Performance-based Superelevation Transition Design

CTS Transportation Research Conference
November 3, 2016
Hopefully not…

Early experiments in transportation
Observation
Observation

I-94 in North Minneapolis
Applicable Criteria

Minnesota DOT (MnDOT) Road Design Manual:
- Two-thirds of the runoff length on tangent; one-third on curve
- 1:400 transition rate; wider pavements require longer transitions

AASHTO “Green Book”:
- “…with a large majority of agencies using 0.67 (i.e. 67 percent) [of the runoff length on the tangent].”
- “…values for the proportion of runoff length on tangent in the range of 0.7 to 0.9 (i.e. 70 to 90 percent) offer the best operating conditions.” (NCHRP Report 439)
Observation

MN 62 at MN 55
Observation

I-35 south of the Twin Cities

$S = 1:200$

Proportion of runoff on tangent: 50%
Green Book Figure 3-7: Methods of Distributing Superelevation and Side Friction
The current national criteria for superelevation transition design – which errs on the side of oversupply of superelevation through the transition – does not optimize driver comfort and may result in erratic operating characteristics.
Physical Concepts

Force Balance in a Curve

- Superelevation = \( e \)
- Curve Radius = \( R \)
- Vehicle Center of Gravity
- \( F \) parallel to pavement
- \( F \) normal to pavement
- Centrifugal Force = \( F = W \cdot \left( \frac{v}{R} \right) \)
- Resultant Force Applied to Pavement
- Vehicle Weight = \( W \)
Physical Concepts

\[ e + f = \frac{V^2}{15R} \]

- \( e \) = superelevation rate
- \( f \) = side friction factor
- \( V \) = design speed (mph)
- \( R \) = radius of curve (ft)
Investigative Approach

\[ f = \frac{V^2}{15R} - e \]

- Side friction (f) computed every two feet through a tangent runout / superelevation transition
- Driving path incorporates a spiral transition of an assumed length based on a 2-second travel time
  - Green Book Table 3-21 (NCHRP Report 439)
- Typical section: 2% normal cross slope
- Spreadsheet allows interactive testing of various combinations of parameters
## Investigative Approach

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<th></th>
<th>e Inside Ln</th>
<th>e Outside Ln</th>
<th>Driven Inside Ln</th>
<th>Driven Outside Ln</th>
<th>f Inside Ln</th>
<th>f Outside Ln</th>
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</table>
DS = 70 mph; $D_c = 2^\circ 00'$; $e = 0.055$; $S = 1:400$; 67% on tangent
Findings

DS = 70 mph; $D_c = 2^{\circ}00'$; $e = 0.055$; $S = 1:400$; 90% on tangent
DS = 70 mph; $D_c = 2^\circ 00'$; $e = 0.055$; $S = 1:250$; 90% on tangent
Findings

DS = 70 mph; \( D_c = 2^\circ 00' \); \( e = 0.055 \); \( S = 1:225 \); 33% on tangent
Findings

\[ DS = 70 \text{ mph}; \ D_c = 2^\circ 00'; \ e = 0.055; \ S = 1:225; \ 33\% \text{ on tangent} \]
DS = 70 mph; $D_c = 2^\circ 00'$; $e = 0.055$; $S = 1:225$; 33% on tangent
Findings

DS = 60 mph
$D_c = 3^\circ 15'$
$e = 0.056$

Proportion of runoff on tangent: 50%
$S = 1:750$

Back to I-94...
Findings

DS = 60 mph; $D_c = 3^\circ 15'$; $e = 0.056$; $S = 1:750$; 50% on tangent
Findings

DS = 60 mph; $D_c = 3^\circ 15'$; $e = 0.056$; $S = 1:750$; 67% on tangent
DS = 60 mph; $D_c = 3°15'$; $e = 0.056$; $S = 1:750$; 90% on tangent
Conclusions

• Observations of negative side friction and markedly varying friction with “standard” designs are confirmed by the methodology.

• Optimal driver comfort appears to be provided by tailoring transition rate and runoff placement to particular circumstances:
  – Generally much less runoff on tangent than recommended by AASHTO.
  – Transition rates sometimes faster than recommended by AASHTO.

• Optimal driver comfort into spiraled curves is provided by fitting the full transition – runout and runoff – to the length of the spiral.
Conclusions

• Very long transitions lead to apparent discomfort BOTH early in the transition and well into the curve proper
• Overarching conclusion: driver comfort does not appear to be served by adherence to AASHTO criteria
  – …particularly the recommendation to provide up to 90% of runoff on the tangent
  – Standards are based on comfort considerations, but they may unwittingly create discomfort…and maybe erratic driving
Recommendations

• This methodology should be explored and refined
• Additional research!
  – Correlate predictions with actual measured effects
• AASHTO Green Book
  – Additional flexibility for both transition rate and placement
  – Reconsider the recommendation to provide up to 90% of runoff on tangent
  – Discuss the phenomenon of negative side friction in transitions – dovetails with NCHRP Report 774 recommendations
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