Highway Design

CE3201 Lab #5
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Agenda

- Problem Statement
- Objective and Constraints
- Horizontal Alignment
- Vertical Alignment
- Mass diagram
- Final Report - Blueprint for construction
Problem

Lombard Street, San Francisco, CA

Highway in west China
Problem Statement

- A service road to connect a new Fire Tower (C---->D)
- Serve the vehicle I3
- Two-lane rural road, design speed 100km/h, width 3.66m, lateral clearance 1.9m
Constraints

- Environmental
  - Wetland, ponds and creeks.

- Geometric
  - 90m flat grade for starting and ending points.
  - Simple horizontal and vertical curve

- Safety
  - Maximum grade
  - Minimum radius
  - Enough stopping sight distance

- Budget
  - Maximum cut-and-fill depth
  - Mass balance
Procedure

Analyze Problem

Define Objective

Identify Constraints

Design

Mission Impossible?

Check

Professional layout

Final Report
Requirements

- Individual report or with a partner
- Presented in professional engineering standard
- Final report before Dec 2nd
- Pdf file naming as CE3201_Lab5_YourName
- Cover page, description, considerations, constraints, calculation and design, profile, mass diagram, discussion, summary, reference...
Software package to assist design

- [http://street.umn.edu/Road/GeometryDesign.html](http://street.umn.edu/Road/GeometryDesign.html)
- Check the global setting before started
- Load the contour and get started
- Use output in your report, format them professionally
Maximum Grade

- When a vehicle is ascending the maximum grade at a given (constant) speed (acceleration=0), all tractive effort is being used to overcome resistance to motion. So the maximum grade is found by solving:

\[
G = \frac{F_t - F_a - F_r}{W}
\]

- \(F_t\) = Tractive Effort (N)
- \(F_a\) = Air Resistance (N)
- \(F_r\) = Rolling Resistance (N)
- \(W\) = Vehicle Weight (N)
Maximum Grade

\[ F_a = \frac{\rho}{2} AC_D v^2 \]
\[ F_t = \frac{1000P}{v} \]

\( v \) = vehicle speed (m/sec)
\( A \) = vehicle frontal area (m\(^2\))
\( C_D \) = Drag Coefficient
\( \rho \) = density of air (1.2kg/m\(^2\))

\( F_r = (0.015)W \) - passenger cars
\( F_r = (0.010)W \) - commercial trucks

\( P \) = available power = nominal power * available power ratio
Minimum Radius

- When a vehicle moves around a horizontal curve, it is subject to the outward radial force (centrifugal force) and the inward force. The inward force is not due to gravity, but rather because of the friction between tires and the roadway. At high speeds, the inward force is inadequate to balance the outward force without some help.

- That help arises from banking the road, what transportation engineers call super-elevation (e). This banking, an inclination into the center of the circle, keeps vehicles on the road at high speed.

\[
\frac{W_u^2}{gR} \cdot \cos \alpha
\]
Minimum Radius

- The minimum radius of circular curve (R) for a vehicle traveling at u km/h can be found by considering the equilibrium of a vehicle with respect to moving up or down the incline.

\[
\frac{mv^2}{R} = \frac{Wv^2}{gR} = W \sin \alpha + Wf_s \cos \alpha
\]

\[f_s = \text{coefficient of side friction}\]

\[
\frac{v^2}{g} = R(\tan(\alpha) + f_s)
\]

Let \( e = \tan(\alpha) \)

\[
R = \frac{(v)^2}{g(e + f_s)} = \left(\frac{v}{3600}\right) = \frac{(v)^2}{127(e + f_s)}
\]
Minimum Radius

- Given e and fs, there is a minimum Radius.
- There are maximum values for e and fs, which depend on the location of the highway, weather, and distribution of slow vehicles.
  - In rural area with no snow or ice, a maximum super-elevation of 0.1 is used.
  - In urban areas, a maximum of 0.08 is used.
  - Less is used in places like Minnesota, where it is 0.06. Values for fs vary with design speed.
## Side-Friction (Mn)

<table>
<thead>
<tr>
<th>Design Speed (km/hr)</th>
<th>Coefficient of Side Friction ($f_s$)</th>
<th>Minimum Radius (m) Urban</th>
<th>Minimum Radius (m) Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.312</td>
<td>0.17</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>0.252</td>
<td>0.17</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>0.214</td>
<td>0.16</td>
<td>70</td>
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<tr>
<td>60</td>
<td>0.186</td>
<td>0.15</td>
<td>115</td>
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<tr>
<td>70</td>
<td>0.162</td>
<td>0.14</td>
<td>175</td>
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</table>

<table>
<thead>
<tr>
<th>Design Speed (km/hr)</th>
<th>Coefficient of Side Friction ($f_s$)</th>
<th>Minimum Radius (m) All High Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>0.147</td>
<td>250</td>
</tr>
<tr>
<td>90</td>
<td>0.14</td>
<td>340</td>
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<tr>
<td>100</td>
<td>0.128</td>
<td>450</td>
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<tr>
<td>110</td>
<td>0.115</td>
<td>590</td>
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<tr>
<td>120</td>
<td>0.102</td>
<td>775</td>
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</tbody>
</table>
Stopping Sight Distance

\[ d_s = d_r + d_b = 0.278 t_r v_i + \frac{v_i^2}{254(f \pm G)} \]

- \( d_r \): perception/reaction distance
- \( d_b \): braking distance
- \( v_i \): initial speed (km/h)
- \( t_r \): perception/reaction time (s)
- \( f \): AASHTO stopping friction coefficient
- \( G \): roadway grade
## Stop friction coefficient

<table>
<thead>
<tr>
<th>Design Speed (km/h)</th>
<th>Coefficient of Skidding Friction (f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.40</td>
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<tr>
<td>40</td>
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<tr>
<td>80</td>
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<tr>
<td>90</td>
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<tr>
<td>100</td>
<td>0.29</td>
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<tr>
<td>110</td>
<td>0.28</td>
</tr>
<tr>
<td>120</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Sight obstruction

\[ m = \text{distance from centerline to sight obstruction} \]
\[ L = \text{Length of Curve} \]
\[ R = \text{Radius of Centerline} \]
\[ S = \text{Sight Distance} \]
Determine m

- When $S \leq L$

  \[ m = R(1 - \cos \left( \frac{28.65S}{R} \right)) \]

- When $S > L$

  \[ m = R(1 - \cos \left( \frac{28.65L}{R} \right)) + \left( \frac{S - L}{2} \right) \sin \left( \frac{28.65L}{R} \right) \]
Crest vertical curve

\[ L = 2S - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{A} \text{ if } S \geq L \]

\[ L = \frac{AS^2}{200(\sqrt{h_1} + \sqrt{h_2})^2} \text{ if } S < L \]

\( L = \) Length of the vertical curve
\( S = \) Sight distance (m)
\( A = L \) The absolute value of change in grades (as percent)
\( h_1 = \) Height of the drive's eyes above the ground (m)
\( h_2 = \) Height of the object above the roadway (m)
Sag vertical curve

- Sight distance provided by the headlight
- Rider comfort
- Control of drainage
- General appearance

The headlight is angled upward at an included angle ($\beta$), the headlight intersects the road at $D$, restricting the available sight distance to $S$. The value for $H$ and $\beta$ are 0.6m and 1 degree.

$$L = 2S - \frac{200(H + S \tan \beta)}{A} \quad \text{if } S > L$$

$$L = \frac{A S^2}{200(H + S \tan \beta)} \quad \text{if } S \leq L$$
Some considerations
Global Setting

- Contour image setting
  - 72 pixel/in or 28 pixel/cm
  - 760 ft/in or 91.2 m/cm

- Parameters setting

- Read altitude from the contour map