
Advanced Design Flexibility Workshop
Session 8
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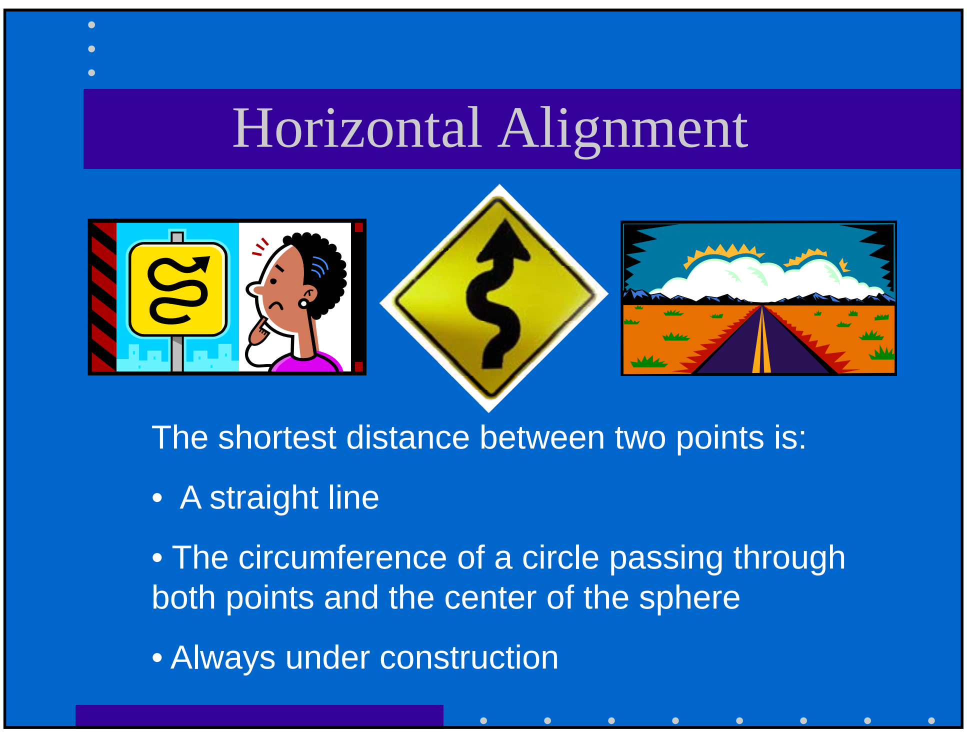
March 5-7, 2010
Horizontal Alignments and
Horizontal - Vertical Coordination
HRGreen


Horizontal Alignment
The shortest distance between two points is:
• A straight line
• The circumference of a circle passing through both points and the center of the sphere
• Always under construction

Horizontal Curve Safety

Approximately 25% of all fatal crashes occur along horizontal curves

Average crash rates for horizontal curve segments are about 3 times that of tangent segments

AASHTO Curve Design Model

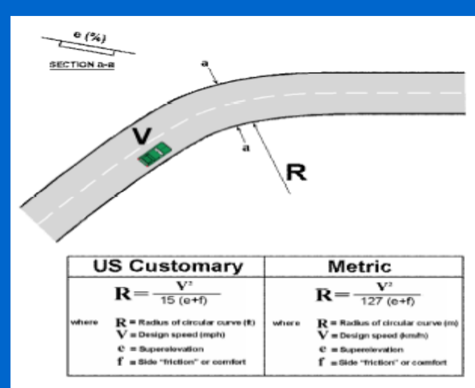
$$e+f = V^2/15\ R$$

e = superelevation

f = side friction factor

V = design speed (mph)

R = radius of curve (ft)



Side Friction Factor Assumptions

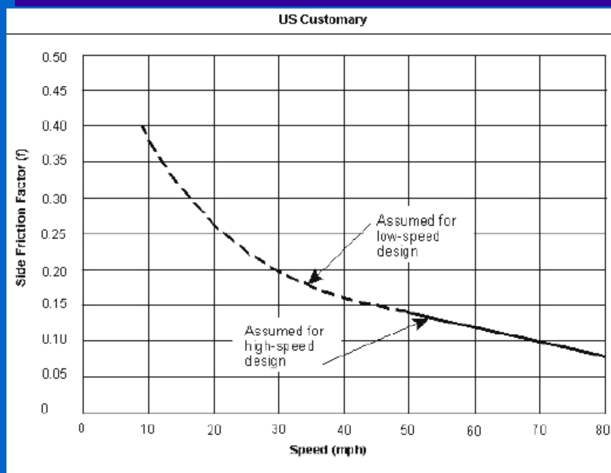
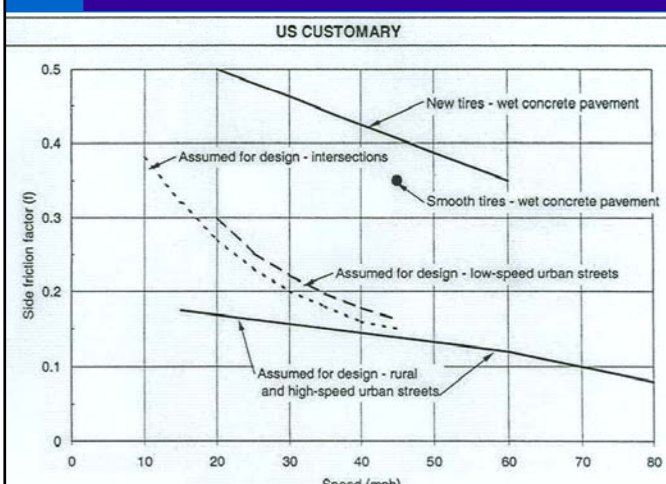


Exhibit 3-12. Side Friction Factors Assumed for Design

- Maximum "f" based upon avoiding driver discomfort
- Provides ample margin of safety against skidding

2004 Greenbook Exhibit 3-12 for recommended side friction values in design

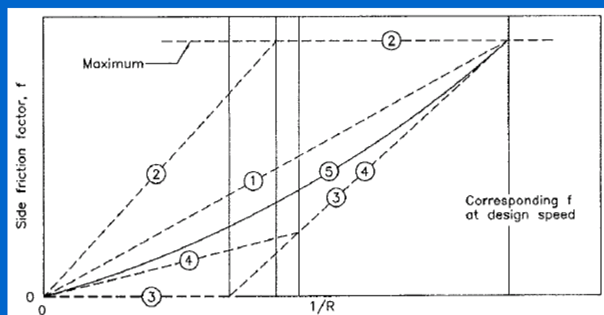
Side Friction Factor Assumptions



- Assumed limit of skidding shown in upper part of graph
- "Maximum" friction factors are based on comfortable operation far short of losing traction around curves

2001 Greenbook Exhibit 3-11: Comparison of Side Friction Factors

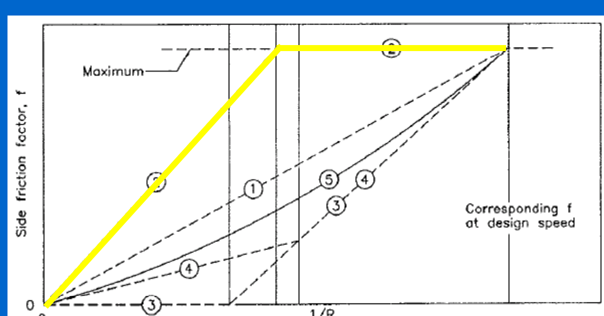
Side Friction Factor Assumptions



- Shows how side friction is developed as degree of curvature increases
- Numbers in circles refer to "methods" of distribution

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

Side Friction Factor Assumptions

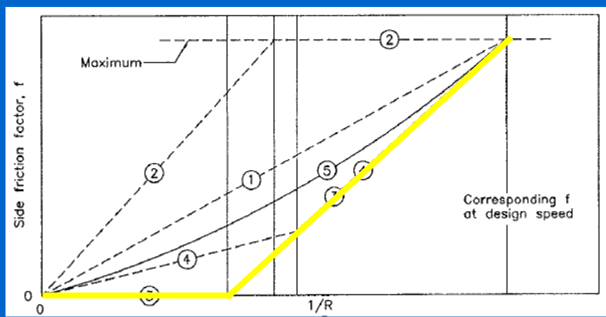


Method 2

- Maxes out side friction before introducing superelevation
- Used for low-speed urban streets

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

Side Friction Factor Assumptions

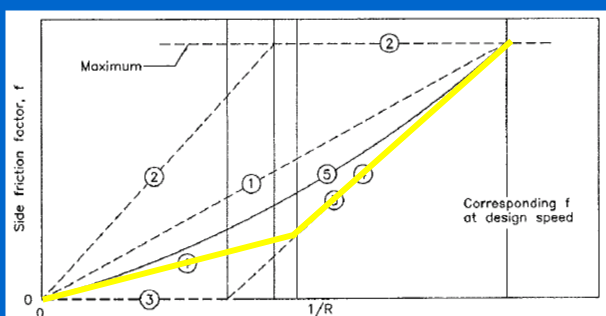


Method 3

- Introduces no side friction at design speed until max super rate is achieved
- Not used for design

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

Side Friction Factor Assumptions

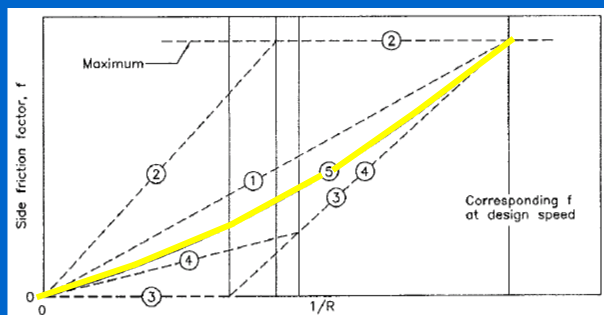


Method 4

- Same as Method 3 except that a running speed is assumed
- Avoids having to steer against super at less than design speed

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

Side Friction Factor Assumptions



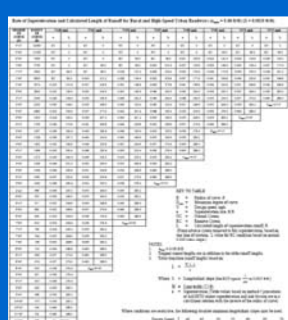
Method 5

- Used for rural and high-speed urban design
- Parabolic smoothing out of Method 4
- Little side friction on flat curves; more as curves sharpen

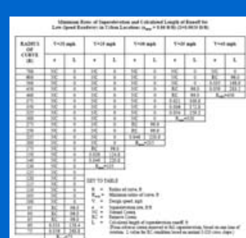
From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

Road Design Manual Criteria

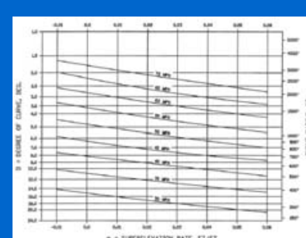
Mn/DOT uses three methods:



High Speed (normal conditions)



Low Speed

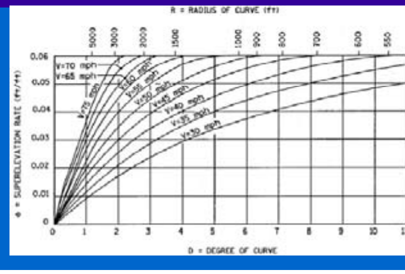


High Speed (restricted conditions)

High Speed (normal conditions)

Table 3-3.02A (below) and Figure 3-3.02A (right)

•Method 5 distribution for rural and high-speed urban design



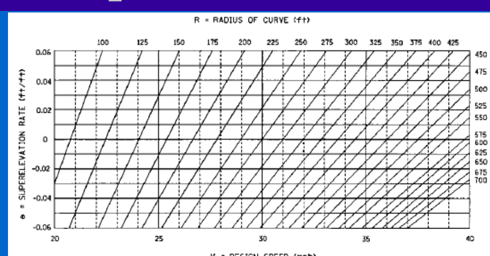
Rate of Superelevation and Calculated Length of Runoff for Rural and High-Speed Urban Roadways (e_{max} = 0.06 ft/ft) (S = 0.0025 ft/ft)

DEGREE OF CURVE (D)	RADIUS OF CURVE (R)	V=40 mph		V=45 mph		V=50 mph		V=55 mph		V=60 mph		V=65 mph		V=70 mph		V=75 mph	
		e	L	e	L	e	L	e	L	e	L	e	L	e	L	e	L
0°15'	22918	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
0°30'	11459	NC	0	NC	0	NC	0	NC	0	NC	0	RC	96.0	RC	96.0	RC	96.0
0°45'	7639	NC	0	NC	0	RC	96.0	RC	96.0	0.021	100.8	0.023	110.4	0.026	124.8	0.029	139.2
1°00'	5730	NC	0	RC	96.0	RC	96.0	0.023	110.4	0.027	129.6	0.030	144.0	0.033	158.4	0.037	177.6
1°15'	4584	RC	96.0	RC	96.0	0.024	115.2	0.028	134.4	0.032	153.6	0.036	172.8	0.040	192.0	0.044	211.2
1°30'	3820	RC	96.0	0.024	115.2	0.028	134.4	0.032	153.6	0.037	177.6	0.041	196.8	0.046	220.8	0.051	244.8
1°45'	3274	0.023	110.4	0.027	129.6	0.031	148.8	0.036	172.8	0.041	196.8	0.046	220.8	0.051	244.8	0.056	268.8
2°00'	2865	0.025	120.0	0.030	144.0	0.035	168.0	0.040	192.0	0.045	216.0	0.049	235.2	0.055	264.0	0.059	283.2
2°15'	2546	0.028	134.4	0.033	158.4	0.038	182.4	0.043	206.4	0.048	230.4	0.053	254.4	0.057	273.6	0.060	288.0

Low Speed

Table 3-3.02B (below) and Figure 3-3.02B (right)

•Method 2 distribution for low-speed urban streets



Minimum Rates of Superelevation and Calculated Length of Runoff for Low-Speed Roadways in Urban Locations (e_{max} = 0.06 ft/ft) (S=0.0025 ft/ft)

RADIUS OF CURVE (R)	V=20 mph		V=25 mph		V=30 mph		V=35 mph		V=40 mph	
	e	L	e	L	e	L	e	L	e	L
700	NC	0	NC	0	NC	0	NC	0	NC	0
600	NC	0	NC	0	NC	0	NC	0	RC	96.0
500	NC	0	NC	0	NC	0	NC	0	0.035	168.0
450	NC	0	NC	0	NC	0	RC	96.0	0.059	283.2

High Speed (constrained conditions)

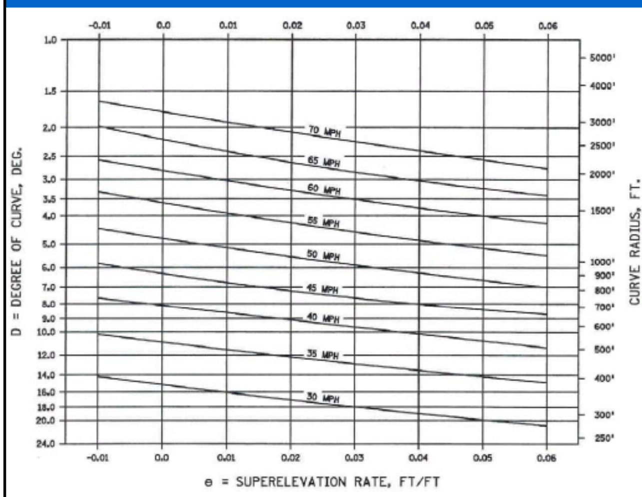


Figure 3-3.03A

- Curvature / speed / superelevation chart using maximum side friction factors
- Useful tool for developing solutions in constrained or special circumstances

Road Design Manual Criteria

Examples:

•Curves approaching a stop condition

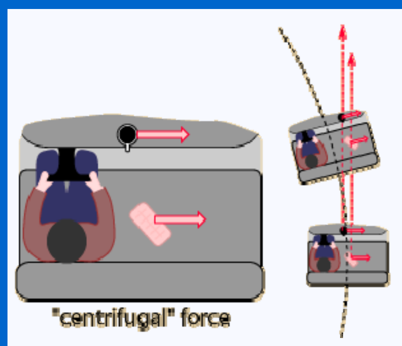
•Second curves on downstream portions of freeway ramps

•Reduced superelevation through intersections

•Flat curves where adverse super or minimal super would be advantageous

HC Model Basis is Driver Comfort

Although the model stems from the laws of mechanics, the values used in design are based on practical limits and empirically determined factors.



Does Model Match Driver Behavior?

- Do vehicles track a curve as designed?
- At what speeds do drivers track curves?
- What are the operations dynamics of trucks vs. passenger cars?

Off-Tracking on Horizontal Curves

Actual Vehicle Path Does Not Follow a Perfect Circle

- Drivers 'Overshoot' (track a path sharper than the radius)
- Driver path is spiral
- Overshoot behavior is independent of speed

Driver tracks a 'critical radius' sharper than that of the curve just past the PC

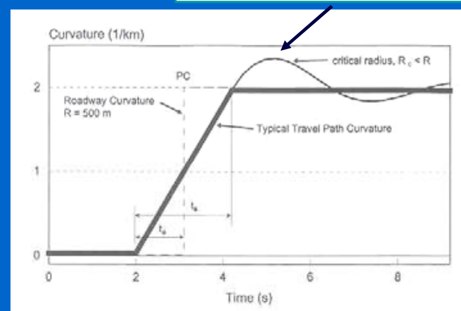
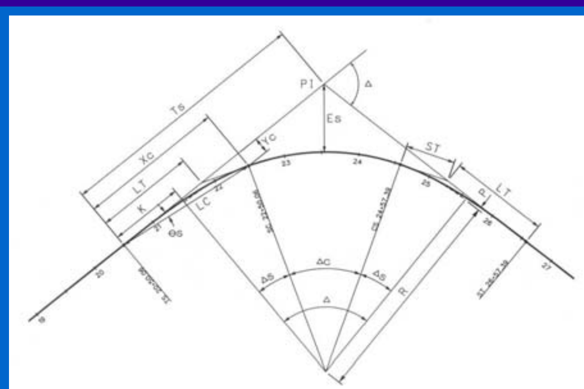


Figure D-2. Relationship between roadway curvature and travel path curvature in a tangent-to-curve transition design.

Spiral Curve Transitions

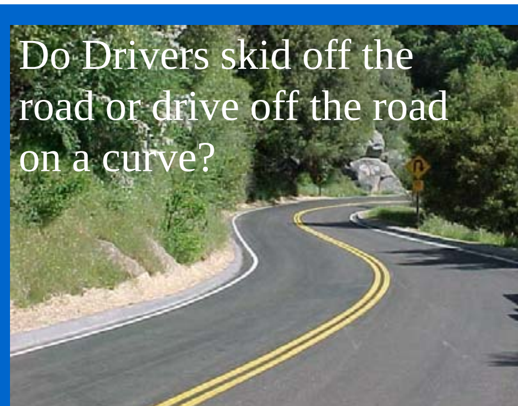


- Provides a more natural turning path
- Minimizes encroachment into adjacent lane
- Provides a suitable location for superelevation runoff

Horizontal Curve Safety

Approximately 25% of all fatal crashes occur along horizontal curves

Average crash rates for horizontal curve segments are about 3 times that of tangent segments



Risk Assessment for Horizontal Alignment

The speed of vehicles entering a curve is influenced by the horizontal and vertical alignment on the approaches. Risk varies as a function of the approach speed distribution.

- Avoid sharp curves at ends of long tangents
- Introduce sharp curvature through series of successively sharper curves
- Eliminate/minimize access near horizontal curves

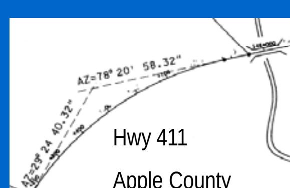
Guide for Achieving Flexibility in Highway Design - AASHTO

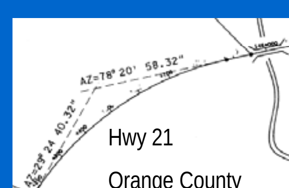
Truck Operations on Curves

- Trucks with high centers of gravity may overturn before losing control due to skidding
- Trucks on downgrade curves generate greater lateral friction
- Margin of safety for ‘f’ is lower for trucks

Managing the Risk

Will two horizontal curves of the same radius with similar cross sections and traffic volumes always have a similar safety performance?

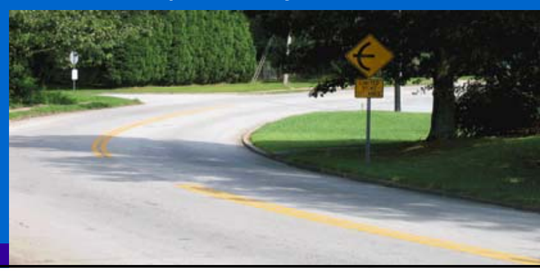




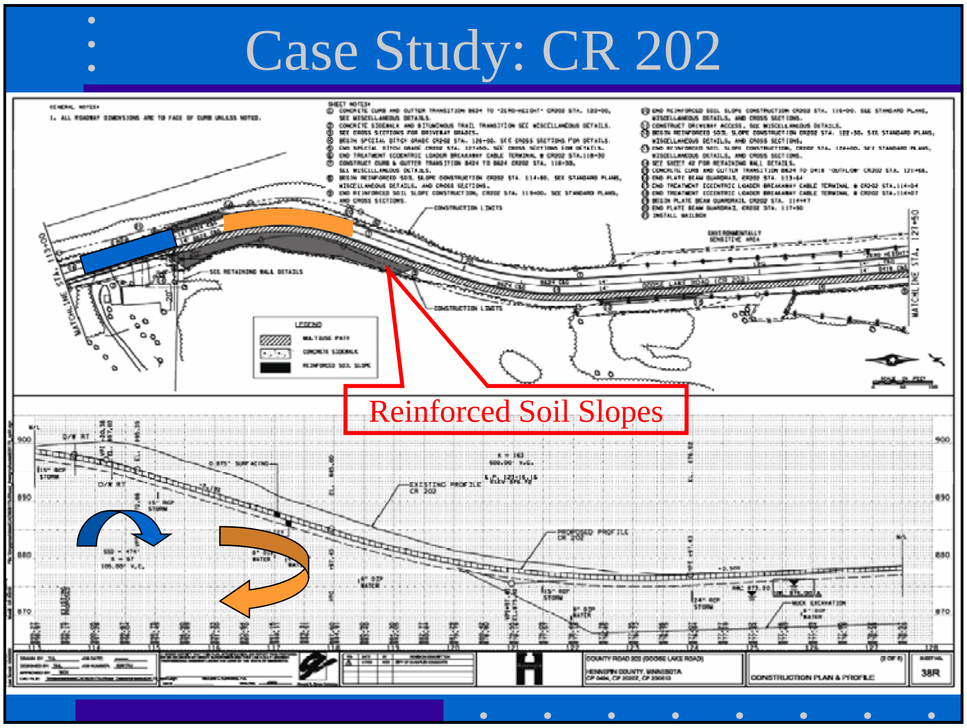
Risk Assessment for Horizontal Alignment

Risk of serious crashes within horizontal curves is a function not only of the curve geometry, but also of:

- The cross section
- Sight distance
- Presence of intersections and driveways
- Roadside features and clear zone
- Driver Expectancy



Case Study: CR 202

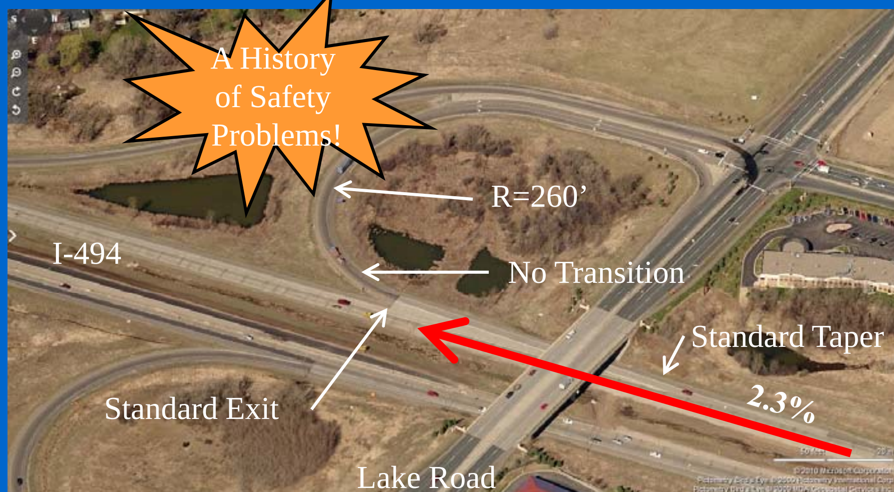

Case Study: CR 202
Reinforced Soil Slopes


C se Study: CR 202
Unknown Unknown!
Trees lost due to
contaminated
soil removal.

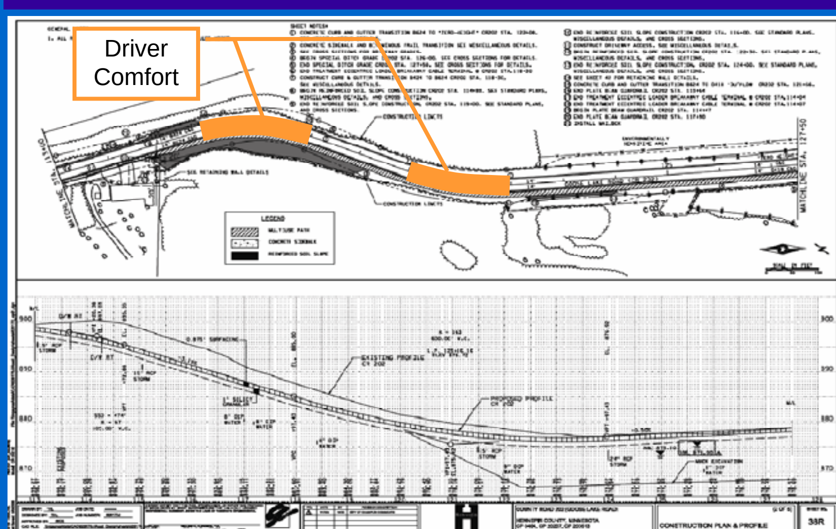
Case Study: CR 202

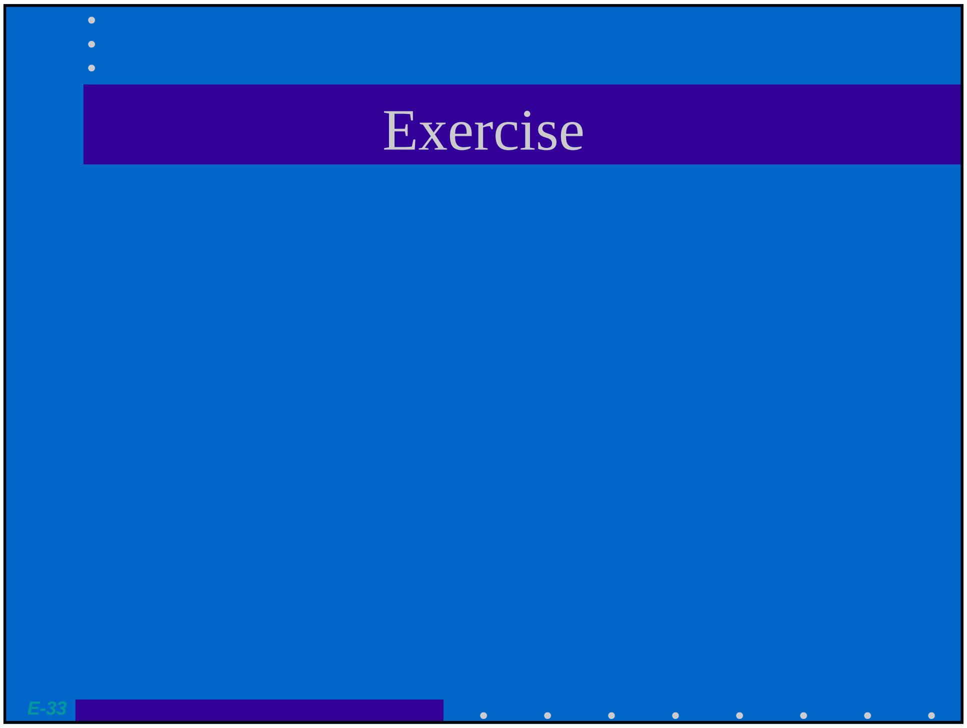
What does the driver see?

Nominally Safe but Substantive Safety Problem



Basis for Standards




Exercise
E-33