FIG WORKING WEEK 2012

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Determination of Minimum Horizontal Curve Radius Used in the Design of Transportation Structures, Depending on the Limit Value of Comfort Criterion Lateral Jerk

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FIG Working Week 2012 Knowing to manage the territory, protect the environment, evaluate the cultural heritage

ROME 2012

Overview

- Introduction
- Determination of Minimum Horizontal Curve Radius
  - Minimum Horizontal Curve Radius based on the limit Value of Superelevation
  - Minimum Horizontal Curve Radius based on the Limit Value of Lateral Acceleration
  - Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk
- Numerical Application
- Conclusion

Introduction

The significance of road projects have been increasing day by day.

Because of

- Depending on social, cultural and economic developments, transportation requirements are increasing,
- As a result of technological developments, vehicles becoming faster and more comfortable,
- Parallel to all developments, the value of time is further increasing.

Introduction

- Constructing of fast, safe, comfortable and economical transportation systems is an important expectation among the people.

- To meet the expectations, during the design of transportation structures, geometric standards related to the project should be investigated very detailed.

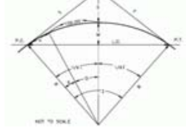
Introduction

- Horizontal and vertical curves used in transportation systems are the critical sections on the alignment.
- On the horizontal curve, lateral acceleration formed by centrifugal force adversely affects the road safety and reduces vehicle travel comfort.
- Evaluation criterion of the alignment geometry in terms of comfort is Jerk.
- During the curve design, to take into account of Jerk criterion is extremely important.

Introduction

- In this study as distinct from other studies, minimum horizontal curve radius is derived using the limit value of lateral Jerk.
- The equations of minimum curve radius related to lateral Jerk are derived by analyzing the equations of lateral Jerk in the literature.
- Minimum curve radius are calculated by using the equations derived.
- Calculated minimum curve radius are compared with the other minimum curve radius which were calculated with respect to different criterion.

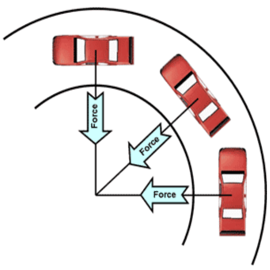
Determination of Minimum Horizontal Curve Radius

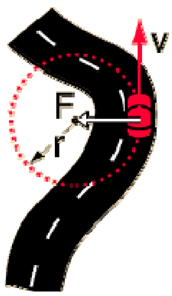


- The minimum curve radius is a limiting value of curvature for a given design speed.
- In the design of horizontal alignment, smaller than the calculated boundary value of minimum curve radius cannot be used. Thus, the minimum radius of curvature is a significant value in alignment design.
- An important issue to be addressed in order to increase road safety and comfort in the design of horizontal curves is determination of the minimum curve radius affected by many factors.

Determination of Minimum Horizontal Curve Radius

- For a given speed, the curve with the smallest radius is also the curve that requires the most centripetal force.





- Minimum curve radius must be selected very well for safe and comfortable driving in the alignment design.

Determination of Minimum Horizontal Curve Radius

- Minimum curve radius can be calculated to take into account various parameters.

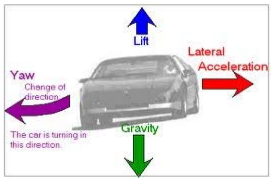
Design Speed

Side Friction Factor

Superelevation

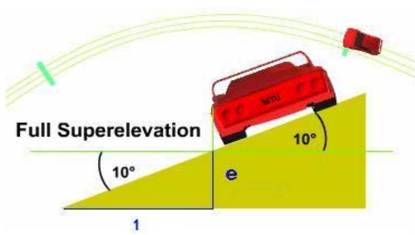
Lateral Acceleration

Lateral Jerk



Minimum Horizontal Curve Radius based on the limit Value of Superelevation

- Superelevation is inclined roadway cross-section that employs the weight of a vehicle in the generation of the necessary centripetal force for curve negotiation.



Minimum Horizontal Curve Radius based on the limit Value of Superelevation

- Minimum curve radius can be derived to take into account the limit value of superelevation.
- Equation of minimum horizontal curve radius depend on the superelevation value is given by American Association of State Highway and Transportation Officials' A Policy on Geometric Design of Highways and Streets (AASHTO Green Book, 2001) as follows:

$$R_{min} = \frac{V^2}{127(0{,}01e_{max} + f_{max})}$$

Minimum Horizontal Curve Radius based on the limit Value of Superelevation

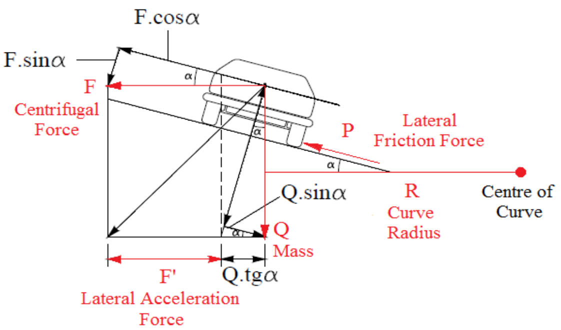
- For railways; equation of minimum curve radius based on the superelevation was expressed as follows: (Baykal,2009).

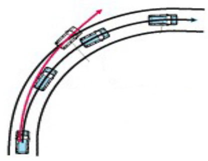
$$R_{min} = \frac{\sqrt{b^2 - u_{max}^2 V_o^2}}{127{,}14\, u_{max}}$$

R_{min} : Minimum curve radius (m)
V : Velocity (km/s)
e_{max} : Maximum superelevation
f_{max} : Maximum allowable side friction factor
u_{max} : Maximum superelevation (m)
V_o : The average speed (km/h)
b : Width of the railway line (m)

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Acceleration

- The vehicles entered horizontal curve from the linear section of the road move under the influence of various forces. These forces are;





Minimum Horizontal Curve Radius based on the Limit Value of Lateral Acceleration

- The change of velocity with respect to time is called acceleration.
- The lateral acceleration is created by centrifugal force.
- Minimum curve radius can be derived to take into account the limit value of the lateral acceleration. It was derived for the horizontal geometry as follows: (Baykal, 2009, p.351)

For highways:
$$R_{min} = \frac{V^2}{12{,}96(\sqrt{1 + e_{max}^2}\, a_Y + e_{max}\, g)}$$

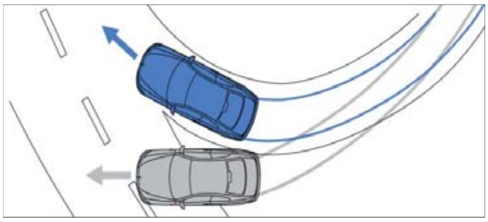
For railways:
$$R_{min} = \frac{\sqrt{b^2 - u_{max}^2}\, V^2}{12{,}96(b\, a_Y + u_{max}\, g)}$$

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk

- The change of the acceleration with respect to time is called Jerk.
- The concept of Jerk is defined as the third derivative of distance
- The Jerk is also called the second acceleration.
- In terms of road safety and comfort, Jerk is an important design criterion.
- Jerk is known as comfort criterion in the alignment design.

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk

- The lateral Jerk is defined as the change of lateral acceleration with respect to time created by the centrifugal force on the horizontal curve.



- For the safety and comfortable driving, lateral Jerk must be below the predetermined limit values.

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk

- Jerk equation is as follows (Baybura, 2001):

$$Z_y = \frac{bV}{\sqrt{u^2+b^2}}\Bigg\{3k_Y a_T + V^2\frac{d_{kY}}{d_l} \pm \frac{u V^2}{b\sqrt{1+W^2}}\frac{d_{kD}}{d_l} + \left(\frac{-k_Y V^2 u}{u^2+b^2} - \frac{g}{b} + \frac{g\,u^2}{b(u^2+b^2)} \pm \frac{k_D V^2}{b\sqrt{1+W^2}} \pm \frac{-k_D V^2 u^2}{b\sqrt{1+W^2}\,(u^2+b^2)}\right)\frac{d_u}{d_l} \pm \frac{-u^2 V^2 k_D W}{b(1+W^2)^{3/2}}\frac{d_W}{d_l} \pm \frac{2\,u\,k_D\,a_T}{b\sqrt{1+W^2}}\Bigg\}$$

Z_y : Lateral Jerk (m/s³)
V : Design speed (m/s)
b : Horizontal width of road platform (m)
u : Superelevation (m)
k_Y : Horizontal curvature (1/m)
k_D : Vertical curvature (1/m)
g : Gravitational acceleration (9, 81 m/s²)
a_T : Resultant tangential acceleration (m/s²)
W : Longitudinal slope
l : Horizontal length of road

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk

- In the equation;
  - ✓ The value of k_Y represents the curvature of horizontal geometry at any point. k_Y is equal to the value of $(1/r_y)$.
  - ✓ The derivatives of the superelevation and radius of curvature with respect to distance are zero.
  - ✓ The expression of $\sqrt{u^2+b^2}$ (sloping width of road platform) can be equal to the value of horizontal width of road platform (b).

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk

- The equation can be edited for horizontal geometry (k_D: 0).
  - ✓ For highways; equation of minimum curve radius based on the lateral Jerk is:

$$R_{min} = \frac{3V_{max}a_T}{Z_y}$$

  - ✓ For railways; equation of minimum curve radius based on the lateral Jerk is:

$$R_{min} = \frac{3V_{max}\sqrt{b^2 - u_{max}^2}\, a_T}{b\, Z_y}$$

Minimum Horizontal Curve Radius based on the Limit Value of Lateral Jerk

- Limit values of lateral Jerk in the literature;

  For highways;
  - ✓ 0.3 - 0.9 m/s^3 (AASHTO, 2001)
  - ✓ 0.6 m/s^3 (Schofield; 2001), (Umar; Yayla; 1997)
  - ✓ 0.5 m/s^3 (Manns; 1985)

  For railways;
  - ✓ 0.5 m/s^3 (Megyeri; 1993), (Evren; 2002)
  - ✓ 0.4 m/s^3 (Förstberg; 2000)
  - ✓ 0.2 m/s^3 (Esveld; 1989)

Numerical Application

- Minimum curve radius based on the different limit values were calculated.

V (Km/h)	R_{min} (m)								
	Z_y (m/s³)							a_y (m/s²)	e (%)
	Z_y: 0.3	Z_y: 0.4	Z_y: 0.5	Z_y: 0.6	Z_y: 0.7	Z_y: 0.8	Z_y: 0.9	a_y: 1.47	e: 4
20	115	85	70	60	50	45	40	15	15
30	170	125	100	85	75	65	60	35	35
40	225	170	135	115	100	85	75	55	60
50	280	210	170	140	120	105	95	85	100
60	335	250	200	170	145	125	115	125	150
70	390	300	235	195	170	150	170	170	215
80	445	335	270	225	195	170	150	220	280
90	500	375	300	250	215	190	170	280	375
100	560	420	335	280	240	210	190	345	495
110	615	460	370	310	265	230	205	415	635
120	670	500	400	335	290	250	225	495	875
130	725	725	435	365	310	275	245	580	1110

- Table shows the minimum curve radius based on the different limit values for highways.

Numerical Application

- Z: 0.3 m/s³ , V: 0-100 km/h → $R_J > R_e > R_a$
  V: 100-130 km/h → $R_e > R_J > R_a$

  Z: 0.5 m/s³ , V: 0-70 km/h → $R_J > R_e > R_a$
  V: 70-90 km/h → $R_e > R_J > R_a$
  V: 100-130 km/h → $R_e > R_a > R_J$

  Z: 0.7 m/s³ , V: 0-50 km/h → $R_J > R_e > R_a$
  V: 50-70 km/h → $R_e > R_J > R_a$
  V: 80-130 km/h → $R_e > R_a > R_J$

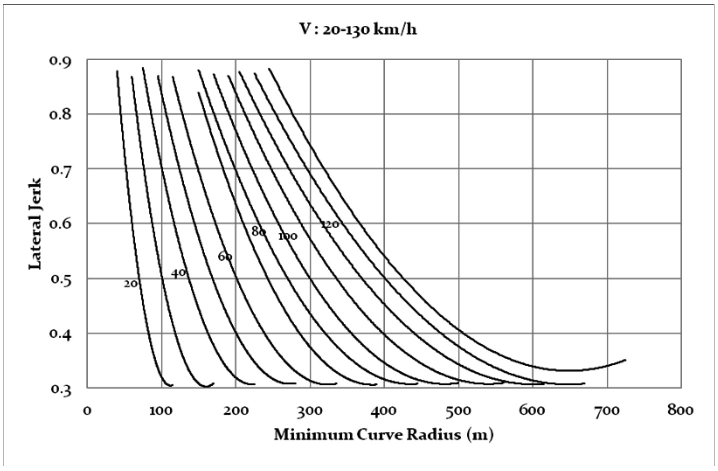
- During the design of horizontal curve, the biggest radius calculated with respect to different criteria must be used for comfortable designing.

Numerical Application

V (Km/h)	Rmin (m)					
	Z_y (m/s^3)				a_y (m/s^2)	u_{max} (m)
	Z_y: 0.3	Z_y: 0.4	Z_y: 0.5	Z_y: 0.6	a_y: 0.65	u_{max} : 0.15
20	110	85	70	55	20	35
30	165	125	100	85	45	70
40	225	165	135	110	75	125
50	280	210	165	140	120	195
60	335	250	200	165	170	285
70	390	290	235	195	230	385
80	445	335	265	225	305	500
90	500	375	300	250	385	635
100	555	415	335	280	470	785
110	610	460	365	305	570	950
120	665	500	400	335	680	1130
130	720	540	435	360	795	1325
140	775	580	465	390	925	1535
160	885	665	530	445	1205	2005
180	995	750	600	500	1525	2535
200	1105	830	665	555	1885	3135
220	1220	915	730	610	2280	3790
250	1382	1040	830	690	2945	4890

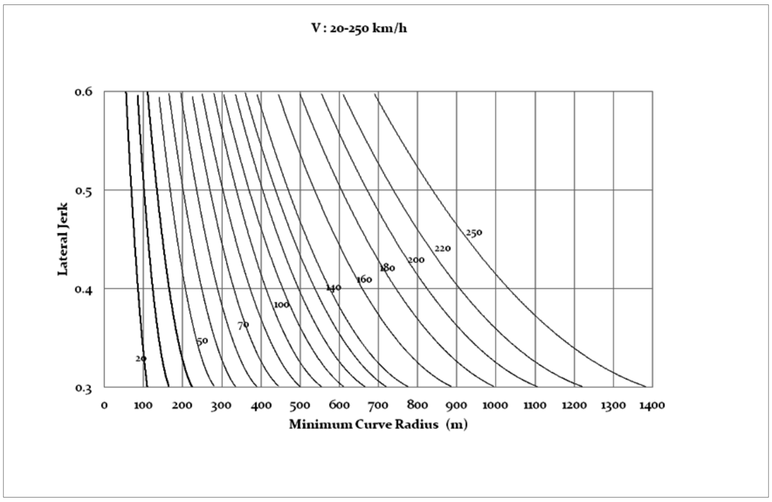
- Table shows the minimum curve radius based on the different limit values for railways.

Numerical Application



Minimum horizontal curve radius depends on the lateral Jerk for highways

Numerical Application



Minimum horizontal curve radius depends on the lateral Jerk for railways

Conclusion

- In this study as distinct from similar studies, minimum curve radius used as design criterion on the design of horizontal geometry of alignment was calculated to take into consideration lateral Jerk criterion.
- The equations of minimum curve radius based on lateral Jerk were derived from the equations of lateral Jerk in the literature.
- Minimum curve radius calculated according to different values of jerk was compared to minimum curve radius calculated according to other methods.
- The results were interpreted in terms of road safety and comfort. The biggest minimum curve radius calculated with respect to different criterion could be used for the design of comfortable and safety highways and railways.

Thank you very much for your attention

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