S=Sight Distance (ft)**

**A=Algebraic difference in grades, percent**

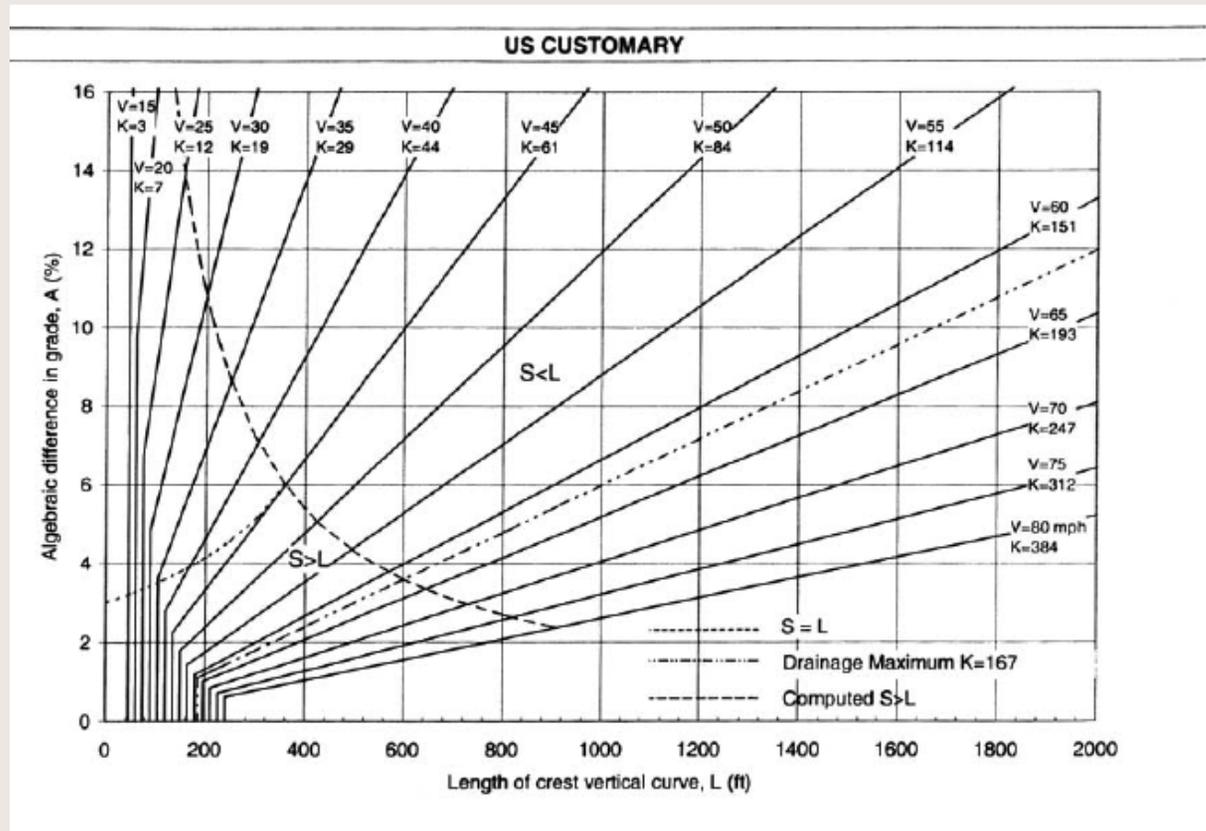
**h<sub>1</sub>=Height of eye above roadway surface (ft)**

**h<sub>2</sub>=Height of object above roadway surface (ft)**

# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

Calculating length of vertical curves based on stopping sight distance using graphs.



# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

Calculating length of vertical curves based on stopping sight distance using tables.

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K <sup>a</sup>		Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K <sup>a</sup>	
		Calculated	Design			Calculated	Design
20	20	0.6	1	15	80	3.0	3
30	35	1.9	2	20	115	6.1	7
40	50	3.8	4	25	155	11.1	12
50	65	6.4	7	30	200	18.5	19
60	85	11.0	11	35	250	29.0	29
70	105	16.8	17	40	305	43.1	44
80	130	25.7	26	45	360	60.1	61
90	160	38.9	39	50	425	83.7	84
100	185	52.0	52	55	495	113.5	114
110	220	73.6	74	60	570	150.6	151
120	250	95.0	95	65	645	192.8	193
130	285	123.4	124	70	730	246.9	247
				75	820	311.6	312
				80	910	383.7	384

<sup>a</sup> Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A).  $K = L/A$

# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

### Vertical SSD and Length of Sag Vertical Curves

Length of sag curves are based on headlight sight distance with the following assumptions (AASHTO Green Book):

- Headlight height = 2 ft
- 1 degree upward divergence of light beam from the longitudinal axis of vehicle.

When taking crest vertical curve lengths into consideration, the equation to be used is:

**$L=KA$**  Where, **L=Length of Vertical Curve (ft)**

**A=Algebraic difference in grades, percent**

**K=Values listed in **Green Book** for sag curves**

# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

### Grades and Vertical Curves

Grades play a greater influence on trucks than passenger cars.

Studies show that trucks increase in speed by up to about 5% on down grades, and decrease in speed up to 7% on up grades.

In recreational routes where the low percentage of trucks does not warrant a climbing lane, designer should consider adding an additional lane.

### AASHTO Recommendations on Control Grades for Design

Maximum grades of 5% are considered for 70 mph design speed

For 30 mph design speed, grades should be kept between 7-12% depending on terrain

Minimum grades of 0.5% is typically used.

Maximum grades can be determined based on AASHTO Green book tables.

# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

### Minimum Design Criteria Guidelines

- ✓ Min. desirable rate of grade = 0.5%
- ✓ Min. ditch grade = 0.3% (0.3' per every 100')
- ✓ PGL on flood plains must keep shoulders at min. 1 ft above the design high water (DHW).
- ✓ Min. length of vertical curve = 300 ft when practical

### AASHTO Green Book Guidelines for Selecting Max. Rate of Grade

Minor Roads		Major Roads	
Local Rural Roads	Chapter 5	Rural Arterials	Chapter 7
Local Urban Roads	Chapter 5	Urban Arterials	Chapter 7
Special Purpose Rd	Chapter 5	Rural Freeways	Chapter 8
Rural Collectors	Chapter 6	Urban Freeways	Chapter 8
Urban Collectors	Chapter 6		

# Elements of Design: SSD & Vertical Alignment

## EPG Category 230.2: Vertical Alignment

### Intersections:

Side roads should connect at  $-1\%$  rate of grade from shoulder of the through roadway, if practical.

Water should flow away from through roadway

### Bridges:

Grades prior to and after bridge ends should maintain level for a distance of at least 50 ft.

Designer should avoid ending horizontal or vertical curves on bridges.

If bridge is on a curve, SE should be kept constant throughout the entire bridge.

All clearances under bridges must be met.

# Elements of Design: Horizontal & Vertical Alignment

## EPG Category 230: Alignments of the Roadway

Some recommendations for balancing horizontal and vertical alignment include:

- ✓ Tangent alignments or flat curves at the expense of long or steep grades and excessive curvature with flat grades are not a good design.
- ✓ Sharp horizontal curves should not be introduced at or near the top of a pronounced crest curve or at or near at the bottom of a sag curve.
- ✓ 2-lane roads need appropriate passing zones, so providing long tangent sections is recommendable.
- ✓ Both horizontal and vertical alignments should be as flat as possible at intersections to provide adequate sight distance.
- ✓ For divided highways, variation of median width and use of independent profiles and chains for the separate one-way roads are sometimes desirable.
- ✓ In residential areas, alignments should be designed to minimized nuisance to the neighborhood.
- ✓ Roadway aesthetics are important; design should combine the natural and manmade features of the land to provide a scenic view.
- ✓ Utilize design software 3D view capabilities of your horizontal and vertical alignment during the preliminary plan stage.

# Elements of Design: Horizontal & Vertical Alignment

## EPG Category 230: Alignments of the Roadway

### **Ramps:**

Grade controls for ramps that intersect the crossroads are the same as for intersections.

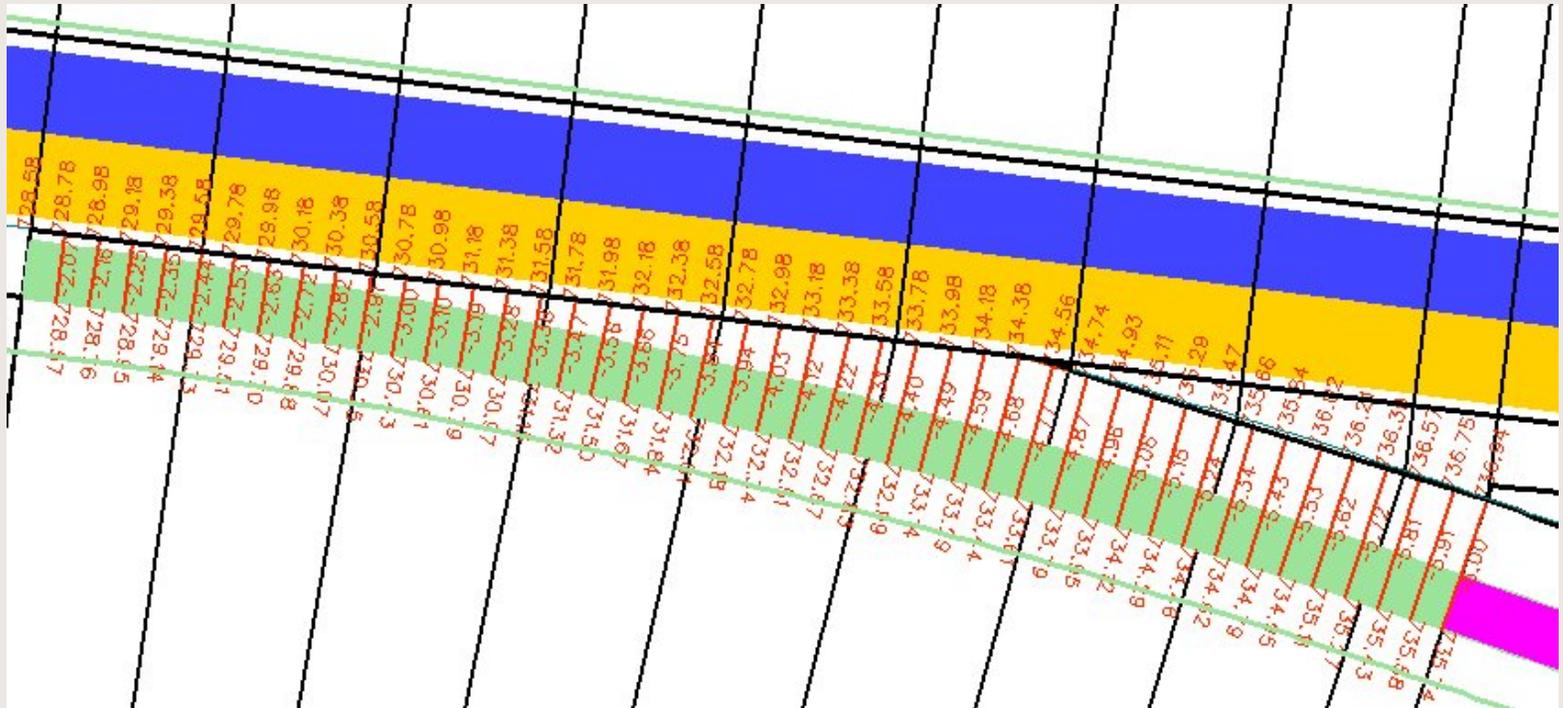
For merging ramps, grades are established by projecting the through roadway profile grade to the ramp edge of pavement for the tangent section of the ramp.

For the curve on the ramp, the horizontal alignment and superelevation must be taking into account while projecting grades/elevations to the baseline of the ramp.

The picture in next slide graphically shows this procedure.

# Elements of Design: Horizontal & Vertical Alignment

## EPG Category 230: Alignments of the Roadway





## Exercise 1: Basic Design Criteria

- 1) Route 17 is a rural minor arterial and it has a design ADT of 4000. The posted speed for this road is 50 mph. Answer the following questions:
  - a) *What design speed should be used?*
  - b) *What's an appropriate lane width?*
  - c) *What's an appropriate shoulder width?*
  - d) *What kind of surface would you design the shoulder for this roadway?*
  
- 2) You are realigning a portion of I-44. Answer the following questions:
  - a) *What design speed should be used?*
  - b) *What's an appropriate lane width?*
  - c) *What's an appropriate shoulder width?*
  - d) *What kind of surface would you design the shoulder for this roadway?*
  
  - e) *What type of R/W access do you think I-44 requires?*
  
- 3) You are designing an urban 4-lane principal arterial. The posted speed is 45 mph. Answer the following questions:
  - a) *What design speed should be used?*
  - b) *What's an appropriate lane width?*
  - c) *What's an appropriate shoulder width?*
  
  - d) *Is it practical to place sidewalks on all urban projects?*

## Exercise 2 Part A: Horizontal Alignment, Simple and Spiral Curves

You were told to fix a substandard curve on Route 179. Looking thru the old files, you find the following information:

Route 179 is a Rural Principal Arterial with an ADT=1500. Posted speed is 50 mph.

The curve must fit between the back bearing of N 85° 49' 13" E and the ahead bearing of S 56° 39' 24" E, which makes a  $\Delta = 37^\circ 31' 23''$  (RT) (37.523 degrees)

Other assumptions: rolling terrain, 2-lane roadway

A) Design a new curve using either the concepts learned in class or using the Green Book. Find the length of curve, and the tangent length.

B) If PC station is 15+63.34, calculate the PI and PT stations.

C) When does MoDOT suggests using spiral curves?

D) Design a spiral curve based on the Std. Drawing 203.20 and compare the answer to the AASHTO Green Book.

1) What's the transition length,  $L_s$ ?

2) Calculate the stationing for the SCS combination. Use SC station 16+50.42.

## Exercise 2 Part B: Horizontal Alignment, Simple and Spiral Curves

You were told to fix a substandard curve on Route 179. Looking thru the old files, you find the following information:

Route 179 is a Rural Principal Arterial with an ADT=1500. Posted speed is 50 mph.

The curve must fit between the back bearing of N 85° 49' 13" E and the ahead bearing of S 56° 39' 24" E, which makes a  $\Delta = 37^\circ 31' 23''$  (RT) (37.523 degrees)

Other assumptions: rolling terrain, 2-lane roadway

A) Design a new curve using Geopak Coordinate Geometry. Name the new curve Exercise2 and station the curve using a PC station of 15+63.34. What are the PI and PT stations for the curve you designed? Check your calculated values against the ones computed by Geopak.

B) Store a SCS in COGO using the parameters used in previous exercise. Name the SCS curve Exercise2. Station the SC 16+50.42. What are the stations for TS, CS, ST?

C) What's the overall SCS PI, total  $\Delta$ , and total SCS length?

### Exercise 3: Horizontal Alignment, Reversed Curves

You had to take over a project that was already in the works. The last thing to design on this project is a temporary bypass. This is the information you have available:

Route 52 is a Rural Minor Arterial with an ADT=1500

There must be at least 20 ft between the EOP of the main line and the EOP of the temporary bypass.

The reverse curve on each end of the bypass needs to be 500 ft in length

Lane width for both the bypass and the mainline is 12ft

- A) Design a reverse curve that can be used at either end of the bypass. Remember that reverse curves are used for temporary conditions only. Use the concepts learned in class.

Find the  $\Delta$ , R, and L for this reverse curve.

- B) If the first PC station on the bypass starts at 20+00, what are the stations for the PRC and PT of the first reverse curve you designed?

## Exercise 4: Horizontal Alignment, Superelevation

Existing US Route 63 in Boone County has an old curve with no superelevation. As a result, many accidents occur at this location. You've been assigned to study the existing curve, and add superelevation to match the most current MoDOT guidelines. Below is the existing curve data.

US Route 63 is a rural principal arterial and the design ADT is 22940 with flat terrain. Posted speed is 70 mph.

Existing Curve data:

PC station=388+72.21

PT station=394+42.77

PI station=391+60.46

$D = 3^\circ$

$T = 288.25$  ft

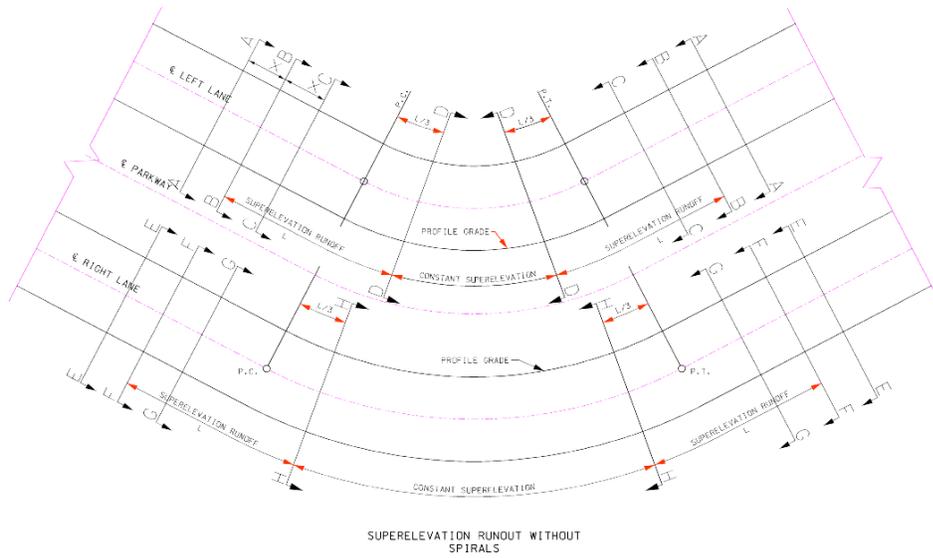
$L = 570.56$  ft

NC (%)=2

- 1) Find the appropriate superelevation rate and runoff length. Please specify what standard plan you used.

2) Calculate the superelevation transition points.

SE Transition Section	Entering the Curve	Exiting the Curve
A-A		
B-B		
C-C		
D-D		



## Exercise 5: Horizontal Alignment, Superelevation

Scope of Work: Bridge replacement with realignment of existing substandard horizontal curve.

Location: Maries County, Rte. AA

Design Data:

Construction AADT = 530

Design AADT = 770

Posted Speed: 40 mph

- 1) Design a new alignment using the Geopak cogo tools. Find the radius, tangent length and curve lengths. Show your manual calculations and compare them to those calculated by Geopak.
  - a)  $R =$  \_\_\_\_\_
  - b)  $T =$  \_\_\_\_\_
  - c)  $L =$  \_\_\_\_\_
  
- 2) Design the superelevation for your alignment. What are the runoff length and tangent runout? Calculate the critical points for superelevation. Can use the back of the page for calculations.

## Exercise 6: Vertical Alignment

Location: Maries County, Rte. AA

Design Data:

Construction AADT = 530

Design AADT = 770

Posted Speed: 40 mph

- 1) Design a vertical alignment for this roadway. See hand out for obtaining the grades and the stationing. Based on the length of curve designed, calculate SSD, PSD, and the K value if appropriate. Use the Green Book for finding these parameters.

2) What is the station and elevation at the VPC and VPT?

3) Calculate the location and elevation of the high point (HP) of the curve.

