Lecture 4.33

4.4 Traffic Geometrics

Grade-Separated Interchanges - Types and Layouts

Grade-separated interchanges eliminate crossing conflicts between major traffic streams by routing opposing movements onto separate vertical bridge levels.

Engineers select interchange types based on traffic volume demand, right-of-way availability, construction cost, and terrain constraints.

Interchange Type	**Characteristics**
Diamond	Standard high-efficiency layout connecting minor arterial roads to major freeways
Full Cloverleaf	4-leg system using loop ramps for left turns; eliminates all crossing conflicts but introduces weaving
Trumpet	Ideal 3-leg junction layout for connecting a highway stub or toll road to a main freeway
SPUI	Compact urban layout consolidating all turning movements under one bridge span

Interchange Ramp Geometrics (Design Speed, Radius, Gradients)

Highway ramps are directional roadways connecting two grade-separated legs of an interchange.

Ramp geometric design balances design speed, minimum horizontal curvature, maximum longitudinal gradients, and adequate super-elevation.

- Ramp Design Speed: Typically 50% to 70% of the mainline freeway design speed (40-70 km/h)
- Minimum Ramp Curvature: Derived from speed and maximum super-elevation ($e_{max} = 8\% - 10\%$)
- Maximum Gradients: Desirably under 4% to 5% to allow heavy trucks to maintain climbing speed
- Loop Ramp Geometry: Radii typically constrained to 40m-60m, requiring low design speeds (30-40 km/h)

Ramp Terminal Design & Merge/Diverge Geometrics

Ramp terminals represent the transition zones where ramps connect with mainline expressway lanes.

Geometric design must provide smooth taper angles, adequate sight distance, and sufficient speed-change lane lengths to prevent lane-changing friction.

- Entrance Terminals (Merging): Flat convergence angles (1:30 to 1:50 taper) allowing gradual merging into traffic stream gap
- Exit Terminals (Diverging): Direct taper design (1:15 to 1:25) allowing exiting drivers to decelerate out of mainline traffic
- Lane Balance Rule: Mainline lanes plus ramp lanes leaving an interchange should equal or exceed total approaching lanes
- Gore Area Geometry: Neutral triangular pavement zone marked with chevrons separating main lanes from ramp lanes

Driveway and Commercial Access Geometry

Driveways act as miniature at-grade intersections connecting private commercial/residential properties to public arterial streets.

Improper driveway geometry introduces severe conflict points, causing rear-end crashes and blocking arterial travel lanes.

- Driveway Widths: 3.5m to 6.0m for residential; 7.5m to 10.5m for commercial double-lane access
- Corner Radius: 4.5m to 9.0m curb return radii permitting smooth turn-ins without encroaching on adjacent lanes
- Driveway Throat Length: Internal storage length preventing exiting vehicles from queuing back onto public streets
- Sight Distance: Unobstructed sight triangles for drivers exiting property driveways onto public roads

Turning Radius for Heavy Commercial Vehicles (Swept Path Analysis)

Heavy trucks and semi-trailers exhibit significant 'off-tracking'—where rear trailer wheels follow a tighter path than front steering wheels during turns.

Engineers perform Swept Path Analysis to ensure intersection curb radii, turn lanes, and roundabouts accommodate maximum design vehicle dimensions.

- Design Vehicle Classes: Light vehicles (P), Single-unit trucks (SU), Semi-trailers (WB-15 / WB-20 per IRC)
- Off-Tracking Phenomenon: Difference in path radius between front outer wheel and rear inner wheel
- Extra Widening on Curves: $W_e = \frac{nL^2}{2R} + \frac{V}{9.5\sqrt{R}}$ (mechanical + psychological widening)
- Software Verification: CAD-based AutoTURN software simulating vehicle turn envelopes

Unsignalized Junction Sight Triangles & Corner Radii

Unsignalized intersections rely on clear geometric sight triangles to allow drivers on side approaches to evaluate safe gaps in major road traffic.

Proper corner curb radii balance turning speeds of passenger cars against pedestrian crossing distance exposure.

- Approach Sight Triangle: Distance required for driver approaching yield sign to perceive and react to crossing traffic
- Departure Sight Triangle: Distance required for driver stopped at stop sign to accelerate into major road stream gap
- Corner Curb Radius Trade-off: Small radii (3-5m) slow turning vehicles and shorten pedestrian crossing length
- Large Corner Radii (10-15m): Accommodate heavy trucks but increase turning speeds and pedestrian hazard exposure

Pedestrian & Bicycle Geometric Provisions (Refuge Islands, Curb Ramps)

Integrating pedestrian and bicycle geometry into road designs ensures safe co-existence with motorized traffic streams.

Engineers apply specific dimensional standards for sidewalk widths, protected cycle tracks, curb extension bulb-outs, and median refuges.

Provision	**Geometric Standard**
Sidewalk Width	Min 1.8m (residential), 2.5m to 4.0m (commercial high-density corridors)
Curb Extensions	Extending kerb line into parking lane at crosswalks to reduce crossing distance by 30-50%
Cycle Track	Minimum 2.0m one-way / 3.0m two-way width separated by 0.5m buffer kerb
Curb Ramp	Maximum 1:12 slope with tactile detectable warning surfaces at footway edges

Traffic Calming Geometry (Chicanes, Speed Tables, Speed Humps)

Traffic calming devices rely on precise geometric dimensions to enforce targeted operating speeds (30 km/h) without damaging vehicles.

Sub-standard geometry causes excessive vehicle discomfort or fails to slow down speeding vehicles effectively.

Device	**Geometry**
Speed Hump	Parabolic profile, 3.7m span, 100mm height designed for 25 km/h crossing speed
Speed Table	Raised flat-topped table (6.0m to 9.0m length) incorporating zebra crosswalks
Chicane	Alternating curb extensions creating S-shaped horizontal slalom path with 45° offset tapers
Mini-Roundabout	Fully traversable domed central island (1.0m to 4.0m diameter) in tight urban grid junctions

Modern Roundabouts vs Signalized Geometrics Comparison

Modern roundabouts differ significantly from old traffic rotaries, featuring smaller diameters, deflection entries, and yield-at-entry priority rules.

Comparing geometric parameters helps civil engineers select between modern roundabouts and signalized intersections.

- Yield-at-Entry Priority: Entering traffic must yield to circulating traffic, eliminating weaving lock-ups
- Entry Deflection Geometry: Curved entry path forcing entering vehicles to decelerate to 20-30 km/h
- Inscribed Circle Diameter (ICD): Compact 25m to 45m diameter compared to old rotaries (¿60m)
- Safety Comparison: Modern roundabouts reduce fatal collisions by 80% compared to signalized junctions

Computer-Aided Highway Geometric Design & CAD Applications

Modern geometric design relies on specialized Civil Engineering CAD software to generate 3D digital terrain models and horizontal/vertical alignments.

Software platforms automate sight distance checks, super-elevation transitions, earthwork cut/fill quantities, and swept path simulations.

- 3D Digital Terrain Models (DTM): Processing LiDAR and survey point clouds into 3D elevation surfaces
- Alignment Design Platforms: Civil 3D, Bentley OpenRoads, MX Road, and MX TransYT
- Automated Sight Distance Audits: 3D ray-tracing algorithms detecting visual obstructions along alignment curves
- Building Information Modeling (BIM): Integrating structural, drainage, and traffic geometric models into unified 3D models

Summary of Advanced Traffic Geometrics

Advanced traffic geometrics encompasses interchange layouts, ramp terminals, swept path analysis, non-motorized infrastructure, and digital CAD modeling.

Rigorous geometric engineering ensures high-speed freeway efficiency while safeguarding urban streets and vulnerable road users.

- Interchanges (Diamond, Cloverleaf, Trumpet) eliminate crossing conflicts at major highway junctions
- Ramp terminals require flat merge tapers, lane balance, and clear gore zone chevron markings
- Swept path analysis and curve widening (W_e) accommodate heavy truck off-tracking without curb mounting
- Modern roundabouts use entry deflection and yield-at-entry rules to achieve superior safety performance