7 Interchanges

Geometric Review and Design (GRAD)
Learning Objectives

- Identify Different Interchange Alignment Elements and Terms
- Understand Ramp Design Guidance
- Learn about the Importance of Signing with Interchange Design
- Review Example Interchange Design Problems
Interchanges

- Sect 501
- An Interchange is a system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways on different levels.
Interchanges

- All interchange configurations fall into two categories:
  - Service - connects freeways and lesser facilities (arterial roadways or local surface streets)
  - System - connects two or more freeways
Service Interchanges

- Common Types of Service Interchanges:
  - Diamond
  - Teardrop/Bowtie
  - Tight Urban Diamond (TUDI)
  - Diverging Diamond Interchange (DDI)
  - Single Point Urban Interchange (SPUI)
  - Partial Cloverleaf
System Interchanges

- Common Types of System Interchanges:
  - Full Cloverleaf
  - Trumpet
  - Three-Leg Directional
  - Four-Leg Directional
Design Considerations

- Interchange Spacing (Sect 502.3)
- Route Continuity (Sect 502.5)
- Signing (Sect 502.6)
- Basic Number of Lanes (Sect 502.7)
- Lane Balance
- Coordination of Lane Balance and Basic Number of Lanes (Sect 502.8)
- Weave Sections (Sect 502.11)
- LA R/W Limits (Sect 801.2.5)
Design Considerations

- Interchange Spacing
  - Sect 502.3
  - Determined by:
    - Weaving requirements
    - Ability to sign
    - Lengths of speed change lanes
    - Capacity of main facility
  - Urban Areas - min distance not less than 1 miles
  - Rural Areas - min distance not less than 3 miles
Design Considerations

- Interchange Spacing
  - Options for Closely-Spacing Interchanges:
    - Auxiliary Lanes
    - Braided Ramps
    - C-D Roads
    - Frontage Roads
      - Split Diamonds
Design Considerations

- Route Continuity (Sect 502.5)
  - Simplifies the driving task by reducing lane changes
  - Simplifies signing
  - Provides a continuous through route without the need to change lanes
  - Through routes, rather than heavy traffic movement, drives interchange configuration
Design Considerations

- Route Continuity
  - Good Example
    - I-71 SB at I-270 on north side of Columbus
  - Bad Example
    - I-71 NB at I-70 west of Columbus
    - I-70 EB through I-270 and I-670 interchanges west of Columbus
Design Considerations

- Signing (Sect. 502.6)
  - Location of and minimum spacing between ramp terminals depends to a large degree on whether or not effective signing can be provided
  - Geometry often must be revised to allow for an acceptable signing strategy
  - “If you can’t sign it, don’t design it!”
Design Considerations

- Signing

The recommendations are based on operational experience and need for flexibility and adequate signing. They should be checked in accordance with the procedure outlined in the Highway Capacity Manual (HCM). Also refer to the HCM for the procedure for measuring the length of the weaving section. The "L" distances noted in the figures above are measured between the painted noses (theoretical gore point). Additionally for EN-EN, a minimum distance of 300 ft is recommended between the end of the taper for the first entrance ramp and the painted nose for the succeeding entrance ramp (similar for EX-EX except use the physical nose).
Design Considerations

- Signing
  - Conform to the Ohio Manual of Uniform Traffic Control Devices (OMUTCD)
  - Overhead guide signs should be spaced to allow for drivers to see, read, and comprehend while traveling at freeway speeds
Design Considerations

- Signing
  - Signing Plan should be developed during early phases of geometric development for an interchange
  - Failure to provide adequate sign spacing can require re-design of the interchange geometry
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Design Considerations

- **Signing**
  - Overhead bridges can impact sightlines of overhead signs and should be accounted for in design
  - Refer to Figure 298-11 in the Traffic Engineering Manual
Design Considerations

- **Basic Number of Lanes (Sect 502.7)**
  - Constant number of lanes assigned to a route, exclusive of auxiliary lanes, based on the capacity needs of the section.
  - Maintained over a significant length of a route.
Design Considerations

- **Lane Balance**
  - At entrances, number of lanes beyond the merge shouldn’t be less than the sum of all traffic lanes minus one
  - At exits, number of approach lanes shouldn’t be less than sum of traffic lanes departing on both roadways minus one
Design Considerations

- Coordination of Lane Balance and Basic Number of Lanes (Sect 502.8)
  - There should be continuity between the basic number of lanes
  - Auxiliary lanes should be provided for variations in traffic demand to achieve lane balance

Source of Image: A Policy on Geometric Design of Highways and Streets, 7th Edition (2018) - Figure 10-51
Design Considerations

- Weave Sections (Sect 502.11)
  - Highway Segments where vehicle paths cross each other, usually within an interchange, between interchanges, or on segments of overlapping routes
  - Interchange designs that eliminate weaving or remove it from mainline via C-D roads are desirable
Design Considerations

- **Weave Sections**
  - **Type A weave configuration**
    - All weaving vehicles must make one lane change
  - **Type B weave configuration**
    - One weaving movement may be made with zero lane changes; other requires one lane change
  - **Type C weave configuration**
    - One weaving movement may be made with zero lane changes; other requires two or more lane changes
Design Considerations

- Dropping Lanes on Mainline
  - Extending lane past ramp terminal (drop/decision diverge)
  - Changes weave configuration; needs to be carried far enough beyond diverge to make it useful
- Based on traffic operations
- Think about lane continuity
Design Considerations

- LA R/W Limits (Sect 801.2.5)
  - Figures 801-1 & 801-2
  - Service Interchanges - Diamond
    - 600 feet to nearest intersection/drive
  - System Interchanges - Cloverleaf
    - 1,000 feet to nearest intersection/drive
- Established to control access and “protect” the ramp intersections and operations
Interchange Ramp Design

- Ramp Design Speed (Sect 503.2)
  - Ramp design speed range is determined by engineering judgment based on several conditions:
    - Type of roadways at each end of the ramp and their design speeds
    - Length of the ramp
    - Terminal conditions at each end
    - Type of ramp (diamond, loop, or directional)

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<table>
<thead>
<tr>
<th>RAMP DESIGN SPEED (mph)</th>
<th>MAINLINE DESIGN SPEED (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>UPPER RANGE</td>
<td>25</td>
</tr>
<tr>
<td>MIDDLE RANGE</td>
<td>20</td>
</tr>
<tr>
<td>LOWER RANGE</td>
<td>15</td>
</tr>
</tbody>
</table>

Note: Ramp design speeds do not pertain to the ramp terminals.
Interchange Ramp Design

- **Ramp Design Speed**
  - **Design Exceptions for speed-related design elements that do not meeting the following:**
    - **Directional Ramps** - do not provide minimum design speed given in Section 503.2.3
    - **Loop Ramps** - do not provide a minimum design speed of 25 mph (150-foot radius)
    - **All other ramps** - do not provide minimum speed equal to lower range design speed in Fig. 503-1.
Interchange Ramp Design

- Ramp Design Speed - Terminals
  - Difference between Ramp and Ramp Terminal
  - Ramp terminals require speed change lanes (deceleration lanes)
  - Ramp terminal - can be less than mainline design speed when speed change (deceleration) lane is present
Interchange Ramp Design

- Ramp Design Speed - Terminals
  - Diverging roadways - design speed through the terminal should match mainline speed
  - No deceleration lane is provided for diverging roadways; speed is maintained
Interchange Ramp Design

- Typical Section (Sect 303.1)
  - Lane widths
    - 16 feet for single lane
    - 12 feet for multiple-lane ramps
  - Shoulder widths
    - Varies based on the number of lanes on the ramp
    - 1-lane or 2-lane ramp is based on the number of lanes that diverge from the mainline; addition of a turn lane doesn’t make it a 2-lane ramp for typical section design
Interchange Ramp Design

- Typical Section
  - Loop Ramps
    - Minimum 150 foot radius - Design Exception required for less
    - For radius less than 200 feet, use 18-foot wide lane
    - For multilane loop ramp, use Truck Turning Template to ensure vehicles don’t encroach; don’t just default to two 18-foot wide lanes
Interchange Ramp Design

- Horizontal Alignment (Sect 503.4)
  - Determined by selected design speed and type of ramp
  - Criteria in Section 202 applies to ramps (superelevation, deflections)
  - Confirm that the required horizontal stopping sight distance is provided
  - Curve widening may be required on a two-lane ramp (see Section 301.1.3 and Figure 301-5c)
  - Use WB-62 for interstate ramps
Interchange Ramp Design

- Vertical Alignment (Sect 503.3)
  - Determined by a number of factors:
    - Flatter the ramp grade relative to freeway grade, the longer the ramp
    - Steepest grade should occur over the center part of the ramp; flatter at the ramp terminals
    - Short upgrades of 7-8% are acceptable for passenger cars & 5% are acceptable for trucks and buses
    - Adequate sight distance is more important than specific grade criteria
    - The design speed provided for the vertical should match or exceed the horizontal at the same location on the ramp
      - Be consistent; easier to perceive horizontal changes than vertical changes when driving; don’t design geometrics in a vacuum!

Table 503.1 Maximum Ramp Upgrades

<table>
<thead>
<tr>
<th>Ramp Design Speed</th>
<th>25-30 mph</th>
<th>35-40 mph</th>
<th>45 mph and above</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desirable Grade (%)</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Maximum Grade (%)</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: Downgrades may exceed the table values by 2%, but should not exceed 8%.
Ramp Terminal Design

- Left Side Ramps
  - Left side ramps are contrary to driver expectancy when intermixed with right side ramps
  - Extreme care should be exercised to avoid left side ramps in the design of interchanges
  - Special attention should be given to signing and the provision for decision sight distance to alert the driver an unusual condition exists
Ramp Terminal Design (Sect 503.6)

- Superelevation at Terminals
  - Rate of superelevation at the nose shall be selected based on design speed of the ramp at the nose
  - All breaks in superelevation shall be made at pavement joint lines
  - High-Speed Terminals: transverse breaks in cross slope shall not exceed a differential of 0.032 at the mainline edge of traveled way or 0.050 at other locations. If double break occurs less than 6 feet apart, it shall not exceed a total differential of 0.032 if adjacent to mainline, or 0.050 elsewhere.
Ramp Terminal Design

- Superelevation at Terminals (cont.)
  - Low-Speed Terminals: transverse breaks in cross slope shall not exceed a differential of 0.05 to 0.06
  - High-Speed Terminals: rate of rotation of a superelevated ramp pavement or speed change lane pavement shall be in accordance with Section 202.4
Ramp Terminal Design

- Superelevation at Terminals (cont.)
  - Prefer to have ramp terminal/gore drain toward the middle/grass area to minimize sheet flow across the pavement; create an artificial swale in the gore area to drain toward the back of gore
  - Mainline curves turning toward the ramp diverge may not be practical to create an artificial swale in the gore area for drainage - safety concern
Ramp Terminal Design
Ramp Terminal Design

- Superelevation at Terminals - Example
Ramp Terminal Design

- **Vertical Alignment**
  - Ramp Terminal design based on cross slopes and breaks through the terminal relative to the mainline
  - Achieve Design Sight Distance preferred; 125% SSD is minimum
  - Create a proposed surface through the terminal
  - Confirm no excessive vertical deflections exist (use Figure 203-2)
Ramp Terminal Design

- **Ramp Terminal Classifications**
  - **High-Speed Terminals**
    - Intended for use on all interstate highways and other limited access freeways
    - Minimum mainline design speed of 50 mph
  - **Low-Speed Terminals**
    - Intended for use on all other limited access expressways with little or no access control other than at interchange
    - Mainline design speed of less than 50 mph
Ramp Terminal Design

- **High-Speed Entrance - Single Lane**
  - Consists of two parts:
    - Acceleration Lane
    - Taper (minimum rate is 50:1)
  - Length of acceleration lane varies depending on design speed of last ramp curve and the design speed of the mainline
  - Adjust acceleration lane length for grades 3% or greater
Ramp Terminal Design

- High-Speed Entrance - Single Lane

Notes For Single Lane Entrance Terminals:

1. The minimum acceleration length, \( L \), shall be \( L_p + L_t \).
2. The 9' to 21' variable width of treated shoulders of the entrance terminal shall be sloped for 12' as required for mainline design (usually 3' to 5'), except for the last 100' to 200' at the 9' end, which shall be sloped as required for proper terminal grading.
3. Normally single lane ramps will have a width of 18'. The width shall be increased to 18' when the ramp radius is less than 200'. When an 18' wide ramp is used, the 25' entrance terminal width shall be retained and the 9' width extended by 2'.
4. If \( L_p \) (parallel length) is not required \( L_p \leq 850' \), then the 200' minimum spiral shall be tangent to the 60' taper.
5. If the entrance terminal results in an odd lane (no merge), delete the last 60' of the 50' taper.
Ramp Terminal Design

- Low-Speed Entrance - Single Lane
Ramp Terminal Design

- Low-Speed Entrance - Single Lane
  - Taper (minimum rate is 35:1)
  - Type A is preferred; Type B may be used if a ramp enters as an added lane or as a combination acceleration-deceleration lane
Ramp Terminal Design

- **High-Speed Exit - Single Lane**
  - Consists of two parts:
    - Taper to maneuver out of through traffic lane
    - Deceleration lane (800 feet MINIMUM)
  - Length of deceleration lane varies depending on design speed of the mainline and the first geometric control of the ramp
    - Usually first horizontal curve
    - Could be back of traffic queue or SSD on a vertical curve

### Table: Minimum Deceleration Lengths for High-Speed Exit Terminals

<table>
<thead>
<tr>
<th>Mainline Design Speed, V (mph)</th>
<th>Deceleration length, L (ft) for design speed of first ramp curve, V (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>435 405 385 355 315 295 275 225 175 -</td>
</tr>
<tr>
<td>55</td>
<td>480 455 440 410 380 350 285 235 -</td>
</tr>
<tr>
<td>60</td>
<td>530 500 480 460 430 405 350 300 240</td>
</tr>
<tr>
<td>65</td>
<td>570 540 520 500 470 440 390 340 280</td>
</tr>
<tr>
<td>70</td>
<td>615 590 570 550 520 490 440 390 340</td>
</tr>
<tr>
<td>75</td>
<td>660 635 620 600 575 535 450 440 390</td>
</tr>
</tbody>
</table>

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"""
Ramp Terminal Design

- High-Speed Exit - Single Lane

**EXIT CURVE TABLE**

<table>
<thead>
<tr>
<th>Mainline Design Speed mph</th>
<th>Maximum Exit Curvature, Go</th>
<th>Rural</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>1' - 13'</td>
<td>1' - 22'</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>1' - 24'</td>
<td>1' - 35'</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>1' - 35'</td>
<td>1' - 55'</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>1' - 50'</td>
<td>2' - 15'</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>2' - 45'</td>
<td>2' - 45'</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>2' - 60'</td>
<td>3' - 30'</td>
<td></td>
</tr>
</tbody>
</table>

Notes for High-Speed Single-Lane Exit Terminals:

1. The Exit Curve should normally be according to the Exit Curve Table where the mainline is on tangent. Where the mainline is on a curving alignment, the maximum differential between the Exit Curve and the mainline curve should normally be the Exit Curve Table value. This differential, however, may vary by as much as one degree in order to avoid a tangent exit alignment. (See Section 503.6.4 for the allowable transverse breaks in super-elevation cross-slope.)

2. When the First Ramp Curve does not exceed 8°, the Exit Curve may be compounded directly with the First Ramp Curve at a PCC 100' beyond the nose. When the First Ramp Curve does exceed 8°, a spiral should be placed between the Exit Curve and the First Ramp Curve and the beginning of the spiral ISC should be at the nose.

3. Normally single lane ramps will have a width of 12'. The width shall be increased to 18' when the ramp radius is less than 200'. When an 18' wide ramp is used, the 35' exit terminal width shall be retained and the 23' width reduced by 2'.

- P.C.C. Or Mid-Point of 200' Spiral
- Or Other Design Speed Limiting Geometric Control Such As The Stopping Sight Distance For A Vertical Curve Or The Back Of A Traffic Queue.

Mainline paved shoulder width as required by Figure 501-3 or 501-4.
Ramp Terminal Design

- Low-Speed Exit - Single Lane
Ramp Terminal Design

- Low-Speed Exit - Single Lane
- Diverging Taper (minimum rate is 35:1)
Ramp Terminal Design

- Development of Turn Lanes on Exit Ramps
  - Identify traffic operations - avoid excessive lane shifts
  - Develop on both sides vs. all to one side
  - Include taper length and deceleration
  - Change in number or type of lanes requires an Interchange Study
    - Design MUST meet Interchange Study requirements
Ramp Terminal Design

- Multi-lane Entrance Ramps and Converging Roadways
  - Converging Roadways are separate roadways which combine into a single roadway having a greater number of lanes beyond the nose than either of the approach roadways
  - Single-Lane Entrance Terminal should be used when a speed change lane is required
Ramp Terminal Design

- Multi-lane Entrance Ramps and Converging Roadways
  - Avoid Inside Merges
  - Preferential Flow - more important of the two roadways, based on traffic volumes, number of lanes, signing, vehicles speeds, and alignment
Ramp Terminal Design

- Multi-lane Entrance Ramps and Converging Roadways
  - Horizontal Curvature - approaching terminal nose; mainline roadway criteria for mainline roadways and ramp entrance criteria for ramps
  - Crest Vertical Curves - provide sight distance applicable to design speed of the roadway; design sight distance shown in Figure 201-6 and Figure 505-1a.
  - When design speeds differ on approaching roadways, higher of the two design speeds should be used
  - Superelevation - follow Section 503-6.4; locate longitudinal joints to coincide with lane lines; SCD BP-6.1
Ramp Terminal Design

- Multi-lane Exit Ramps and Diverging Roadways
  - Diverging Roadways are defined as a single roadway which forks into two separate roadways without the need for a speed change lane
  - Avoid excessive cross slope breaks
  - Avoid option lane crossing cross slope break if possible

Multi-Lane Exit Ramps and Diverging Roadways

- Diverging Roadways are defined as a single roadway which forks into two separate roadways without the need for a speed change lane
- Avoid excessive cross slope breaks
- Avoid option lane crossing cross slope break if possible
Ramp Terminal Design

- Multi-lane Exit Ramps and Diverging Roadways
  - High-Speed - When one or both of the diverging roadways are mainline roadways of an expressway or divergence of high-speed directional ramps within an interchange
  - Low-Speed - divergence of low-speed directional ramps within an interchange or with non-limited access facilities
Ramp Terminal Design

- **Multi-lane Exit Ramps - System Interchanges**
  - Also used at two-lane CD Road exits from a mainline
  - Use Figure 505-2a for nose width, gore length and diverging curvature values.
  - Best to use curvature from Table B and the “N” value provided at the nose
Ramp Terminal Design

- Multi-lane Exit Ramps - System Interchanges
  - Lane Balance - avoid drop lane situation. May be necessary to add lanes along mainline prior to the diverge - see Figure 505-2b
  - Provide pacing length (2,500 feet) to allow for that lane to be utilized
Ramp Terminal Design

- Multi-lane Exit Ramps - Service Interchanges
  - Type I should normally be used
  - Type II should only be used when queuing in the optional lane doesn’t extend to the physical gore (example would be long ramps, Parclo B, etc.)
Ramp Terminal Design

- Multi-lane Exit Ramps and Diverging Roadways
  - Horizontal Curvature - Table B; Figure 505-2a lists recommended values for the curve differential between the outer edges of diverging roadways; these values apply for tangent and simple curve alignments
  - On compound and spiral curvature is used in diverging area, design the two roadways individually to provide proper “L” and “N”
  - Crest Vertical Curves - provide sight distance applicable to design speed of the roadway; DSD shown in Figure 201-6.
  - Superelevation - follow Section 503-6.4; locate longitudinal joints to coincide with lane lines; SCD BP-6.1
Ramp Terminal Design

- Multi-lane Exit Ramps and Diverging Roadways
  - Difference between Figure 503-3c and Figure 505-2a

### Notes for High-Speed Single-Lane Exit Terminals

1. The Exit Curve should normally be according to the Exit Curve Table where the radius is on tangent. Where the radius is on a curve alignment, the maximum difference between the Exit Curve and the circular curve should normally be the Exit Curve Table value, plus a difference, however, may vary by as much as one degree in order to avoid a tangent exit alignment. (See Section 503.8 for the allowable traverse breaks in separation on cross-slopes.)

2. When the First Ramp Curve does not exceed 8%, the Exit Curve may be compounded directly with the First Ramp Curve up to 500 ft beyond the lane when the First Ramp Curve does exceed 8%, a spiral should be placed between the Exit Curve and the First Ramp Curve and the beginning of the Spiral (CD) should be at the base point.

3. Normally single lane ramps will have a width of 8', the width shall be increased to 10' when the ramp radius is less than 200. When an 8' width ramp is used, the 8' exit terminal width shall be retained and the 2' width reduced by 2'.

### Table 6

<table>
<thead>
<tr>
<th>Speed</th>
<th>Minimum Radii</th>
<th>Minimum Curvature</th>
<th>Minimum Length</th>
<th>Minimum Ramps</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>100</td>
<td>0.05</td>
<td>200</td>
<td>3</td>
</tr>
<tr>
<td>55</td>
<td>150</td>
<td>0.06</td>
<td>300</td>
<td>4</td>
</tr>
<tr>
<td>60</td>
<td>200</td>
<td>0.08</td>
<td>400</td>
<td>5</td>
</tr>
<tr>
<td>70</td>
<td>300</td>
<td>0.12</td>
<td>500</td>
<td>6</td>
</tr>
</tbody>
</table>

* The lane combination shall be determined from Table 6 and includes a hard shoulder when lanes are on both sides of the exit lane in addition or more lanes in the exit lane on both sides of the exit lane.

* A hard shoulder includes a hard shoulder width of 1' on both sides.
Ramp Terminal Design

- Multi-lane Exit Ramps and Diverging Roadways
Ramp Terminal Design

- Multi-lane Exit Ramps and Diverging Roadways
Collector-Distributor Roads

- Sect 504
- Used to minimize weaving problems and reduce conflict points (merging and diverging) along the mainline
- May be used within a single interchange, through two adjacent interchanges, or continuously through several interchanges
Collector-Distributor Design

- C-D Road between interchanges - minimum of two lanes
- C-D Road within an interchange - one or two lanes
- Cross section should adhere to one-lane or two-lane directional roadway criteria in Figure 303-1
- Design speed should normally match mainline and no more than 10-mpg less than mainline
Collector-Distributor Design

- **C-D Road Entrance Terminals**
  - Superelevation shall be developed similar to that described in Section 503.6.4
  - C-D edge of pavement taper rate relative to the mainline
  - Preferred to finish the C-D lane taper prior to beginning the C-D merge into the mainline if possible.
Collector-Distributor Design

- **C-D Road Exit Terminals**
  - Three examples shown in Figure 504-2
  - These terminal designs should be applied to highways using high-speed exit terminals
  - Superelevation shall be developed similar to that described in Section 503.6.4
Module Review

- Key Terms
  - Service & System Interchanges
  - Route Continuity
  - Lane Balance
  - Conceptual Signing Plan
  - Ramp Terminal
  - Converging & Diverging Roadways
  - Collector-Distributor Roads