Safety Assessment of Control Design Parameters through Vehicle Dynamics Model

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Background

- Design speed
  - key parameter for defining critical geometric elements

- Road design practice
  - simplified approach
  - failure to assess interactions between parameters

\[ R_{\min} = \frac{V^2}{127(f_{R,perm} + e_{\text{max}})} \]

where
- \( R_{\min} \): minimum curve’s radius (m)
- \( V \): vehicle speed – usually design speed (km/h)
- \( e_{\text{max}} \): maximum superelevation rate (%/100)
- \( m \): vehicle’s mass
- \( f_{R,perm} \): permissible side friction factor as a portion of peak friction

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Point Mass Deficiencies

- Steady state cornering is assumed
  - acceleration effect is ignored
- Key vehicle parameters ignored
  - type, mass and position of gravity (mass) center, loading - driving configuration, horse-power supply, etc.
- Vehicle motion is examined independently in tangential - lateral direction of travel
  - respective friction components interact
- Utilized lateral friction based on empirical vehicle accident considerations
  - assumed as fixed portion of the relevant peak (40%-50%)
- Longitudinal profile disregarded
Necessity for More Sophisticated Models

• Current control grade values
  • based mostly on experience
  • limitations from the operational point of view
  and not an outcome of a safety assessment

• Simulate vehicle’s cornering process
  • especially in cases of steep grades
    (reduction of safety margin)
  • upgrade road sections more critical
    in terms of horizontal radii requirements
Objective

• Lift restrictions imposed by point mass model

• Assess the ability of a typical passenger car to maintain design speed values for the corresponding control design parameters
  • critical upgrade values
  • various tire – road friction values

• Investigate the safety impact of vehicle’s peak attainable constant speed against design parameters imposed by design speed
Vehicle Dynamics Model

• Moving 3D coordinate system

• Parameters correlated
  • vehicle technical characteristics
  • road geometry
  • tire friction

• 4-wheel model
  • lateral load transfer
Methodology

- Output: $V_{\text{safe}}$ vehicle’s peak attainable constant speed
- C class passenger car utilized (KIA Proceed)
- Assessment for AASHTO-2011 design guidelines ($V_d = 50\text{km/h} - V_d = 90\text{km/h}$)
- 3 pavement friction values (0.35, 0.50, 0.65)
- Definition of critical wheel (impending skid conditions)
Define critical wheel:

\[ \frac{dV}{dt} = 0 \]

\[ V = V + V_{\text{step}} \]

\[ \frac{dV}{dt} > 0 \]

\[ V_{\text{safe}}, n \]
Grade Impact during $V_{safe}$ Determination

- **Impending skid**

\[ f_R \text{ demand: critical on mild grades} \]
\[ f_T \text{ demand: critical on steep grades} \]
HP Utilization Rates during $V_{\text{safe}}$ Determination

• Impending skid

vehicle skids when driven above suggested HP utilization values
Friction Safety Margins for $V < V_{safe}$

- **Comfortable driving**

<table>
<thead>
<tr>
<th>Friction values</th>
<th>70</th>
<th>65</th>
<th>60</th>
<th>55</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_T$ grade dependent</td>
<td>0.16</td>
<td>0.13</td>
<td>0.10</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>$f_R \approx f_R$ point mass model</td>
<td>0.16</td>
<td>0.12</td>
<td>0.10</td>
<td>0.08</td>
<td>0.05</td>
</tr>
</tbody>
</table>

![Friction vs Comfortable Speed](image)

- **Friction vs Comfortable Speed ($f_{max}=0.35$, $V_d=70\,\text{km/h}$, $R=184\,\text{m}$)**

  - $f_f$ (s=12%)
  - $f_f$ (s=0%)
  - $f_R$ point mass model

S. Mavromatis, "Safety Assessment of Control Design Parameters through Vehicle Dynamics Model"
**$V_{safe}$ Variation for Control Design Values ($f_{max} = 0.35$)**

- **Impending skid**

  critical cases ($f_{max} = 0.35$):
  - $V_d = 50\text{km/h}$, $s>11\%$
  - $V_d = 60\text{km/h}$, $s>11\%$

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• **Impending skid**

**Critical cases** ($V_d = 50\text{km/h}$):

- $f_{\text{max}} < 0.40$
- $s > 11\%$
Conclusions

• Investigation of the ability a C-class passenger car on steep grades to maintain $V_d$:
  • AASHTO 2011 design guidelines ($V_d = 50\text{km/h} \rightarrow V_d = 90\text{km/h}$)
  • 3 pavement friction values (0.35, 0.50, 0.65)

• 2 cases examined for assessing safety margins:
  • comfortable curve negotiation ($V < V_{\text{safe}}$)
  • $V_{\text{safe}}$ impending skid conditions
Comfortable curve negotiation \((V < V_{\text{safe}})\)

- \(f_R\) demand independent to grade
- \(f_T\) demand increases with grade
Conclusions

$V_{\text{safe}}$ impending skid conditions

- $f_R^{\text{demand}}$ critical on mild grades
- $f_T^{\text{demand}}$ critical on steep grades

- Steady state cornering not always feasible
  - $V_d = 50\text{km/h}, s>11\%, f_{\text{max}} = 0.35$
  - $V_d = 60\text{km/h}, s>11\%, f_{\text{max}} = 0.35$

- Point mass model somehow underrates lateral friction requirements

- Vehicles equipped with excessive HP rates must be driven very conservatively in road with poor friction pavement
Recommendations - Further Research

• Identified critical cases to be treated cautiously through actions
  • adoption of acceptable parameter arrangements (new alignments)
  • posted speed management (existing alignments)
  • scheduling friction improvement programmes more accurately (both cases)

• Assessment on entire vehicle fleet

• Further analysis of interaction between driver – vehicle
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