Chapter 3 Design Elements

3.1 Introduction

The alignment of a roadway consists of multiple design elements that together should provide a facility that achieves a safe and efficient design. These elements of design include sight distance, horizontal alignment, vertical alignment, and superelevation.

3.2 Sight Distance

3.2.1 General Considerations

Sight distance is the length of roadway over which an object of a specific height is continuously visible to a driver. Use design criteria including roadway classification, design speed, horizontal alignment and vertical alignment to provide adequate sight distance for the proposed facility. Provide sufficient sight distance to ensure a vehicle can operate in a safe and efficient manner. Three types of sight distance are discussed below: stopping sight distance, decision sight distance, and passing sight distance. For each of the three sight distance calculations, the height of the driver's eye is considered to be 3.5 feet above the road surface. The height of an object is 2 feet above the roadway for stopping and decision sight distances, and 3.5 feet for passing sight distance. Select the appropriate sight distance methodology for the project under design.

Refer to GB Chapter 3 Section 3.2.1 for more detail on sight distance general considerations.

3.2.2 Stopping Sight Distance

Stopping sight distance is the distance a driver needs to be able to see to prevent collision with an object in the roadway. The total distance required is the sum of brake reaction distance (the distance a vehicle travels from the time the driver sees an object requiring a stop, to the time brakes are applied) and braking distance (the distance required for the vehicle to stop when the brakes are applied) for level roadways. Adjust the stopping sight distance calculation as needed when the roadway grade is greater or less than 0 percent. Table 3-1 below provides the stopping sight distances for level roadways as well roadways with grades.

Table 3-1 Stopping Sight Distance on Grades

Design Speed (mph)	Stopping Sight Distance (ft)						
	Level	Downgrades			Upgrades		
	0%	3%	6%	9%	3%	6%	9%
15	80	80	82	85	75	74	73
20	115	116	120	126	109	107	104
25	155	158	165	173	147	143	140
30	200	205	215	227	200	184	179
35	250	257	271	287	237	229	222
40	305	315	333	354	289	278	269
45	360	378	400	427	344	331	320
50	425	446	474	507	405	388	375
55	495	520	553	593	469	450	433
60	570	598	638	686	538	515	495
65	645	682	728	785	612	584	561
70	730	771	825	891	690	658	631
75	820	866	927	1003	772	736	704
80	910	965	1035	1121	859	817	782
85	1010	1070	1149	1246	949	902	862

Source: GB Chapter 3 Section 3.2.2 Tables 3-1 and 3-2 (information combined into one table).

Refer to GB Chapter 3 Section 3.2.2 and GB Tables 3-1 and 3-2 for more detail on stopping sight distance.

3.2.3 Decision Sight Distance

Decision sight distance is the distance needed by a driver to detect an unexpected object on a roadway, recognize the object, and react to the object by determining the appropriate speed and path to avoid the object. Decision sight distance is greater than stopping sight distance because it provides a margin of error to allow a driver time to complete complex maneuvers at the same or reduced speed.

Refer to GB Chapter 3 Section 3.2.3 and GB Table 3-3 for more detail on decision sight distance.

3.2.4 Passing Sight Distance

Passing sight distance is the length of roadway required for a driver to safely make a passing maneuver without colliding with a vehicle in the opposite lane. It also allows a driver to abort the passing maneuver. The three main components of passing sight distance are: distance traveled during perception-reaction time and acceleration into opposing lane, distance required to pass in opposing lane, and distance necessary to clear the slower vehicle.

3.2.4.1 Passing Sight Distance for Two-Lane Roadways

Minimum passing sight distance is based on the warrants for no-passing zones presented in the *FHWA Manual on Uniform Traffic Control Devices* (MUTCD). The passing sight distance provided on a two-lane roadway should be greater than the stopping sight distance. Base the passing sight distance on a single passenger vehicle passing a single passenger vehicle.

Refer to GB Chapter 3 Section 3.2.4 and GB Table 3-4 for more detail on passing sight distance for two-lane roadways.

3.2.4.2 Passing Sight Distance for Multilane Highways

Passing maneuvers on multilane roadways and streets with two or more lanes in each direction of travel are expected to occur within the limits of the travel way for each direction of travel. Therefore, passing sight distance is not a factor to be considered on multilane highways.

Refer to GB Chapter 3 Section 3.2.5 for more detail on sight distance for multilane highways**.**

3.3 Horizontal Alignment

The horizontal alignment is the route of the road, geometrically considered a series of tangents, horizontal curves, and spiral transitions. Factors that often influence the location of a horizontal alignment are speed, superelevation, and travel way widths. Horizontal curves provide transitions between two tangent sections. Superelevation helps the driver to negotiate through the horizontal curve and is influenced by design speed of the roadway and the radius of the horizontal curve.

3.3.1 General Considerations

The horizontal alignment of a roadway and its associated design criteria should be consistent with the type of facility, surrounding topography, and other design features. Consider environmental variables (wetlands, historical properties, Section 4(f) properties), right of way, utilities, existing and proposed adjacent development, and drainage patterns when developing the horizontal alignment for a roadway. In areas where environmental or right of way impacts are a constraint, minimum design criteria can be considered.

Refer to GB Chapter 3 Section 3.3.2 for more detail on horizontal alignment general considerations.

3.3.2 Spiral Curves

Spiral curves are used to provide a smooth transition between tangent sections and horizontal curves. Spirals provide a natural path for drivers entering and exiting curves while minimizing encroachment into adjacent lanes.

Spiral curves are required on interstates, freeways, expressways, and major arterials. Where terrain and topography restrict their use, the roadway designer will have the option to eliminate spirals on collector roads, local roads and streets, and on minor arterials with a posted speed of 45 mph (50 mph design speed) or less. Do not use spiral curves on roadway facilities that have curb and gutter. Due to constructability issues with deck pours, avoid spirals on bridges. In all cases, a spiral should not begin or end on the bridge. In special cases where spirals cannot be avoided on bridges, design increment spacing to be equally spaced as a multiple of the bridge span and set transitions at substructure elements. Coordinate spiral placement on bridges with NCDOT Structures Management Unit.

Design spiral curves long enough so superelevation runoff can be completed over the spiral. Tangent runout is applied prior to the spiral curve and full superelevation is attained at the end of the spiral curve or the beginning of the circular curve.

Refer to GB Chapter 3 Equations 3-26 and 3-27 to calculate the minimum length of spiral curve and GB Chapter 3 Table 3-19 for desirable lengths for spiral curves.

On high-speed facilities where the horizontal curve requires a superelevation of 3 percent or less, the spiral curve may be eliminated to avoid long superelevation transitions. Coordinate with NCDOT Roadway Design Unit and the hydraulic designer to determine if the spiral curve should be eliminated.

Refer to GB Chapter 3 Section 3.3.8 for more detail on spiral curves.

3.3.2.1 Compound Spirals

Use compound spirals between two curves if the radius of one curve is twice the radius of the second curve. Use compound spirals also on all interstates, freeways, expressways, arterials, and on ramps in interchange areas as the preferred method to change superelevation rates.

3.3.3 Traveled Way Widths

Minimum traveled way and shoulder widths are based on the classification of the roadway, the design speed, and the specified design volume (vehicles/day). Discuss any reductions to the traveled way or shoulder widths with the Roadway Design Unit team lead. For reconstruction projects, the existing travel lane and usable shoulder widths should not be reduced below existing conditions. The following tables provide minimum width of traveled way and shoulders for rural arterials, collectors, and local roads.

Table 3-2 Minimum Width of Traveled Way and Usable Shoulder for Rural Arterials

Design Speed (mph)	Minimum Width of Traveled Way (ft)[a] for Specified Design Volume (veh/day)		
	under 400[c]	400 to 2000	over 2000
40	20	22	24
45	20	22	24
50	22	22	24
55	22	24	24
60	22	24	24
65	22	24	24
70	22	24	24
75	22	24	24
All speeds	**Width of Usable Shoulder (ft)[b]**		
	4	**6**	**8**

[a] On roadways to be reconstructed, an existing 22-foot traveled way may be retained where the alignment is satisfactory and there is no crash pattern suggesting the need for widening.
[b] Preferably, usable shoulders on arterials in rural areas should be paved; however, where volumes are low or a narrow section is needed to reduce construction effects, the paved shoulder width may be a minimum of 2 feet provided bicycle use is not intended to be accommodated on the shoulder.
[c] Where frequent use by trucks is anticipated, additional traveled way width should be considered.
Source: GB Chapter 3 Section 7.2.3 Table 7-3

Table 3-3 Minimum Width of Traveled Way and Shoulders for Collector Roads

Design Speed (mph)	Minimum Width of Traveled Way (ft) for Specified Design Volume (veh/day)		
	under 400	400 to 2000	over 2000
20	20[a]	20	22
25	20[a]	20	22
30	20[a]	20	22
35	20[a]	22	22
40	20[a]	22	22
45	20	22	22
50	20	22	22
55	22	22	22[b]
60	22	22	22[b]
65	22	22	22[b]
All speeds	**Width of Shoulder on Each Side of Road (ft)**		
	2	**4**	**6**

[a] An 18-foot minimum width may be used for roadways with design volumes under 250 veh/day.
[b] Consider using lane width of 24 feet where substantial truck volumes are present or agricultural equipment frequently use the road.
Note: See GB text for discussion of roadside barrier and off-tracking considerations.
Source: GB Chapter 6 Section 6.2.2 Table 6-5

Table 3-4 Minimum Width of Traveled Way and Shoulders for Two-Lane and Local Roads in Rural Areas

Design Speed (mph)	Minimum Width of Traveled Way (ft) for Specified Design Volume (veh/day)		
	under 400	400 to 2000	over 2000
15	18	20[a]	22
20	18	20[a]	22
25	18	20[a]	22
30	18	20[a]	22
35	18	20[a]	22
40	18	20[a]	22
45	20	22	22
50	20	22	22
55	22	22	22[b]
60	22	22	22[b]
65	22	22	22[b]
All speeds	**Width of Graded Shoulder on Each Side of the Road (ft)**		
	2	**3**	**6**

[a] For roads in mountainous terrain with design volume of 400 to 600 veh/day, an 18-foot traveled way width may be used.
[b] Consider using traveled way width of 24 feet where substantial truck volumes are present or agricultural equipment frequently uses the road.
Source: GB Chapter 5 Section 5.2.2 Table 5-5

Widening the traveled way on certain horizontal curves is needed for two reasons:

1. The rear wheels of the vehicle track inside the front wheels negotiating the curve.
2. The driver cannot steer the vehicle in the center of the lane.

Refer to GB Chapter 3 Section 3.3.10 Tables 3-24a and 3-25 for more detail on traveled way widening on horizontal curves.

3.3.4 Widths for Turning Roadways at Intersections

Design width of pavement for turning roadways is based on traffic conditions and edge treatment. Factors for traffic conditions are the radius of the inner edge of pavement and the operation of the roadway. The operation of the roadway is divided into three cases:

- Case I – one-lane, one-way operation, no provision for passing a stalled vehicle
- Case II – one-lane, one-way operation, with provision for passing a stalled vehicle
- Case III – two-lane operation, either one-way or two-way

The use of an edge treatment such as vertical curb may require additional pavement width depending on if the curb is placed on one or both sides and how the road operates (Case I, II, or III). Lane widths may also be reduced if stabilized shoulder is provided.

Refer to GB Chapter 3 Section 3.3.11 Tables 3-27 through 3-30 for more detail on widths for turning roadways.

3.4 Superelevation

Superelevation is the rotation of the pavement cross slope on the approach and through a horizontal curve. Superelevation assists the driver by counteracting the effect of centrifugal force and reducing the possibility of a vehicle overturning. The maximum superelevation used on a roadway is based on multiple variables such as roadway classification, terrain, climate, highway setting (rural or urban), and design speed.

The maximum superelevation rate most commonly used is 8 percent. Rates as high as 10 percent may be used to facilitate drainage, but rates of 6 percent or less are recommended in areas with snow and ice. Use a maximum superelevation rate of 4 percent with a curb and gutter typical section in urban areas where travel speeds are lower due to traffic congestion or adjacent land usage. Minimize or omit superelevation at intersection locations where travel speeds are low. On structures, do not use superelevation more than 6 percent and keep all superelevation transitions outside the limits of the structure.

Table 3-5 Superelevation Guidelines

Classification	Location & Condition	Superelevation [1]
Interstates & Freeways	• Statewide	.08 or .10 [2]
Ramps & Loops	• Statewide	.08
Flyovers (Directional ramps with bridges)	• Statewide	.06
Arterials & Rural Collectors	• Statewide • Limited Access	.08
Arterials & Urban Collectors with 60 mph design speed or greater	• Statewide • Partial or no control of access	.06
Urban Collectors with 50 mph or less design speed	• Statewide • Curb & Gutter or shoulders with driveways	.04
Bridge replacement projects, Local Roads, & Secondary Roads	• Statewide	.04 or .06 [3]
Bridges	• Statewide	.06 [4]

Notes:
1. Refer to GB Chapter 3 Section 3.3.5 for particular design superelevation tables the designer should use.
2. Do not use in locations susceptible to icy conditions.
3. Choose table that fits characteristics of area.
4. For cored slab and box beam bridges, do not exceed a .04 superelevation.

Refer to GB Chapter 3 Section 3.3 for design superelevation tables and more detail on superelevation.

3.5 Vertical Alignment

The vertical alignment of a roadway is made up of a series of straight grades and vertical curves. Vertical curves provide a smooth transition from one straight grade to another. The terrain of the roadway is an important element of the vertical alignment and is classified as level, rolling, or mountainous. Maximum grades of a vertical alignment are dependent upon the roadway classification, terrain, and design speed.

3.5.1 Maximum Grades

The maximum grade of a roadway is based on the classification of the roadway, the terrain, and the design speed. Avoid use of maximum grades whenever possible when developing a vertical alignment. Limit the use of grades steeper than the maximum to cases where the grade is for a short length (less than 500 feet) or for low-volume roadways in rural areas.

Refer to GB Chapter 3 Section 3.4 for more detail on maximum grades.

Refer to the following tables in the GB for maximum grades for specific roadway classifications:

- Local roads – GB Chapter 5 Table 5-2
- Collectors (rural) – GB Chapter 6 Table 6-2

- Collectors (urban) – GB Chapter 6 Table 6-7
- Arterials (rural) – GB Chapter 7 Table 7-2
- Arterials (urban) – GB Chapter 7 Table 7-4a
- Freeways – GB Chapter 8 Table 8-1

3.5.2 Minimum Grades

Use a minimum grade of 0.5 percent which will typically provide adequate pavement surface drainage. Use flatter grades of 0.3 percent if pavement is adequately sloped and supported by a firm subgrade. In cases where the minimum 0.3 percent grade cannot be met, coordinate with a hydraulic designer to determine viable options to provide positive drainage. Document this coordination and final decision and include the documentation as part of the appropriate design submittal package.

Refer to GB Chapter 3 Section 3.4.2.2 for more detail on minimum grades.

3.5.3 Vertical Curves

Vertical curves provide a gradual change between tangent grades and may be either a crest or sag curve. Design vertical curves to allow the driver to see the roadway ahead and to provide adequate drainage. Design crest vertical curves based on stopping sight distance and sag vertical curves for headlight sight distance. The rate of vertical curvature, K, is the length of curve per percent algebraic difference in the intersecting grades.

Refer to GB Chapter 3 Tables 3-35 and 3-37 for K values for crest and sag curves.

Refer to GB Chapter 3 Section 3.4.6 for more detail on vertical alignments.

3.5.4 Design Controls for Vertical Curves

Refer to GB Chapter 3 Section 3.4 for more detail on design controls of vertical curves.

Refer to GB Chapter 3 Section 3.4.6.2 Table 3-35 for more detail on design controls for crest vertical curves based on stopping sight distance.

Refer to GB Chapter 3 Section 3.4.6.3 Table 3-37 for more detail on design controls for sag vertical curves.

3.5.5 Climbing Lanes

A climbing lane is the response to the increasing amount of traffic delays and the number of serious crashes occurring on uphill grades due to heavy loaded and slow-moving vehicles that could impede following vehicles. Consider the need for climbing lanes during the original construction planning stage and on safety improvement projects. Two-lane roads create the greatest need for climbing lanes based on limited passing opportunities but can be considered on multilane facilities. The decision to provide a climbing lane will be based on discussions with the project team.

Refer to GB Chapter 3 Section 3.4.3 for more detail on climbing lanes.

Use report *FHWA-IP-88-015 Grade Severity Rating System (GSRS)* to determine the maximum safe descent speeds for trucks according to weight and to determine the need for an auxiliary lane.

Discuss proposed climbing lane locations with the Roadway Design Unit, NCDOT Project Manager and the Division Engineer. Justification studies and cost estimates are required when climbing lanes are proposed.

3.5.6 Emergency Escape Ramps

Use emergency escape ramps (EER) on long mountainous grades in rural areas. Consider their use also in urban areas on steep, short grades where high truck volumes are mixed with dense traffic and development. Urban areas have a higher probability of fatalities or property damage than the rural areas especially if a stop condition or turn occurs at the end-of-grade.

It is recommended a brake-check area be provided at the top of the grade for truckers to inspect their equipment, check their brakes, read any information available about the upcoming grade and prepare for the downgrade.

Justification for an EER involves several considerations that have not been formalized into specific warrants or processes. The principal factor for an EER need is determined by runaway accident experience. Site conditions such as grade length, percent of grade, horizontal alignment, and end-of-grade conditions should all be considered. The decision to provide an EER will be based on discussions with the project team.

Average daily traffic and percentage of trucks count about the same as site conditions. Although available right of way and topography are factors in site selection, they are not factors in determining the need for a ramp.

The GSRS was developed to determine the maximum safe speed for vehicles of different weights. It can also be used to establish the need and location for truck escape ramps by calculating the brake temperatures at 0.5-mile intervals on a grade.

A very informative Transportation Research Board publication regarding truck escape ramps is available in the Roadway Design Unit library: *NCHRP Synthesis 178 Truck Escape Ramps A Synthesis of Highway Practice*

Refer to GB Chapter 3 Section 3.4.5 for more detail on emergency escape ramps

3.5.7 Pedestrian Considerations

Design crosswalks for accessibility for pedestrians with disabilities. At crosswalk locations, the roadway grade will become the pavement cross slope along the crosswalk. Similarly, the superelevation of the roadway will become the grade of the crosswalk Take both of these into account when establishing grades and superelevation through an intersection.

Refer to GB Chapter 3 Section 3.4.2.2.3 and *NCDOT Complete Streets Policy* for more detail on pedestrian considerations

Refer to *2010 ADA Standards for Accessible Design* for more information on design for pedestrians with disabilities.

Refer to RDM Part I Chapter 4 Section 4.14.3 for more detail on curb ramps.

Refer to RDM Part I Chapter 8 Section 8.11.3 for more detail on intersection design considerations.

This page intentionally left blank.