Basic Geometric Road Design

Key Road Design Goals

- Safety Considerations of users & non-users
- Operational Efficiency – time, comfort, convenience, appearance
- Cost Effectiveness – Construction / Maintenance and operation of road.
- Minimize Envrionmental Impact – Noise, Air Pollution, Vegetation, Visual etc.…

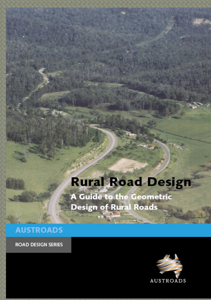
Road Designers Role

Taking into account inputs from relevant disciplines, road users and stakeholders, produce the most appropriate design to achieve the specific functionality, safety and efficientic for the project.

Road Design References & AusRoads

Urban and Rural Road Design References

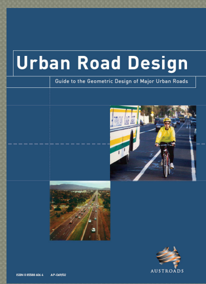
- Austroads (2002) Urban Road Design – Guide to the Geometric Design of Major Urban Roads.
- Austroads (2003) Rural Road Design – Guide to the Geometric Design of Rural Roads.
- ARRB (2000) Unsealed Roads Manual – Guidelines to Good Practice.
- Roads & Traffic Authority (RTA) - Road Design Guide (RDG).
- Queensland Main Roads (QMR) - Road Design Guide.



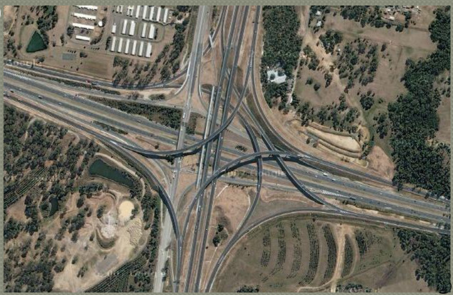
Note: These Design manuals are **Guides** only.

AUSTROADS

- Austroads is the association of Australian and New Zealand road and traffic authorities.
- 11 members include;
  - six states, NSW, Vic, Qld, WA, SA and Tas
  - two territories – ACT, NT
  - Federal government – DOTARS
  - Aust. Local Gov. Association
  - Transit NZ



Key Design Inputs



Design Inputs

1. Traffic Flow / Road capacity (Road Classification)
2. Cross Section – traffic considerations / lanes / shoulders / verge
3. Speed Parameters / Operating speed determination
4. Horizontal Alignment (Curve radii, side friction)
5. Superelevation development and transition curves (Spirals)
6. Curve widening (is it required?)
7. Vertical Alignment (Grades, Crests and Sag parabolas)
8. Horizontal & Vertical sight distance checks.
9. Horizontal & Vertical co-ordination consideration.
10. Earthworks quantities estimation.

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1. Traffic Flow / Road Capacity

1. Traffic Flow / Capacity

The traffic engineer determins the AADT (Annual Average Daily Traffic), via detector loops, weigh in motion etc. Future traffic volumes obtained from projected traffic growth, corridor studies, Transportation studies.

What is the Traffic composition? N°. Cars v Trucks v Motorbikes v Bicycles

Future Traffic Volume

$Vol_2 = Vol_1 \times (1 + p)^n$

Where:

Vol_2 = Future traffic volume

Vol_1 = Current traffic volume

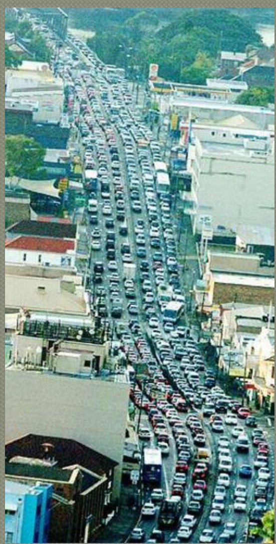
p = growth rate (percent/100)

n = design period / life (years)

eg. Current project has a 2500 AADT
Growth rate expected is 3% over the design life of the road (30 years).

$Vol_2 = 2500 \times (1 + 0.03)^{30}$

$Vol_2 = 3800$



Victoria Road, Sydney

Reference: Austroads Guide to Traffic Engineering Practice Part 2 (GTEP 2)

2. Road Cross Section

2. Cross Section – traffic considerations / lanes / shoulders / verge

The selection of cross-section elements for rural / urban roads is an iterative process that considers various criteria. eg: safety, environmental impact, economy and aesthetics.

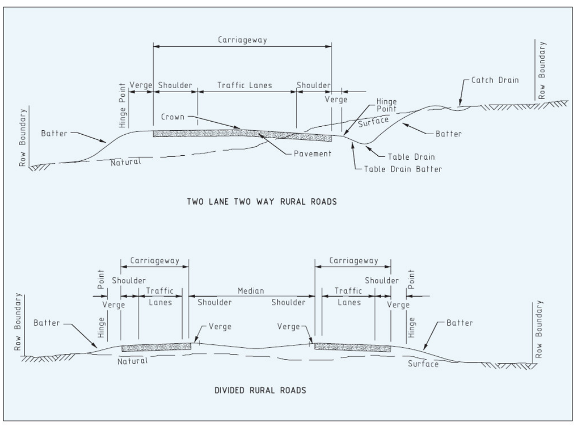
The major elements of a cross section are illustrated in Figure 11.1.

Reference: Austroads – Rural Road Design (Part 11)

Table 11.1: Single Carriageway Road Widths

Element	Design AADT				
	1-150	150-500	500-1,000	1,000-3,000	>3,000
Traffic Lanes	3.5 (1 x 3.5)	6.2 (2 x 3.1)	6.2-7.0 (2 x 3.1/3.5)	7.0 (2 x 3.5)	7.0 (2 x 3.5)
Total Shoulder	2.0	1.5	1.5	2.0	2.5
Shoulder Seal	0.5	0.5	0.5	1.0	1.5

Figure 11.1: Typical Cross Sections



2. Cross Section Continued…..

2. Clear Zones

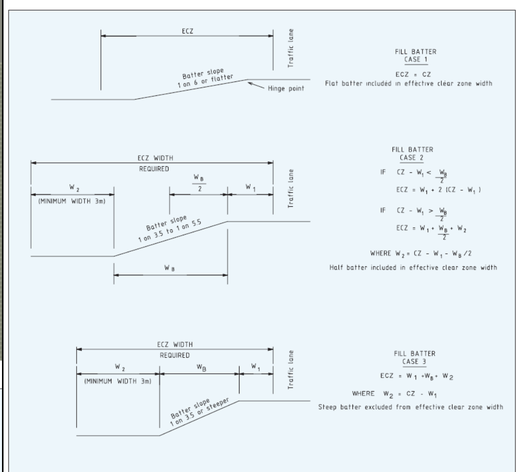
The most widely accepted form of risk management for roadside hazards is the 'clear zone concept'. The clear zone is the horizontal width measured from the edge of the traffic lane that is kept free from hazards to allow an errant vehicle to recover.

The clear zone should be kept free of non-frangible hazards where economically possible; alternatively, hazards within the clear zone should be shielded. The clear zone width is dependent on:

- Speed;
- Traffic volumes;
- Batter slopes; and
- Horizontal geometry.

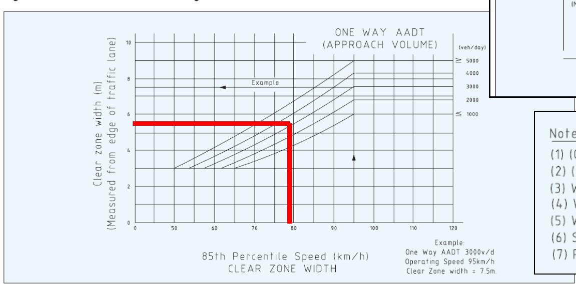
Reference: Austroads – Rural Road Design (Part 17.3)

Figure 17.5: Effective Clear Zone Widths on Batters



Notes:
(1) (CZ) Is the clear zone width determined from Figure 17.2
(2) (ECZ) Effective Clear Zone Width
(3) W_1 is width from edge of through lane to hinge point
(4) W_B is batter width
(5) W_2 is width from toe of batter
(6) S is batter slope (m/m)
(7) Provide bater rounding to all batter top and toe hinge points

Figure 17.2: Clear Zone Widths on Straights



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3. Speed Determination

3. Speed Parameters

Historically, a single "design speed" was used as the basic parameter for each road. Although roads designed in this way had consistent minimum design standards, problems arose because vehicle operating speeds differed from the design speed and, in some cases, the speed difference was sufficient to create a hazard. The most common location where problems occur is at the end of straights where vehicle operating speeds often exceed the design speed of the curve.

Vehicle speed range is as follows:
- High speed: 100km/h or greater
- Intermediate: 80km/h to 99km/h
- Low speed: 79km/h or less

Driver operating speeds are not constrained by the geometry of the road but by a number of other factors, which include:
- The degree of risk the drivers are prepared to accept;
- Speed limits and the level of policing of these limits; and
- Vehicle performance.

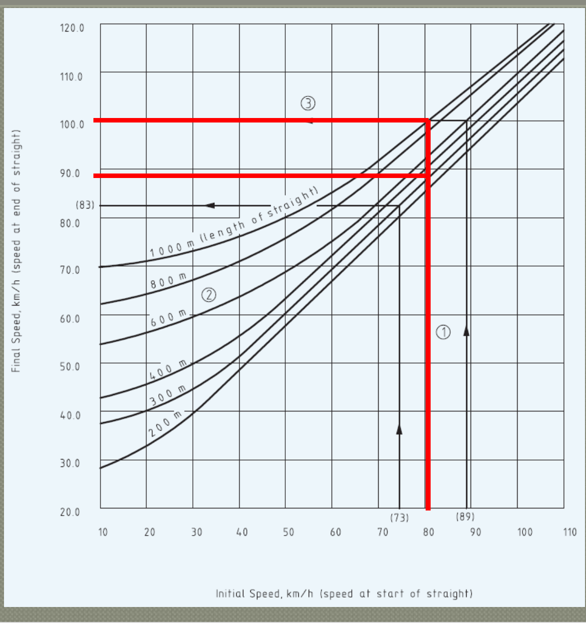
The term "**Operating Speed**" in this guide is the 85th percentile speed of cars at a time when traffic volumes are low, that is when drivers are free to choose the speed at which they travel. In effect, this means that designs based on the 85th percentile speed will cater for the majority of drivers. For design purposes, the 15% of drivers who exceed this speed are considered to be aware of the increased risk they are taking and are expected to maintain a higher level of alertness, effectively reducing their reaction times.

Reference: Austroads – Rural Road Design (Part 3, Section 7)

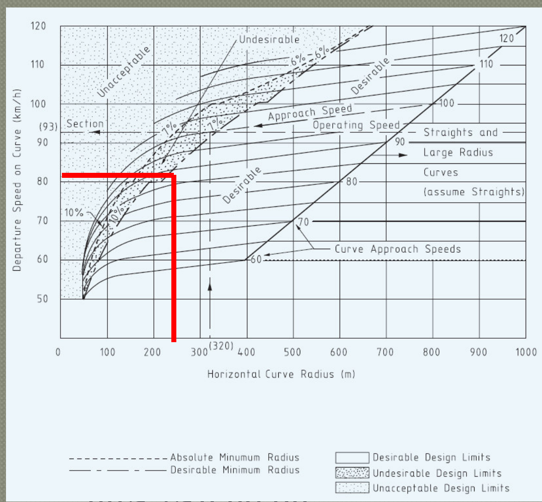
3. Speed Continued……

3. Operating Speed determination

The Operating Speed of vehicles is estimated by establishing the approach speed of the vehicle for the direction of traffic flow being considered. The approach speed is then applied to the first curve and an operating speed is read. This speed then becomes the approach speed for the subsequent curves and separating straights. The Operating Speed estimating graphs are:



Reference: Austroads – Rural Road Design (Figure 7.2 & 7.3)



3. Speed Continued……

3. Section Operating Speed

Vehicle speeds on a series of curves and short straights tend to stabilise at a value related to the range of curve radii. This speed is called the "Section Operating Speed".

Reference: Austroads – Rural Road Design (Figure 7.1 & 7.4)

Figure 7.4: Road Study Length

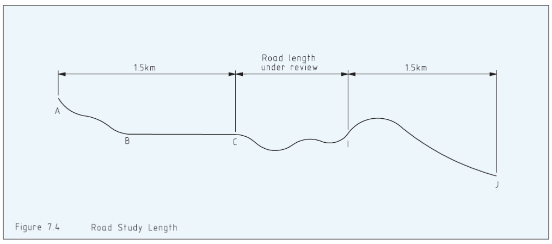
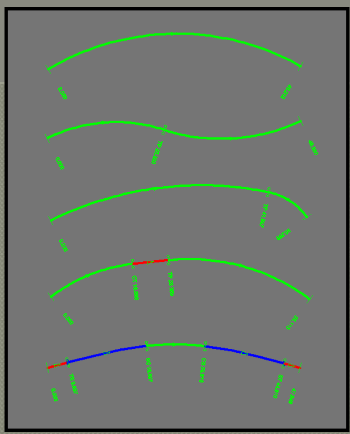


Table 7.1: Section Operating Speeds

Range of Radii In Section (m)	Single Curve Section Radius (m)	Section Operating Speed (km/h)	Range of Radii In Section (m)	Single Curve Section Radius (m)	Section Operating Speed (km/h)
45-65	55	50	180-285	235	84
50-70	60	52	200-310	260	86
55-75	65	54	225-335	280	89
60-85	70	56	245-360	305	91
70-90	80	58	270-390	330	93
75-100	85	60	295-415	355	96
80-105	95	62	320-445	385	98
85-115	100	64	350-475	410	100
90-125	110	66	370-500	440	103
100-140	120	68	400-530	465	105
105-150	130	71	425-560	490	106
110-170	140	73	450-585	520	107
120-190	160	75	480-610	545	108
130-215	175	77	500-640	570	109
145-240	190	79	530+	600	110
160-260	210	82			

4. Horizontal Alignment



4. Horizontal Alignment Consideration

- Horizontal Curve Types:
  - Circular (plain) curve
  - Reverse curves
  - Compound Curves
  - Broken Back Curves
  - Transition Curves

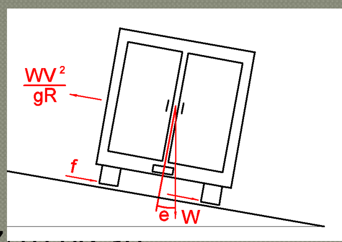
- Side Friction Factor

e = superelevation
f = side friction
V = operating speed
R = radius of curve
W = weight of vehicle
g = gravity

$$(e + f) = \frac{V^2}{127\,R}$$

Table 9.1: Side Friction Factors

Operating Speed (km/h)	f	
	Des max.	Abs max.
50	0.30	0.35
60	0.24	0.33
70	0.19	0.31
80	0.16	0.26
90	0.13	0.20
100	0.12	0.16
110	0.12	0.12
120	0.11	0.11
130	0.11	0.11



Reference: Austroads – Rural Road Design (Part 4)

4. Horiz. Align. Continued…..

4. Minimum Radius Curves

9.5.1 Minimum Radius Values

The minimum radius of a horizontal curve for a given operating speed can be determined from the formula (9.1). It can be rearranged as follows:

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

where

R_{min} = *minimum radius (m)*
V = *operating speed (km/h)*
e_{max} = *maximum superelevation (m/m)*
f_{max} = *maximum coefficient of side frictional force developed between vehicle tyres and road pavements.*

Using the values for f_{max} from Table 9.1, the approximate minimum radii for various vehicle speeds for typical maximum superelevations are as shown in Table 9.2.

Table 9.2 Minimum Radii of Horizontal Curves
Based on Superelevation and Side Friction at Maximum Values

Operating Speed (km/h)	Km/h Minimum Radius m (rounded up)							
	Flat Terrain e = 3%		Undulating Terrain e = 6%		Rolling Terrain e = 7%		Mountainous Terrain e = 10%	
	Des min	Abs min	Des min	Abs min	Des min	Abs min	Des min	Abs min
50	60	52	56	40	53	47	49	44
60	105	79	95	73	91	71	83	66
70	175	113	154	104	148	102	133	94
80	265	173	229	157	219	153	194	140
90	315	219	335	245	319	236	277	213
100	525	415	437	358	414	342	-	-
110	635	635	529	529	501	501	-	-
120	810	810	667	667	-	-	-	-
130	950	950	782	782	-	-	-	-

9.5.2 On Steep Down Grades

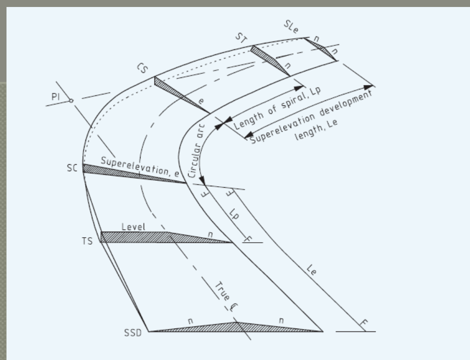
On steep down grades, the minimum curve radius from Section 9.5.1 should be increased by 10% for each 1% increase in grade over 3%.

$$R_{MIN\ on\ Grade} = R_{MIN\ from\ Table\ 9.2}\,[1 + (G - 3)/10]$$

where
G = grade (%)
R = radius (m)

Reference: Austroads – Rural Road Design (Part 4, Section 9)

5. Superelevation Development



5. Superelevation

Superelevation is the rotation of pavement from normal cross fall, (eg.-3%) to the superelevated cross fall.
There is a close relationship between Speed, Curve Radius & Superelevation.

The superelevation to be adopted is chosen primarily on the basis of safety.

How much (e_1) Super ?

$$e_1 = \frac{V^2 e_{max}}{127 R (e_{max} + f_{max})}$$

Figure 9.1(b): Relationship between Speed, Radius and Superelevation Based on Desirable Maximum f for e > 6% and a Linear Distribution of f for e ≤ 6%

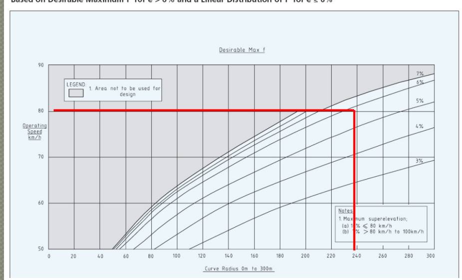
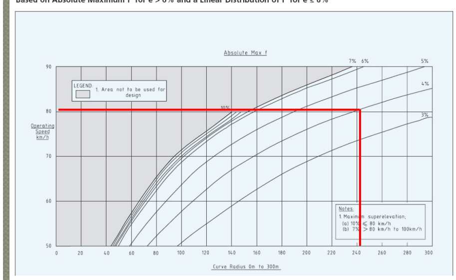


Figure 9.2(b): Relationship between Speed, Radius and Superelevation Based on Absolute Maximum f for e > 6% and a Linear Distribution of f for e ≤ 6%



Reference: Austroads – Rural Road Design (Part 4, Section 9)

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5. Super Continued…..

5. Development of Superelevation

- Rate of Pavement Rotation

The rate of rotation of 3.5% (0.035 radians/sec) per second is appropriate for operating speeds < 80 km/h:

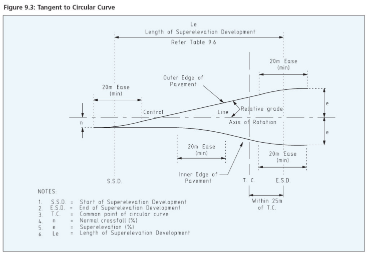
The rate of rotation of 2.5% (0.025 radians/sec) per second is appropriate for operating speeds ≥ 80 km/h:

$$L_{rr} = \frac{0.278(e_1 - e_2)V}{r}$$

where:

L_{rr} = superelevation development length (m) based on the rate of rotation criterion
e_1 = normal crossfall (%)
e_2 = full superelevation crossfall (%)
V = operating speed (km/h)
r = rate of rotation (% per second).

Figure 9.3: Tangent to Circular Curve



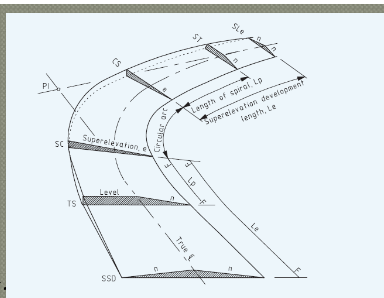
$$S_{ro} = L_e - L_e \left[\frac{e_1}{e_1 + e_2}\right]$$

$$T_{ro} = L_e - S_{ro}$$

where:

L_e = superelevation development length (m)
S_{ro} = superelevation runoff (m)
T_{ro} = tangent runout (m)
e_1 = normal crossfall (%)
e_2 = full superelevation crossfall (%)

A vertical curve may be used to ease the grade changes from crossfall to superelevation at the edges of the pavement and formation.



Superelevation Development Length

$L_{rr} = \frac{0.278\ (-3\ -\ +6)\ 80}{2.5}$ = 80.064m = 80m

- Superelevation Runoff 'Spiral' (Clothoid Transition Curves)

$S_{ro} = 80 - 80 \left[\frac{-3}{-3+6}\right]$ = 53.33m = 55m

Reference: Austroads – Rural Road Design (Part 4, Section 9)

6. Curve Widening

6. Widening of Lanes on Curves

Pavements may be widened on curves to maintain the lateral clearance between vehicles equal to the clearance available on straight sections of road. Widening is required for two reasons:

- A vehicle travelling on a curve occupies a greater width of pavement than it does on a straight as the rear wheels at low speeds track inside the front, and the front overhang reduces the clearance between passing and overtaking vehicles. (At high speeds the rear wheels track outside the front.); and

- Vehicles deviate more from the centreline of a lane on a curve than on a straight.

Use turning templates to determin tracking movements of vehicals at slow speeds.

Reference: Austroads – Rural Road Design (Part 4, Section 9)

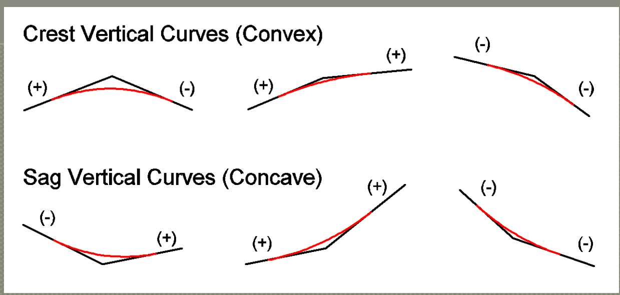
Table 9.10: Lane Widths on Curves in Mid-Block Sections

Vehicle Type			19m Semi Trailer	
Vehicle Width, u (m)			2.5	
No. of rigid units, n			2	
Wheelbase lengths (m)			5.4 & 9.5	
Ave. vehicle wheelbase, L (m)			7.45	
Front overhang, A (m)			1.6	
	2 lane-2 way		Multi-Lane	
Operating speed, V (km/h)	60	> 70	60	> 70
Radius, R (m)				
75	4.3		4.0	
100	4.1		3.8	
100 – 200	3.8	3.8		
> 200				

Notes:

- All lane widths have been calculated using 0.6m for the lateral clearance, C, and have been rounded up to the nearest 0.1 m
- (dark blue) Radii below absolute minimum radii for operating speed – not to be used. Refer Table 9.2
- (light blue) Lane widening is not required. A standard lane width of 3.5m is adequate.
- Where the operating speed is substantially < 60 km/h, lane widening should be calculated using the formula for Wc.

7. Vertical Alignment



7. Vertical Geometry

Vertical alignment is the longitudinal profile along the centreline of a road. It is made up of a series of grades and vertical curves.

The grades are generally expressed as a percentage (eg. –5%), vertical curves are parabolic in shape and are expressed as a K Value.

K = L (Curve Length) / A (Algebraic difference in Grade)   or   L = (K x A)

Increased road Grades cause speed disparities between vehicle types. This leads to queuing and overtaking requirements within design. Where posible designers should use lower values depending on local terrain.

Reference: Austroads – Rural Road Design (Part 4, Section 10)

Table 10.2: General Maximum Grades (%)

Operating Speed (km/h)	Terrain		
	Flat	Rolling	Mountainous
60	6-8	7-9	9-10
80	4-6	5-7	7-9
100	3-5	4-6	6-8
120	3-5	4-6	-
130	3-5	4-6	-

7. Vertical Continued…

7. Crest Vertical Curves

Safety or "Sight Distance" is the over riding factor in the vertical design of our roads. With a known SSD (Stopping Sight Distance) the correct K values (length of vertical curve) can be applied to ensure the safety of the driver.

On crests we need to achieve;

Table 10.3: Length of Crest Vertical Curves – Appearance Criterion when S < L

Operating Speed (km/h)	Minimum grade change requiring a crest vertical curve, % (1, 2)	Minimum length of crest vertical curve, m (3)	Minimum K Value (4) S < L
50	0.9	30 – 40	33 – 44
60	0.8	40 – 50	50 – 62
70	0.7	50 – 60	71 – 86
80	0.6	60 – 80	100 – 133
90	0.5	80 – 100	160 – 200
100	0.4	80 – 100	200 – 250
110	0.3	100 – 150	333 – 500

Note:
(1) In practice, crest vertical curves are frequently provided at all changes of grade.

Table 10.4: Minimum Crest Vertical Curve K Values, S < L. Refer Table 8.3(a) and 8.4

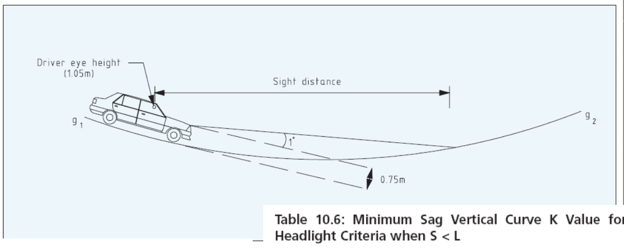
Operating Speed (km/h)	h_1 = 1.05m h_2 = 0.20m K value based on Stopping Sight Distance for Cars		h_1 = 2.4m h_2 = 0.20m K value based on Stopping Sight Distance for Trucks		h_1 = 1.05m h_2 = 1.05m Car to Car K value based on Overtaking Sight Distance for Cars
	R_T = 2.5sec	R_T = 2.0sec	R_T = 2.5sec	R_T = 2.0sec	R_T = 2.5sec
50	7	5	6	5	120
60	12	10	10	8	210
70	20	16	17	14	321
80	31	25	25	22	488
90	46	38	37	32	706
100	67	57	55	48	1008
110	98	84	85	75	1440
120	139	-	-	-	2010
130	197	-	-	-	2680

Note:
(1) Correction of Stopping Sight Distance for Grade Refer Table 8.3(a)
(2) Overtaking zones rarely occur on a single vertical curve, so the corresponding K value are rarely relevant

Reference: Austroads – Rural Road Design (Part 4, Section 10)

7. Vertical Continued…

Figure 10.1: Car Headlight Sight Distance on Curves



7. Sag Vertical Curves

Appearance is important when considering small and larger changes in grade (the same as for crest curves).

Sag vertical curves are generally designed to achieve the comfort criterion as a minimum.

A person subjected to rapid changes in vertical acceleration feels discomfort.

On sags we need to achieve;

Table 10.5: Minimum K Values for Sag Vertical Curves

Operating Speed (km/h)	K value	
	a = 0.05g	a = 0.1g
50	4	2
60	6	3
70	8	4
80	11	6
90	14	7
100	17	9
110	20	10
120	24	12
130	28	14

Table 10.6: Minimum Sag Vertical Curve K Value for Headlight Criteria when S < L

Operating Speed (km/h)	h = 0.60 m, q = 1°	
	Stopping Sight Distance	
	K value	
	Des. Min. R_T = 2.5 sec	Abs. Min R_T = 2.0 sec
50	10	8
60	14	12
70	19	17
80	25	22
90	32	29
100	41	37
110	50	46
120	62	57
130	72	66

Reference: Austroads – Rural Road Design (Part 4, Section 10)

8. Sight Distance Checks

8. Horizontal & Vertical Sight Distance

The principal aim in road design is to ensure that the driver is able to see any possible road hazards in sufficient time to take action to avoid mishap.

Adequate sight distance is essential for safe. The designer should consider the length of vertical curves, the radius of horizontal curves and the terrain on the inside of horizontal curves in providing adequate sight distance.

Stopping Sight Distance (SSD) is the distance to enable a normally alert driver, at the design speed on wet pavement, to perceive, react and brake to a stop before reaching a hazard on the road ahead. This distance is considered to be the minimum sight distance that should be available to a driver.

Figure 8.1: Sight Distance

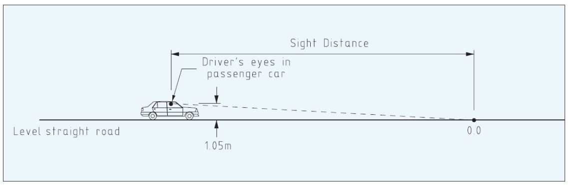
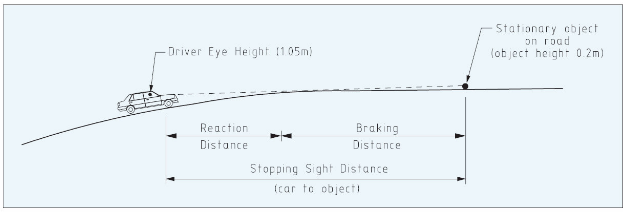


Figure 8.2: Stopping Sight Distance



Stopping sight distance has two components, namely the distance traveled during the driver's perception-reaction time and distance travelled during braking.

Reference: Austroads – Rural Road Design (Part 4, Section 10)

8. Sight Distance Continued…

8. Horizontal & Vertical Sight Distance

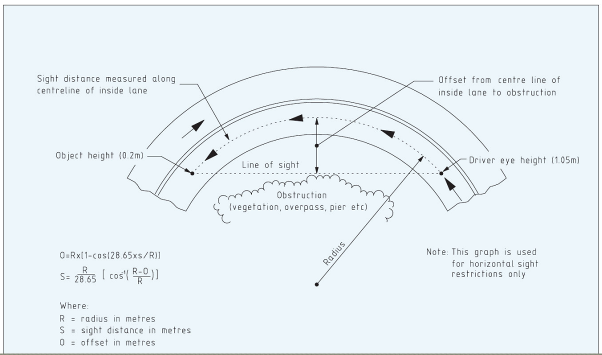
Table 8.3(a): Minimum Car Stopping Sight Distances (1.05m to 0.2m)

		Operating Speed (km/h)								
		50	60	70	80	90	100	110	120	130
Longitudinal Friction Factor		0.52	0.48	0.45	0.43	0.41	0.39	0.37	0.35	0.35
SSD	2.5 Des. min.	54	71	91	114	140	170	205	245	280
(m, level grade)	2.0 Abs. min.	47	63	82	103	128	157	190	229	262
Correction for Grade (m)										
Upgrade	2 %	-	-1	-2	-3	-4	-5	-7	-9	-11
	4 %	-1	-2	-4	-5	-7	-9	-13	-17	-21
	6 %	-2	-3	-5	-7	-10	-14	-18	-24	-31
	8 %	-3	-4	-7	-9	-13	-17	-23	-30	-38
Downgrade	- 2 %	-	1	2	3	4	6	7	10	14
	- 4 %	2	3	4	6	8	12	16	21	27
	- 6 %	3	4	7	10	13	18	25	34	44
	- 8 %	4	6	9	13	19	26	36	48	62

Note:

- *Desirable minimum stopping sight distances are calculated for a reaction time of 2.5 seconds and absolute minimum stopping sight distances are calculated for a reaction time of 2.0 seconds.*
- *Corrected stopping sight distances should be rounded conservatively to the nearest 5 metres.*

Figure 9.5: Horizontal Stopping Sight Distance



Reference: Austroads – Rural Road Design (Part 4, Section 10)

9. Co-ordination of Horizontal & Vertical Alignment

The operation of a road is influenced partly by terrain and the horizontal alignment. Therefore if these two factors are similar, the road will provide the best level of consistency in driver expectancy and thus safety.

Further, a road having both horizontal and vertical curvature carefully designed to conform to the terrain will result in the desirable aesthetic quality of being in harmony with the landform.

In flat open terrain, long straight road sections are common, but generally there is advantage in avoiding excessive lengths of straight road. A gentle curvilinear design helps to keep the operating conditions (speed) 'under control'.

Things to Note:
- The most pleasing three-dimensional result is achieved if the horizontal and vertical curvature is kept in phase,
- A small movement in one direction should not be combined with a large movement in the other.

Horizontal curves combined with crests have an effect on safety, as the crest can obscure the direction and severity of the horizontal curve. Minimum radius horizontal curves, therefore, should not be combined with crest vertical curves.

Perfect harmony of course is not always possible, and the designer must consider what matters are beyond control and make full allowance for their influence on driver behaviour.

Reference: Austroads – Rural Road Design (Part 1, Section 3)

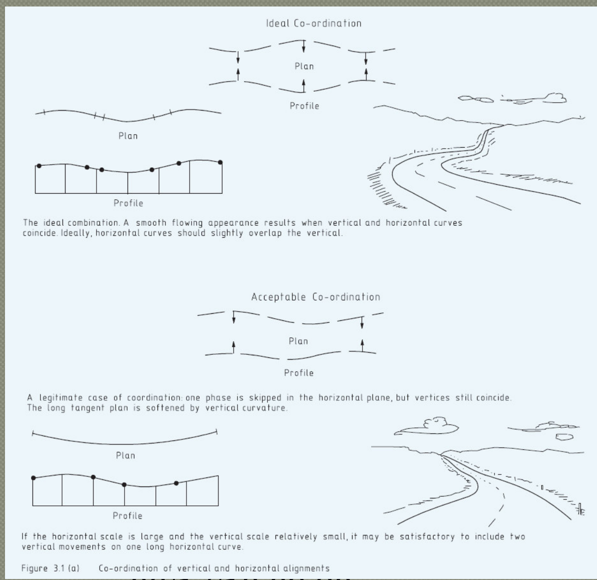


Figure 3.1 (a) Co-ordination of vertical and horizontal alignments

10. Earthwork Quantities

10. Earthworks Calculations

Earthworks is the process of excavating existing land to a subgrade level so that pavement construction can commence.

Earthworks normally consist of both cuts and fills. The aim is to minimise earthwork quanties and seek to balance the quantities.

Some points to remember in calculating earthwork quantities;

- The top-soil (stripping surface) is not suitable for areas of fill due to the organic matter it contains.
- Excavated material needs a "Bulking Factor" applied, as air voids now exist within previous compacted material.
- Material in areas of fill will need a "Shrinkage Factor" applied, as air voids are removed through compaction processes.
- The soil or material properties. "Ease of digging", removing sand or hard rock?

Earthworks alone can determine a project viability and the construction of a road design needs to consider where it's posible to reduce this cost.

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