VIRGINIA DEPARTMENT OF TRANSPORTATION

TRAFFIC ENGINEERING DIVISION

MEMORANDUM

NUMBER: TE-363	**DATE:** July 28, 2009
SUPERSEDED: N/A	**SUNSET DATE:** (see footnote)
GENERAL SUBJECT: Engineering and Administration	
SPECIFIC SUBJECT: Use of Ballbank Indicator Device	
DISTRIBUTION TO: Regional Operations Directors Regional Traffic Engineers Regional Operations Maintenance Managers	

COMMONWEALTH OF VIRGINIA
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The Regional Traffic Engineers have brought to my attention the fact we, as an agency, do not have a universal practice regarding the method used to establish the need for Horizontal Alignment Signs (W1-1 through W1-5, W1-11, W1-15); and, the posting of Advisory Speed Panels with these signs. To this end, they have performed a literature and recommendations research for the latest trends and practices.

After a review of available literature and recommendations (National review - Executive Summary attached), it has been concluded that the use of the 85% speed as gained from speed studies will not meet the need of VDOT as well as the use of the Ballbank/limiting angle method would. Therefore, the Ballbank/limiting angle method will be our standard with the following set as our limiting angle practice.

For a posted speed from **0 to 24 MPH**, the limiting angle shall be **16 degrees**.
For a posted speed from **25 to 34 MPH**, the limiting angle shall be **14 degrees**.
For a posted speed from **35 to 49 MPH**, the limiting angle shall be **12 degrees**.
For a posted speed from **50 and greater**, the limiting angle shall be **10 degrees**.

This standard is adopted for statewide use with the issuance of this document.

CC: Mr. Greg Whirley
Ms. Constance S. Sorrell
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Sunset upon adoption of a *Virginia Supplement to the MUTCD* subsequent to the date of issuance of this document

Review of Ball-Bank Reading Criteria for Advisory Speed on Curves

Traffic Engineering Section

Jung-Taek Lee

May 13, 2009

Executive Summary

It has been reported that about 25 percent of all fatalities occur on curved sections of a roadway. Fatalities are three times more likely to result on a curved section than on a similar tangent section. In rural areas, about two-thirds of all fatalities take place on curved sections. To reduce potential accidents on curves, criteria for safe speed has been studied since the 1930's, resulting in a variety of methods.

In 1935 the Bureau of Public Roads issued research testing of safe driving speeds on curves, resulting in side friction factors from 0.07 to 0.20 with an average of 0.16 for speeds between 20 and 60 mph. In 1937 the Missouri State Highway Department began experiments with ball-banking indicators, reporting that a 10-degree ball-bank reading corresponded to an approximate side friction factor of about 0.14 to 0.15, depending on the body roll of the vehicle. It was reported in 1995 that 88 percent of states, cities and counties use ball-bank indicators. Since the 1940's, it has been recommended that the ball-bank reading for setting the advisory speed on a curve would be:

- 14-degrees for speeds below 20 mph
- 12-degrees for speeds between 20 and 35 mph
- 10-degrees for 35 mph or greater

The latest national *MUTCD* includes language of ball-bank reading of 16-degrees for the section of advisory signs, and the *2001 Traffic Control Devices Handbook* by ITE recommended earlier ball-bank reading criteria.

However, both the methods and ball-bank criteria for setting advisory speed on curves vary from state by state and even within a state. Furthermore, over the past few decades, arguments on the criteria have risen to either modify or to omit the ball-bank reading language in many references. Recently the Regulatory and Warning Signs Technical Committee (RWST) for the National Committee on Uniform Traffic Control Devices (NCUTCD) recommended removing advisory speed posting recommendations, such as ball-bank values, from future versions of the *MUTCD* and simply recommended the use of the term "engineering judgment." The committee also recommended the increase of ball-bank criteria by 2-degrees to a new 12-, 14- and 16-degree threshold in the next edition of *Traffic Control Devices Handbook* by ITE, which is comparable to the AASHTO 2003 *Greenbook* design values.

In the state of Virginia, the use of ball-bank criteria also varies from the national *MUTCD* or a typical value of 10-degrees. This report presents findings in historical ball-bank criteria and the ball-banking criteria use in other states.

Major Chronicle of Ball-Bank Reading Criteria

1940 *Marking Highway Curves with Safety Speed Indications*, proceedings of the Annual Meeting of the Highway Research Board (by Moyer, R.A. and D.S. Berry), Volume 20, pages 399 to 428:

- 10-degree ball-bank reading was reported to correspond to a side friction factor of about 0.14 to 0.15
- 10-degree became a primary factor in application of the ball-bank indicator for curve signing
- Further finding in the same report:
    - 10-degree (30 mph <Speed<= 50 mph)
    - 12-degree (20 mph <Speed<= 30mph)
    - 14-degree (Speed <= 20 mph)

1983 *Traffic Control Devices Handbook* by FHWA:

- 10-degree (35 mph <Speed<= 60 mph)
- 12-degree (20 mph <Speed<= 30mph)
- 14-degree (Speed <= 20 mph)

It is to be noted that many states simply use the 10-degree reading to represent the maximum safe speed as a conservative value as provided by this single threshold.

1991 *Analysis of Advisory Speed Setting Criteria, Public Roads* (by Chowdhury, M.A., D.L. Warren and H. Bissell), Volume 55, Number 3, pages 65 to71:

- 12-degree (40 mph <Speed)
- 16-degree (30 mph <=Speed<= 40 mph)
- 20-degree (Speed < 30 mph)

1999 *Relationships between Ball Bank Indicator Readings, Lateral Acceleration Rates, and Vehicular Body-Roll Rates* (by Carlson P.J. & and Mason, J.M.), TRR 1658, pages 34 to 42:

- Tested with 1992 Ford Taurus on a test track.
    - 9-degree (30 mph <Speed)
    - 12-degree (20 mph <=Speed<= 30 mph)
    - 16-degree (Speed < 20 mph)

1999 *Advisory Speeds on Maryland Highways Technical Report* (by Brudis & Associates, Inc. (BAI)), MDOT, Hanover, Maryland:

Evaluated “lean angle” as a value equating to the ball-bank angle to MDOT; 42 MD curves on rural roads:

Posted Advisory Speed	Average Lean Angle	85th Percentile Speed
15 mph	15.5 degrees	26 mph
20 mph	18.3 degrees	30 mph
25 mph	16.0 degrees	36 mph
30 mph	15.0 degrees	45 mph
35 mph	15.6 degrees	45 mph
40 mph	13.2 degrees	52 mph
45 mph	16.3 degrees	55 mph

2000 *MUTCD 2000*:

Engineering judgment is a standard to indicate the need to advise road users of the recommended speed on an exit, a ramp, or a curve (W13-2, @13-3, W13-5).

2001 *Traffic Control Devices Handbook* (ITE 2001); newer edition of *1983 FHWA Traffic Control Devices Handbook*:

- 10-degree (35 mph <Speed<= 60 mph)
- 12-degree (20 mph <Speed<= 30mph)
- 14-degree (Speed <= 20 mph)

2003 *MUTCD 2003* (Revisions 1 and 2)
Section 2C.36 Advisory Exit, Ramp, and Curve Speed Signs (W13-2, W13-3, W13-5)
Section 2C.46 Advisory Speed Plaque (W13-1):

Option — "The advisory speed may be the 85th percentile speed of free-flowing traffic, the speed corresponding to a 16-degree ball bank indicator reading, or the speed otherwise determined by an engineering study because of unusual circumstances."

Support — "A 10-degree ball-bank indicator reading, formerly used in determining advisory speeds, is based on research from the 1930's. In modern vehicles, the 85th-percentile speed on curves approximates a 16-degree reading. This is the speed at which most drivers' judgment recognizes incipient instability along a ramp or curve."

2004 *A Policy on Geometric Design of Highways and Streets 2004 Edition* provides summary diagrams of side friction factors for speed on curves from various research findings in Exhibits 3-10, 3-11 and 3-12:
Summary table of side friction factor values from *Consistency and Effectiveness of Advisory Speeds: An Evaluation of Current Posting Techniques*, (by Joshan W. Rohani, Master's Thesis, Oregon State University, 2007):

Table A1.1: Side Friction Factor Values

Speed, mph	Moyer & Berry (1940) *f* values	Carlson & Mason 1999		AASHTO 1990 & 2001 Max. *f* values		Bonneson, 2000 (Interpolated)	MRI, 2003 Values shown are max. demand *f*		AASHTO 2004 Max. *f* values (All Roads)
		Adjusted Moyer & Berry Values	Proposed Values	Low Speed	High Speed or Rural		Car	Truck	
20	0.21	0.24	0.28	0.300	0.170	0.223	0.17	0.19	0.27
25	0.18	0.21	0.21	0.252	0.165	0.209	---	---	0.23
30	0.18	0.21	0.21	0.221	0.160	0.193	0.16	0.18	0.20
35	0.15	0.17	0.15	0.197	0.155	0.178	---	---	0.18
40	0.15	0.17	0.15	0.178	0.150	0.164	0.15	0.17	0.16
45	0.15	0.17	0.15	0.163	0.145	0.145	---	---	0.15
50	0.15	0.17	0.15	---	0.140	0.134	0.14	0.15	0.14
60	---	---	---	---	0.120	0.103	0.12	0.13	0.12
70	---	---	---	---	0.100	0.075	0.10	0.11	0.10
80	---	---	---	---	0.080	---	0.08	0.09	0.08

<u>2007</u> Regulatory and Warning Signs Technical Committee (RWST) for the National Committee on Uniform Traffic Control Devices (NCUTCD):

- NCUTCD recommended removing advisory speed posting recommendations, such as ball-bank values, from future versions of the *MUTCD* and simply recommend the use of the term “engineering judgment.”
- Recommended the ball-bank criteria be increased by 2-degrees from 10-, 12-, 14-degree thresholds to a new 12-, 14- and 16-degree threshold in the next edition of *TCD Handbook* by ITE, which is comparable to the *AASHTO 2003 Greenbook* design values:
    - 12-degree (30 mph <Speed<= 60 mph)
    - 14-degree (20 mph <=Speed<= 30 mph)
    - 16-degree (Speed <= 20 mph)

Documented State Ball-Bank Readings

<u>California MUTCD</u> (FHWA's *MUTCD* 2003 Revision 1, as amended for use in the state of California. As of September 26, 2006, the chart is used to determine comfortable speed from ball-bank indicator readings.

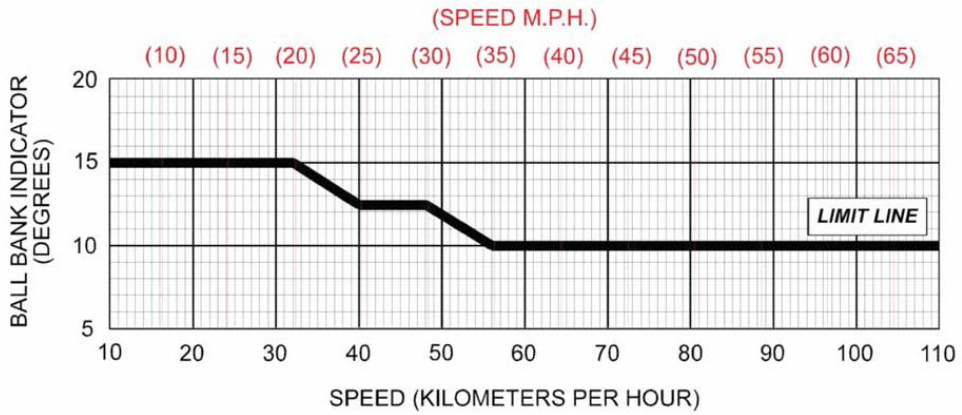
<u>California MUTCD Section 2C.101 (CA)</u>

Figure 2C-101 (CA). Determination of Comfortable Speed From Ball Bank Indicator Readings

Driver_____
Observer_____
Vehicle_____
Date_____

Type of Pavement_____
Condition of Pavement_____
Min. Sight Dist. Thru Curve_____
Approach Speed
(Estimated or Observed)_____

Co._____Rte._____PM_____
Sta._____To_____
Direction_____
Weather_____



Ball Bank Readings	Advisory Speed
10 degrees	> 35 mph (55 km/h)
12.5 degrees	25-30 mph (40 to 50 km/h)
15 degrees	<= 20 mph (30 km/h)

<u>New York State MUTCD</u> NYS Supplement Revision 1 replaces entire section of *Advisory Speed Plaque* (W13-1). Three methods are proposed under the subheading:

Option

The advisory speed may be determined using one of the following methods:

A. A calculation of the speed using the curve radius, superelevation, and the simplified curve formula from AASHTO's *A Policy on Geometric Design of Streets and Highways 2004*, using a side friction factor of:
    1. 0.24 for speeds up to 24 mph
    2. 0.21 for speeds of 25 to 34 mph
    3. 0.18 for speeds of 35 to 49 mph
    4. 0.15 for speeds of 50 mph or more

B. A calculation of the speed using ball bank readings of:
    1. 16 degrees for speeds up to 24 mph
    2. 14 degrees for speeds of 25 to 34 mph
    3. 12 degrees for speeds of 35 to 49 mph
    4. 10 degrees for speeds of 50 mph or more

C. A calculation of the speed using an engineering analysis that considers all of the factors:
    1. Approach speeds.
    2. Roadway geometry including width, radius, superelevation, stopping sight distance, and horizontal sight distance
    3. Truck rollovers
    4. Roadside hazards
    5. Pavement surface conditions
    6. Crash experience
    7. Driver expectancy

Support:
The ball bank readings for advisory speeds are based on the side friction factors used for curve design in the AASHTO's *A Policy on Geometric Design of Streets and Highways 2004*. The values used for the advisory speed are more conservative for speeds under 50 mph to account for the tendency of vehicles with a high center of gravity to roll over before skidding at lower speeds.

Oregon Department of Transportation State *MUTCD* directs a method in Sign Policy and Guidelines under the Traffic Roadway Section:

Values for Determining Comfortable Safe Speeds on
Horizontal Curves Using a Ball-Bank Indicator

Curve Speed in Miles-per-Hour	Ball-Bank Reading Limiting Values in Degrees
15	13
20	13
25	13
30	13
35	10
40	10
45	10
50	10
55	10
60	7
65	7