

Recommendations for AASHTO Superelevation Design

September, 2003

**Prepared by:
Design Quality Assurance Bureau
NYSDOT**

TABLE OF CONTENTS

<u>Contents</u>	<u>Page</u>
INTRODUCTION	1
OVERVIEW AND COMPARISON	1
Fundamentals	1
Maximum Superelevation Rates	2
Rollover	2
Friction	3
Superelevation Distribution Methods	4
RECOMMENDATIONS	13
REFERENCES	14

List of Exhibits

1	Cornering Forces on Banked Roadways	1
2	NCHRP 439 and AASHTO Friction Values	4
3	AASHTO Distribution Methods	5
4	NCHRP 439 Distribution Method for Low Speed Urban Streets	7
5	NCHRP 439 Distribution Method for Rural Highways and High Speed Urban Streets	7
6	NCHRP 439 Speed Reduction Values	8
7	Comparison of Tangent and Curve Speeds	8
8	Comparison of Design Speeds	9
9	Comparison of AASHTO and NCHRP 439 Minimum Radii	10
10	Minimum Radius Without Superelevation	11
11	Qualitative Cost Comparison	11
12	Comparison of 2001 AASHTO and NCHRP 439 Recommendations	12

Attachments

- Proposed Rewrite of Pages 131-206 of the 2001 AASHTO “A Policy on Geometric Design of Highways and Streets.”
- A marked-up Copy of Pages 131-206 of the 2001 AASHTO “A Policy on Geometric Design of Highways and Streets.”

INTRODUCTION

This paper provides an overview and comparison of the superelevation distribution methods presented in the AASHTO's "A Policy on Geometric Design of Highways and Streets," 2001 and NCHRP Report 439 "Superelevation Distribution Methods and Transition Designs" along with recommendations for future AASHTO revisions.

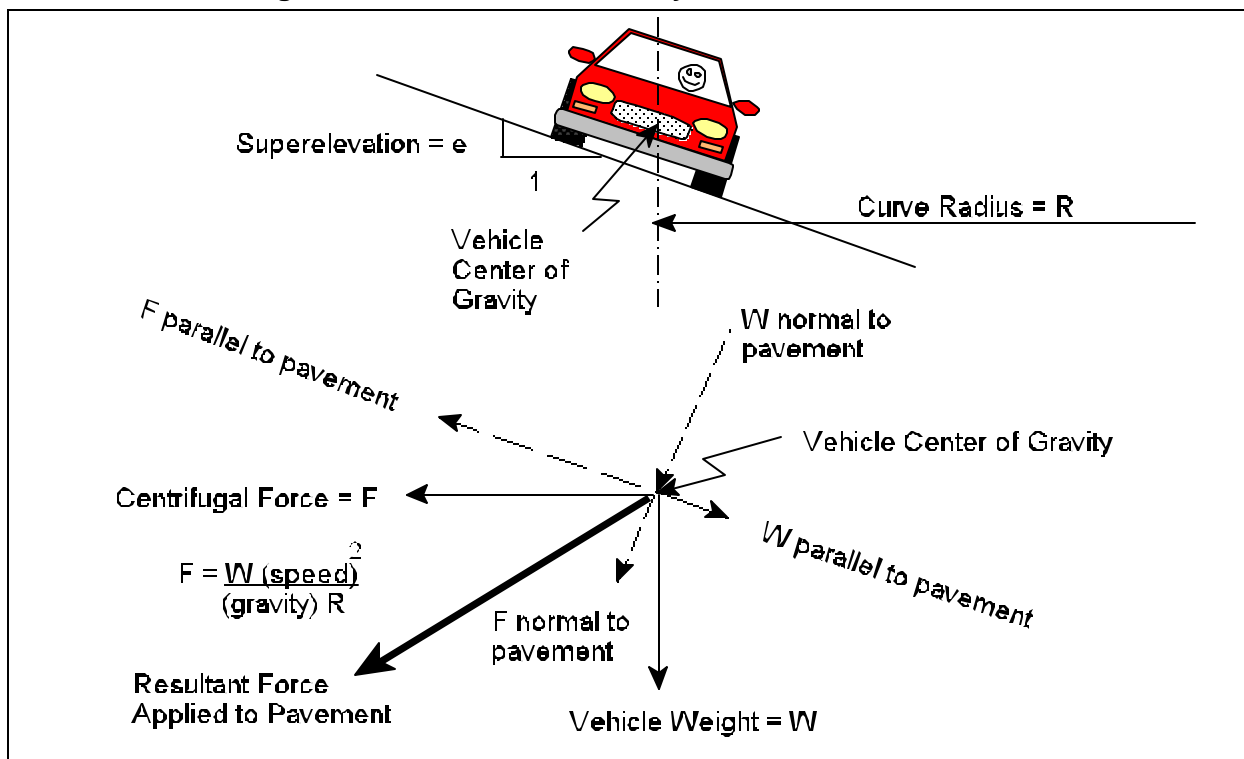
The paper is presented in dual units created by performing all calculations in metric units and soft (i.e., exact) converting to U.S. customary units.

OVERVIEW AND COMPARISON

FUNDAMENTALS

When a vehicle goes around a curve, it experiences a lateral force known as centrifugal force. This lateral force pushes the vehicle and occupants outward from center of the circle. The lateral force is caused by the directional change of the vehicle (i.e., directional change of the velocity vector) called centripetal acceleration. This is similar to the acceleration forces from increasing vehicle speed, with the exception that the acceleration is towards the center of the circle.

Exhibit 1 - Cornering Forces on Banked Roadways



Superelevation is the banking (rotation) of a highway to counter some of the lateral force. As shown in Exhibit 1, the banking causes a portion of the lateral acceleration to act normal (perpendicular) to the banked pavement. This is felt as a downward (with respect to the vehicle) force by the vehicle occupants. The remaining portion of the lateral force may act one of three ways depending on the banking and speed of the vehicle.

- If the speed is balanced for the banking, the lateral force acting outward on the vehicle will be countered by the forces pushing the vehicle down the slope of the banking. The vehicle and occupants will experience a downward force (perpendicular to the roadway) and the vehicle will travel around the curve with little steering input. This is a neutral or equilibrium condition.
- If the vehicle is traveling faster than the equilibrium speed, the resultant lateral force acts outward on the vehicle and occupants. At excessive speeds, the vehicle will skid or roll off the road.
- If the speed is lower than the equilibrium speed, the vehicle and occupants are forced inward. Extreme banking can cause top heavy vehicles to rollover towards the inside of the curve. Additionally, icy conditions can cause the vehicle to slide down the banking, particularly when the tires are spinning to accelerate in stop and go traffic.

MAXIMUM SUPERELEVATION RATES

High rates of superelevation may cause slow moving vehicles to slide down the banking in snow and ice. High superelevation rates can be difficult to attain in urban settings due to closely spaced intersections, numerous driveways, and limited right of way. Maximum superelevation rates are chosen to limit the adverse effects of superelevation.

Five maximum superelevation rates are commonly used.

- Maximum superelevation rates of 4% and 6% are for urban areas.
- Maximum superelevation rates of 6% and 8% are for areas that have frequent ice and snow.
- Maximum superelevation rates of 10% and 12% in rural areas without ice or snow concerns represent a practical limit to accommodate occasional slow moving vehicles, construction equipment, and maintenance equipment.

ROLLOVER

The typical passenger car will skid long before it rolls over on the pavement, particularly in wet weather. Trucks, vans, and sport utility vehicles have much higher centers of gravity and may roll over before skidding, particularly in dry weather and at lower speeds.

FRICTION

Friction allows cornering, braking, and acceleration forces to be transmitted from the tires to the pavement. Rather than using the “coefficient of friction” from dynamics, highway engineers use a ratio of the lateral forces that the pavement can resist. This lateral ratio is most commonly referred to as the “friction factor.”

The friction factor to counter centrifugal forces is reduced by vehicle braking (decelerating) and accelerating. For example, when most of the friction is used for a panic stop, there is little friction available for cornering. Antilock Braking Systems (ABS) have greatly improved this aspect.

The friction factor also depends on numerous variables, including the vehicle speed, weight, suspension, tire condition (wear, tire pressure, tire temperature), tire design (tread, contact patch, rubber compound, sidewall stiffness), pavement, and any substance between the tire and pavement. Since the friction factor decreases as speed increases, numerous studies have been performed to develop friction factors for various speeds. Note that the friction factor diminishes substantially when the tires are spinning faster or slower than the vehicle speed (e.g., in a skid, spinning tires when attempting to accelerate or stop on ice, and during a “burn out” or “peel-out”).

2001 AASHTO Green Book

The Green Book presents three sets of friction factors, shown in Exhibit 2. A set is provided for rural and high speed urban highways, intersection curves, and low speed urban streets. The friction factors were developed empirically as follows:

- Rural and high speed urban highways - Based on the limits of comfort as reported by motorists.
- Intersection curves - Measured from motorists traveling at the 95th percentile speed.
- Low speed urban streets - Based on the limits of comfort as reported by motorists.

The friction factors for intersection curves are higher (less conservative) than those for high speed facility values since higher lateral forces are expected and tolerated by motorists. The friction factors for low-speed urban streets are the highest (least conservative) since even higher lateral forces are expected and tolerated by motorists.

NCHRP 439

NCHRP 439 defines the following three friction terms:

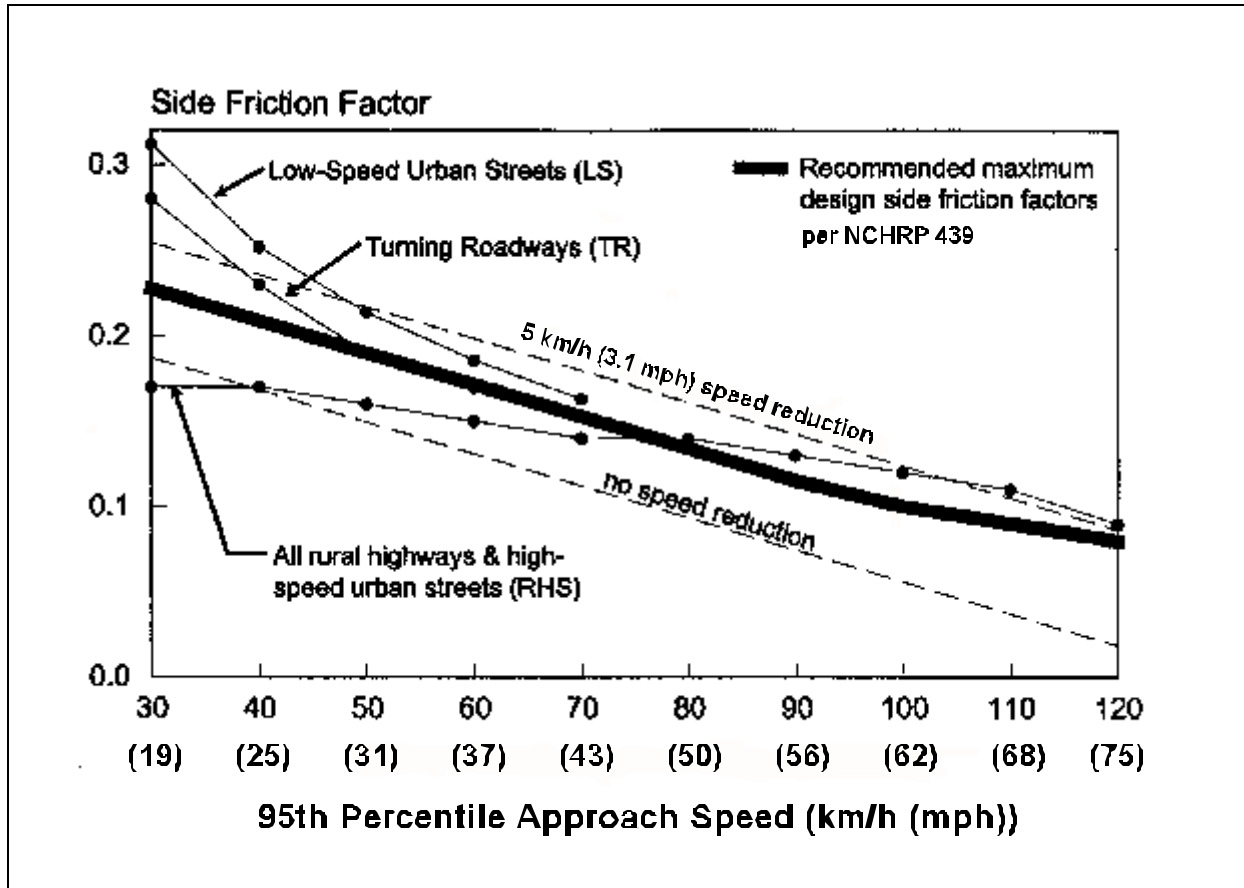
- Maximum design side friction factors - Equivalent of the AASHTO side friction factor.
- Side friction demand factor - Friction needed based on the superelevation and vehicle speed.
- Side friction supply factor - Friction available based on the vehicle speed.

NCHRP 439 recommends using the 95th percentile speed rather than 85th percentile speed since the probability of a crash is higher for inadequately designed horizontal curves. However, a speed reduction of 3 km/h to 5 km/h is used to account for speed reductions observed at curves with minimum radii.

Exhibit 2 - NCHRP 439 and AASHTO Friction Values

SUPERELEVATION DISTRIBUTION METHODS

Superelevation distribution is the amount of banking applied for various combinations of design speed, radii, and maximum superelevation rates.



2001 AASHTO Green Book

The Green Book presents five different methods for distributing superelevation as described below and shown in Exhibit 3. The numbered curves in Exhibit 3 correspond to the five methods below.

1. Superelevation (e) and side friction (f) are increased linearly as the radius decreases.
2. Superelevation is minimized so that a vehicle traveling at the design speed has all the lateral acceleration sustained by side friction until the side friction is at the maximum. For sharper curves, the side friction remains at a maximum and superelevation is increased to sustain lateral acceleration until $e = e_{max}$. In this method, first f and then e are increased as the radius decreases.

3. Superelevation is increased so that a vehicle traveling at the design speed has all lateral acceleration sustained by superelevation until the superelevation is at its maximum. For sharper curves, the superelevation remains at the maximum and side friction is then used to sustain lateral acceleration until f reaches f_{\max} . In this method, first e and then f are increased as the radius decreases.
4. This method is the same as method 3, except that it is based on average running speeds instead of design speed.
5. This method uses values between methods 1 and 3 so that extra superelevation is provided for curves with radii above the minimum radius (i.e., intermediate curves).

For low speed facilities, AASHTO recommends method 2 since it minimizes the disturbance of superelevation to adjacent property in urban areas, closed drainage systems, low speed operations, and intersections.

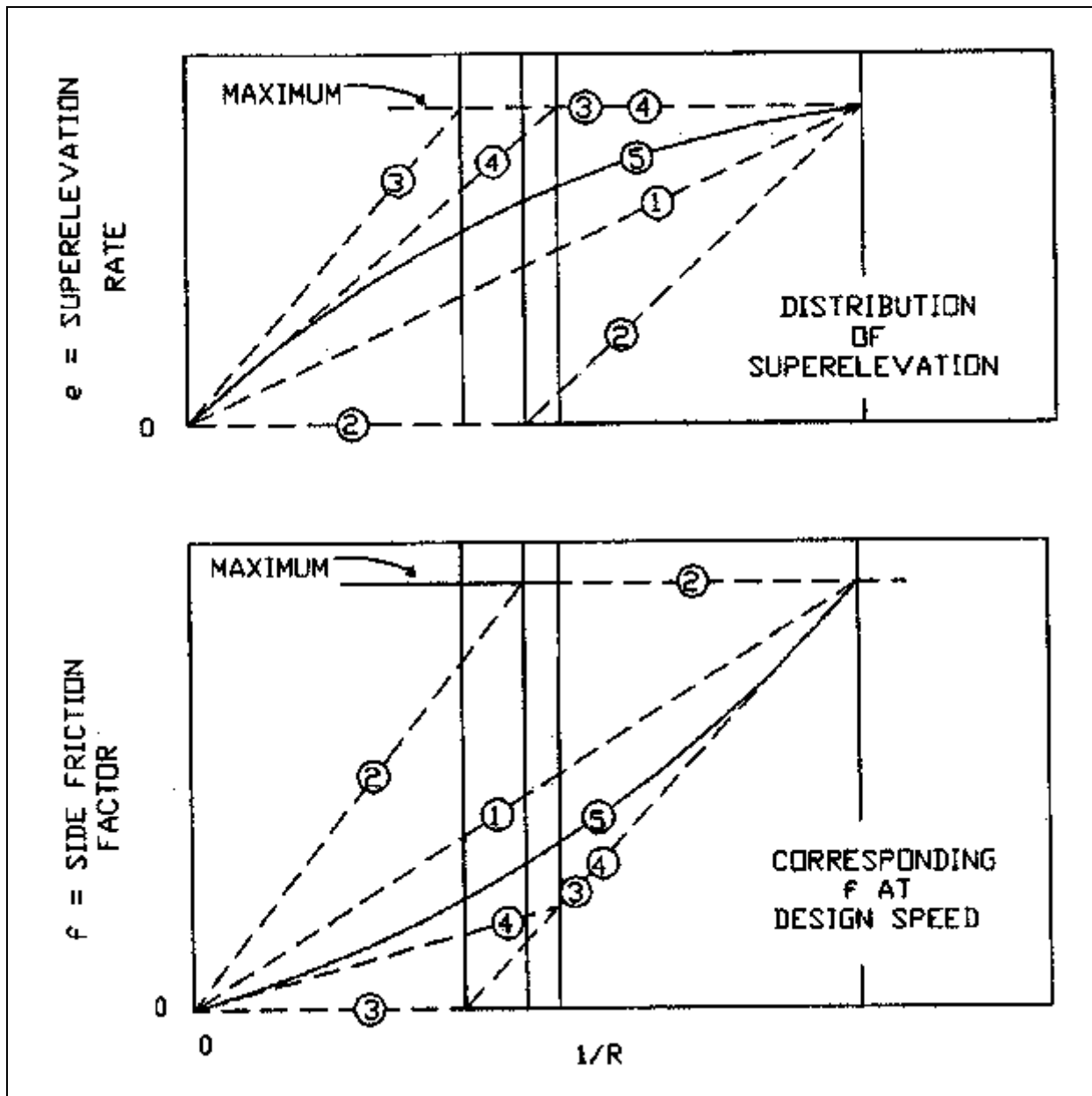
For high speed facilities, AASHTO recommends method 5. To accommodate overdriving that is likely to occur on flat to intermediate curves, it is desirable to use superelevation to offset the need for side friction. This provides ample friction for braking and steering, reduces the demand placed on the driver to keep the vehicle in the travel lane, and greatly reduces the risk that a driver will lose control of the vehicle.

It is also desirable to limit the application of superelevation. This reduces the need for transition sections and construction material for banked highways, thereby reducing design and construction effort and costs. As a practical compromise, the Green Book recommends method 5 to reasonably limit the application of superelevation while reducing the reliance on side friction for flat and intermediate curves.

The method 5 distribution creates a unique distribution curve for each maximum superelevation rate. Therefore, the Green Book includes five figures for each of the five maximum superelevation rates.

AASHTO uses the approach design speed (generally the 85th percentile speed) for curve design. The tabulated superelevation rates are rounded to the nearest 0.1%.

Exhibit 3 - AASHTO Distribution Methods



NCHRP 439

To simplify superelevation distributions, NCHRP 439 recommends two methods of developing superelevation, illustrated in Exhibits 4 & 5. One method is for low speed urban streets and the other for rural highways and high speed urban streets. The method for rural highways and high speed urban streets is also recommended for turning roadways.

NCHRP values distribute superelevation similar to AASHTO's Method 2 and 5. For high speed facilities, superelevation is increased at a greater rate than the need for side friction as the radii is reduced. For low speed and turning roadways, side friction is used first as the radii reduces. Superelevation is added when the radii is reduced beyond what side friction can handle.

Exhibit 4 - NCHRP 439 Distribution Method for Low Speed Urban Streets

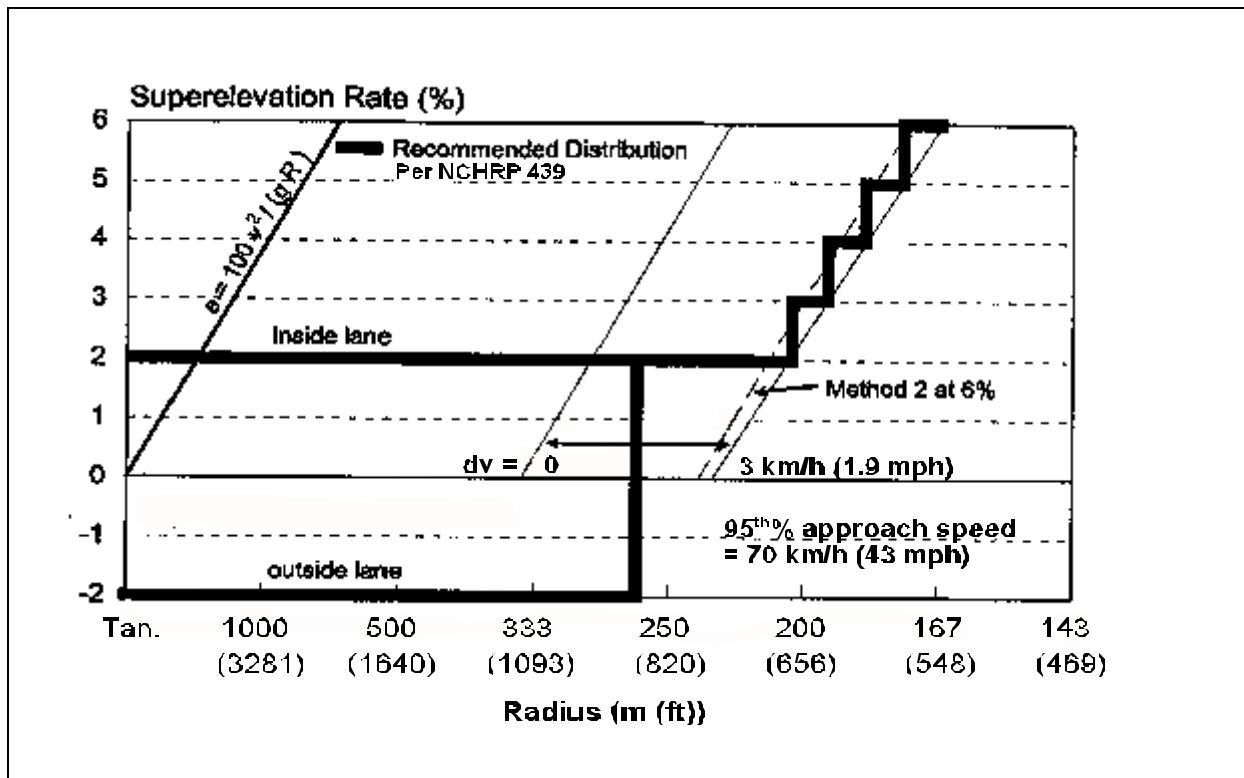
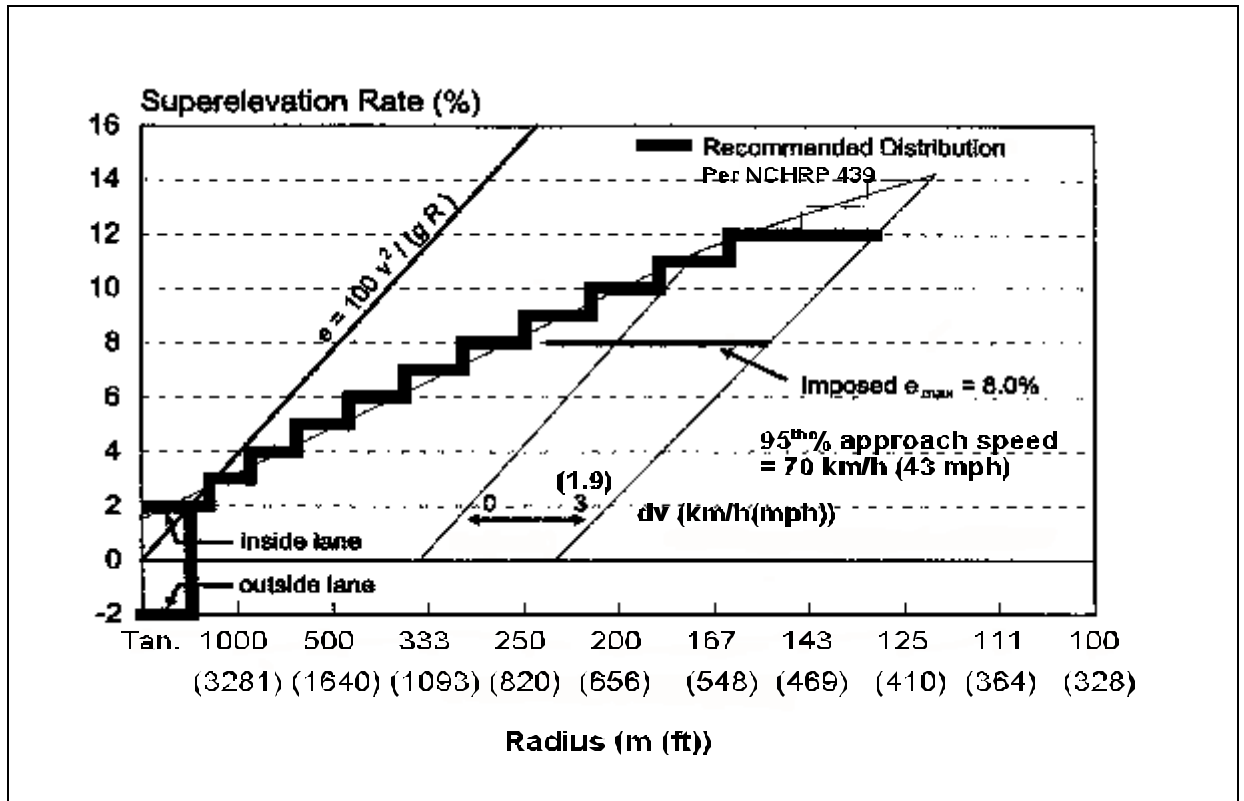


Exhibit 5 - NCHRP 439 Distribution Method for Rural Highways and High Speed Urban Streets



NCHRP uses the 95th percentile approach speed for curve design. The basis for the 95th percentile speed rather than 85th percentile speed is due to the higher probability of failure for inadequately designed horizontal curves. Speed is the only variable that determines if the vehicle can negotiate a curve under prevailing conditions. Unlike stopping sight distance, events such as a fallen tree, deer, or a second vehicle are not required to cause an accident if the vehicle is traveling too fast around the curve.

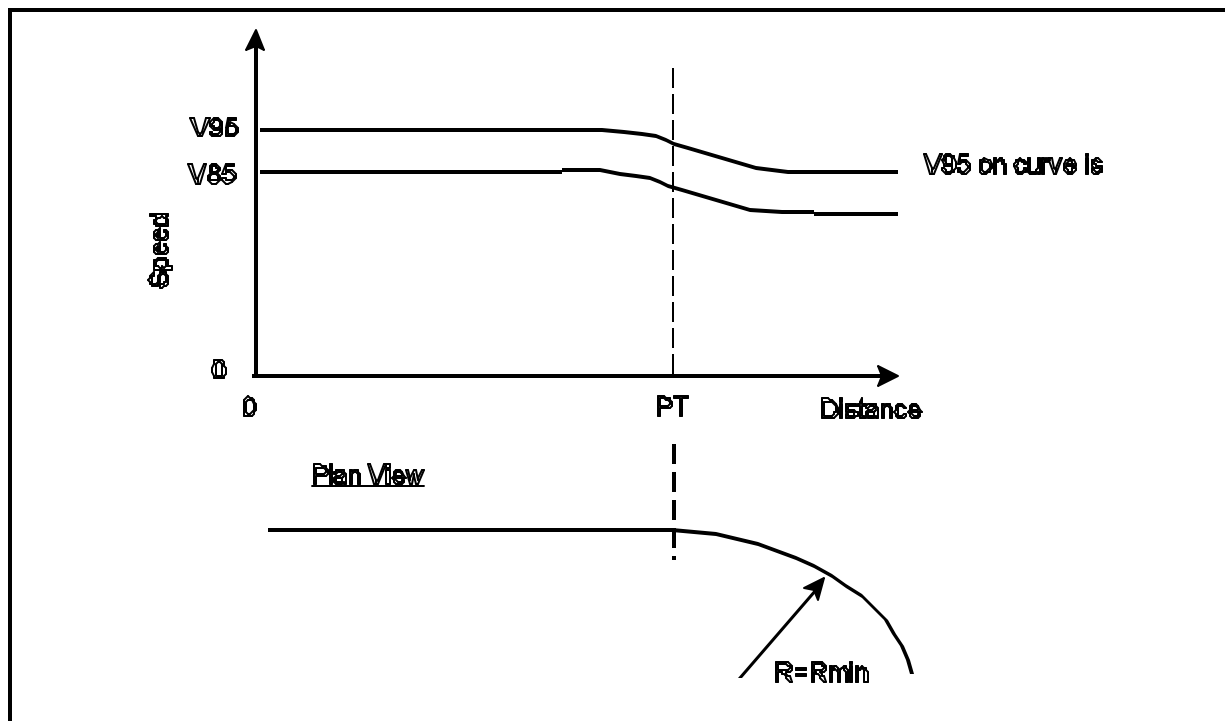
As shown in Exhibit 6, a small speed reduction is used for the minimum radii for a given maximum superelevation rate. This is based on observations of motorists slowing before entering sharp radius curves, as illustrated in Exhibit 7.

Exhibit 6 - NCHRP 439 Speed Reduction Values

Design Speed	Speed Reduction
30 km/h to 100 km/h (20 - 60 mph)	3 km/h (1.9 mph)
110 km/h (70 mph)	4 km/h (2.5 mph)
120 km/h (75 mph)	5 km/h (3.1 mph)

Exhibit 7 provides a comparison of speeds on the tangent and curve portions of a highway. The comparison illustrates that the 85th percentile tangent speed is comparable to the 95th percentile curve speed used in NCHRP 439.

Exhibit 7 - Comparison of Tangent and Curve Speeds



(Courtesy: J. A. Bonneson, May, 2002)

Exhibit 8 provides a comparison of speeds based on speed studies at 13 locations in New York State. The locations included various functional classes and legal speed limits. Sample sizes ranged from 104 to 39,236 vehicles. The comparison illustrates that the NCHRP 439 design speed method is ± 4 km/h (3 mph) of the 85th percentile speed.

Exhibit 8 - Comparison of Design Speeds

95 th Percentile Speed km/h (mph)	95 th Percentile Speed with speed reduction km/h (mph)	85 th Percentile Speed km/h (mph)	Difference between 95 th Percentile Speed with Reduction and 85 th Percentile Speed km/h (mph)
64 (40)	61 (38)	63 (39)	- 2 (-1)
77 (48)	74 (46)	76 (47)	- 2 (-1)
97 (60)	94 (58)	95 (59)	- 1 (-1)
97 (60)	94 (58)	95 (59)	- 1 (-1)
81 (50)	78 (48)	76 (47)	+ 2 (+1)
77 (48)	74 (46)	76 (47)	- 2 (-1)
74 (46)	71 (44)	72 (45)	- 1 (-1)
97 (60)	94 (58)	95 (59)	- 1 (-1)
105 (65)	101 (63)	98 (61)	+ 3 (+2)
101 (63)	98 (61)	97 (60)	+ 1 (+1)
118 (73)	113 (70)	111 (69)	+ 2 (+1)
116 (72)	112 (70)	108 (67)	+ 4 (+3)
87 (54)	84 (52)	81 (50)	+ 3 (+2)

Superelevation rates are rounded to the nearest 0.5% from 2% to 7%, and whole numbers to 12%. The bases for the rounding are:

- The difference in the rounded superelevation values equate to only a 4 km/h speed variation for large radii and a 1.5 km/h speed variation for small radii,
- they are consistent with cross slope construction tolerances, and
- they create distinct curve radii and superelevation values for each design speed and therefore promote design consistency.

Based on a study of friction demand, NCHRP 439 recommends an adjustment to the superelevation rate for steep grades. NCHRP 439 page 146 recommends excess superelevation on facilities with significant truck volumes and downgrades in excess of 5%.

Exhibits 9 and 10 compare AASHTO and NCHRP 439 minimum radii for the normal crown and common maximum superelevation rates. Exhibit 12 contains a comparison of the AASHTO and NCHRP 439 recommendations and the pros and cons of each.

Note that the 95th percentile curve speed with a reduction is comparable to the 85th percentile tangent speed, which generally represents the AASHTO design speed. Therefore, the NCHRP and AASHTO superelevation values are compared directly in Exhibits 9, 10 and 11.

Exhibit 9 - Comparison of AASHTO and NCHRP 439 Minimum Radii

Comparison of Minimum Radii for e = 4.0% for Low Speed Urban Facilities

Methods	Design Speed (km/h (mph))				
	30 (19)	40 (25)	50 (31)	60 (37)	70 (43)
AASHTO 85 th % Speed	20 m 66 ft	45 m 148 ft	80 m 262 ft	125 m 410 ft	190 m 623 ft
NCHRP 439 95 th % Speed w/ 3 km/h (1.9 mph) decrease	21 m 69 ft	43 m 141 ft	76 m 249 ft	121 m 397 ft	183 m 600 ft

Comparison of Minimum Radii for e = 6.0% for Low Speed Rural Facilities

Methods	Design Speed (km/h (mph))				
	30 (19)	40 (25)	50 (31)	60 (37)	70 (43)
AASHTO 85 th % Speed	30 m 98 ft	55 m 180 ft	90 m 295 ft	135 m 443 ft	195 m 640 ft
NCHRP 439 95 th % Speed w/ 3 km/h (1.9 mph) decrease	20 m 66 ft	40 m 131 ft	70 m 230 ft	111 m 364 ft	166 m 545 ft

Comparison of Minimum Radii for Turning Roadways

Methods	Design Speed (km/h (mph))				
	30 (19)	40 (25)	50 (31)	60 (37)	70 (43)
AASHTO 85 th % Speed	24 m 79 ft e = 2.0%	47 m 154 ft e = 4.0%	79 m 259 ft e = 6.0%	113 m 371 ft e = 8.0%	161 m 528 ft e = 9.0%
NCHRP 439 95 th % Speed w/ 3 km/h (1.9 mph) decrease	20 m 66 ft e = 6.0%	40 m 131 ft e = 6.0%	70 m 230 ft e = 6.0%	111 m 364 ft e = 6.0%	166 m 545 ft e = 6.0%

Comparison of Minimum Radii for e = 6.0% for High Speed Facilities

Methods	Design Speed (km/h (mph))				
	80 (50)	90 (56)	100 (62)	110 (68)	120 (75)
AASHTO 85 th % Speed	250 m 820 ft	335 m 1099 ft	435 m 1427 ft	560 m 1837 ft	755 m 2477 ft
NCHRP 439 95 th % Speed w/ 3 km/h (1.9 mph), 4 km/h (2.5 mph), and 5 km/h (3.1 mph) decrease	241 m 791 ft	341 m 1119 ft	461 m 1512 ft	591 m 1939 ft	750 m 2461 ft

Exhibit 10 - Minimum Radius Without Superelevation

Low-Speed Urban Streets			
Design Speed (km/h (mph))	NCHRP 439 Minimum Radius (m (ft)) using $e_{NC} = 2\%$	AASHTO Minimum Radius (m (ft)) using $e_{NC} = 2\%^*$	Difference (m (ft))
30 (19)	28 (92)	24 (79)	+ 4 (13)
40 (25)	57 (187)	54 (177)	+ 3 (10)
50 (31)	102 (335)	101 (331)	+ 1 (4)
60 (37)	169 (554)	171 (561)	- 2 (7)
70 (43)	266 (873)	270 (886)	- 4 (13)
Rural Highways and High Speed Urban Streets			
Design Speed (km/h (mph))	NCHRP 439 Minimum Radius (m (ft)) using $e_{NC} = 2\%$	AASHTO Minimum Radius (m (ft)) using $e_{NC} = 1.5\%^{**}$	Difference (m (ft))
30 (19)	354 (1,161)	450 (1,476)	- 96 (315)
40 (25)	630 (2,067)	800 (2,625)	- 170 (558)
50 (31)	984 (3,228)	1,110 (3,642)	- 126 (414)
60 (37)	1,417 (4,649)	1,530 (5,020)	-113 (371)
70 (43)	1,929 (6,329)	2,020 (6,627)	- 91 (298)
80 (50)	2,520 (8,268)	2,500 (8,202)	+ 20 (66)
90 (56)	3,189 (10,463)	3,030 (9,941)	+ 159 (522)
100 (62)	3,937 (12,917)	3,700 (12,139)	+ 237 (778)
110 (68)	4,746 (15,571)	4,270 (14,009)	+ 476 (1660)
120 (75)	5,521 (18,114)	4,990 (16,371)	+ 531 (1743)

Notes: * Based on AASHTO Exhibit 3-40. ** Based on AASHTO Exhibit 3-26.

Exhibit 11 - Qualitative Cost Comparison

Facilities	NCHRP 439 vs. AASHTO	Recommendations vs. AASHTO
Turning Roadways, Intersections, and Low Speed Facilities	At lower speeds, NCRHP 439 reduces the superelevation. However, these facilities are usually found in urban areas where superelevation is rarely applied in any case due to the impact on drainage and adjacent sidewalk, buildings, side streets, and driveways.	little, if any, change in cost
High Speed Facilities	NCHRP 439 increases superelevation at higher speeds; increasing the cost, and possibly the ROW impact. Resurfacing projects using this criteria (e.g., Interstate 3R projects), will require more asphalt to create superelevation where it does not presently exist. On new and reconstruction projects, curve lengths would tend to increase.	little, if any, change in cost

Exhibit 12 - Comparison of 2001 AASHTO and NCHRP 439 Recommendations

Issue	2001 AASHTO Green Book		NCHRP 439	
	Green Book Text	Pros & Cons	NCHRP Recommendations	Pros & Cons
Friction Factor	Three separate curves. high speed curve = upper levels of comfort, turning roadways curve = 95 th percentile driver, low speed curve = tolerable degree of discomfort.	Pro - Curves reflect driver tolerances and comfort. Low speed and turning roadways are less conservative, reducing superelevation. Cons - The separate curves for low speed and intersections are similar and could be combined.	A single curve that represents a compromise for the three curves in AASHTO.	Pro - A single curve is used for side friction. Con - Curve is very conservative at low speeds for low speed and turning roadways. Curve is less conservative at low speeds for rural highways.
Methods of Distributing Super-elevation	2 methods. Method 5 for high and low speed rural facilities. Method 2 for low speed urban streets.	Pro - Reduces side friction demand on high speed intermediate curves by providing additional superelevation. Minimizes superelevation on low speed and intersection curves. Con - More superelevation is needed on high speed intermediate curves as compared to some other methods.	2 methods. One for high speed and one for low speed.	Pro - Same as AASHTO methods. Con - None.
Design Speed for Horizontal Curve Design	Recommends "use of design speed," which generally represents the off-peak 85 th % speed on a tangent section.	Pro - Similar to all other design parameters. Tangent 85 th % speed is close to curve 95 th % speed. Con - Not extremely precise.	95 th % (with speed reductions at minimum radii). 95 th % speed used due to higher risk of an accident if the speed is too fast for the curve.	Pro - Based on study results. Con - Minor increase in effort to determine 95 th % speed. May appear to the public as encouraging higher operating speeds.
Super-elevation Rate Rounding	To the nearest tenth of a percent.	Pro - Very precise. Con - May be too precise and not reflect construction tolerances.	Superelevation values are rounded to whole and half percentages. Degree of precision equates to a 1.5 - 4 km/h (0.9 - 2.5 mph) variation in speed.	Pro - Simplifies superelevation tables and reflects construction tolerances. Con - May not be accurate enough.
Maximum Super-elevation Rates	4, 6, 8, 10, and 12 percent	Pro - Reflects need to have multiple maximum rates due to climate and urban settings. Con - Requires use of flatter curves or exceptions in urban settings.	4, 6, 8, 10, and 12 percent	Pro - Same as AASHTO method. Con - Same as AASHTO method.
Number of Curves/ Tables for Each Method	A curve/ table is needed for each of the 5 maximum rates.	Pro - Very precise. Con - A large number of tables and figures are needed in AASHTO book.	Three tables for all of the maximum rates.	Pro - Decreases the number of tables needed in the AASHTO book. Con - May be confusing to designers familiar with AASHTO methods.

RECOMMENDATIONS

Maximum Superelevation Rate

1. Recommend continued use of 4%, 6%, 8%, 10% and 12% maximum rates. Promote design consistency with an area of similar climate and character.

Friction Factor

2. Use two curves; one for all high-speed facilities (using the current AASHTO curve for rural and high-speed urban streets) and one for all low-speed facilities (using the current AASHTO curve for intersections). Refer to the revised Exhibits 3-10 through 3-12 in the attached draft revision to the AASHTO text for the proposed friction curves. The revised Exhibit 3-15 uses the low-speed friction values for the low-speed minimum radii.

Distribution Methods

3. Since no safety or operational problems were identified using the current distribution method, continue to use AASHTO Method 2 distribution for low-speed urban streets. Also allow reconstruction of these streets to retain superelevation rates meeting current AASHTO values. The method 2 values are included in the revised Exhibit 3-16 in the attached revision to the AASHTO text.
4. Since no safety or operational problems were identified using the current distribution method, continue to use AASHTO Method 5 distribution for rural highways, turning roadways, and all high-speed facilities, including rural roads, urban streets, and turning roadways. While the use of method 5 on low speed facilities increases the negative side friction for vehicles traveling at very low speeds, the lower speeds allow motorists to correct for the negative side friction by turning the wheel to the outside of the curve. The increased side friction factor for low-speed rural highways will slightly reduce the superelevation rate and offset some of the negative side friction for very low-speed vehicles.
5. Roundup superelevation rates to the nearest 0.2% for consistency and to reflect construction tolerances while not substantially impacting the factor of safety provided by the current AASHTO methods. The revised Exhibits 3-25 through 3-29 in the attached revision to the AASHTO text were developed to eliminate the need to interpolate. A separate Exhibit 3-29 was developed to present the superelevation runoff for horizontal curves. Current AASHTO Green Book Exhibits 3-16 through 3-20 and Exhibit 3-26 can be deleted. To use the revised Exhibits 3-25 through 3-29, a designer would:
 - (1) select the appropriate exhibit based on the units (metric or U.S. customary) and the maximum superelevation rate;
 - (2) move down the appropriate design speed column until the radius in the exhibit is less than or equal to the radius for the proposed design; and
 - (3) go across to find the recommended superelevation rate.

For example, using the 2001 AASHTO Green Book, a designer must interpolate the superelevation rate between 4.7% and 5.5% for a curve with a 110 km/h (68 mph) design speed, 1130 m (3707 ft) radius, and an 8.0% maximum superelevation rate. Using the recommended table in Exhibit 3-27, a designer would quickly determine the superelevation rate to be 5.0%.

6. Recommend the approach 85th percentile speed be used for determining curve design speed. The 95th percentile speed and a speed reduction have been found to be ± 4 km/h (3 mph) of the 85th percentile speed. The use of design speeds in 10 km/h (5 mph) increments, rounding superelevation, and the accuracy of using existing speed data to predict speeds on new or rehabilitated curves negate the increased accuracy of the NCHRP 439 methodology.
7. Develop the minimum radii with normal crown for each of the five maximum superelevation rates. The 2001 AASHTO Green Book only presents the minimum radius for a 1.5% normal crown and a maximum superelevation rate of 10%. The revised Exhibits 3-25 through 3-29 show the minimum radii for sections with normal crown (both $e = 1.5\%$ and 2%) in the top rows for each of the five maximum superelevation rates.
8. Recommend an adjustment to design speed for downgrades in excess of 5%, especially if the truck volumes are high or the facility is a low-speed urban street with intermediate curves (since they use Method 2 and have high values of friction demand). This is based on NCHRP 439 pages 97 and 98.

REFERENCES

1. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design for Highways and Streets*, AASHTO, Washington, D. C., 2001, pp. 131 - 203.
2. Bonneson, J. A., *Superelevation Distribution Methods and Transition Designs*, NCHRP Project 439, Washington, D.C.: Transportation Research Board, 2000.
3. Lamm, R., B. Psarianos, and T. Mailaender. *Highway Design and Traffic Safety Engineering Handbook*, McGraw Hill, New York, 1999. pp. 10.1 - 10.69.
4. Meyer, Carl F., *Route Surveying*, Third Edition, International Textbook Co., Scranton, PA, 1967, pp. 193 - 211.