Engineers Ireland

First Principles Road and Junction Design

NRA TD 9/12 Road Link Design

Road Link Design

- NRA TD 9/12 - current version being revised
- Major objective - ensure designs achieve value for money without significant effect on safety
  - greater flexibility to achieve economic and sustainable design in difficult circumstances
- Standard applies to - all new or improved National Roads
  - all roads affected by National Road Projects

Road Link Design

- Alignment Design
  - relates physical elements of road to requirements of driver
  - dependent on topography
  - nature of traffic
  - functional use of road
- Features
  - horizontal alignment
  - vertical alignment
  - cross section
  - junctions

Road Link Design

- NRA TD9 - Initially developed in UK in 1981
  - Hierarchy of permitted values for geometric parameters
  - Desirable Minimum Standards
  - Research
  - Various criteria
  - Maximum/minimum levels of provision
  - Desirable level of performance in average conditions (traffic safety, operation, economic & environmental effects and sustainability)
  - Relaxations or Departures

Design Speed Factors

- Alignment Constraint – Ac measures degree of constraint imparted by road alignment (bendiness/visibility)

  Dual carriageways: Ac = 6.6 + B/10

  Single carriageways: Ac = 12-Visi/60 + 2B/45

- Layout Constraint - Lc measures degree of constraint imparted by road cxs, verge width, frequency of junctions and accesses
- Mandatory Speed Limits – may be set at a lower speed than driver might naturally adopt

Design Speed

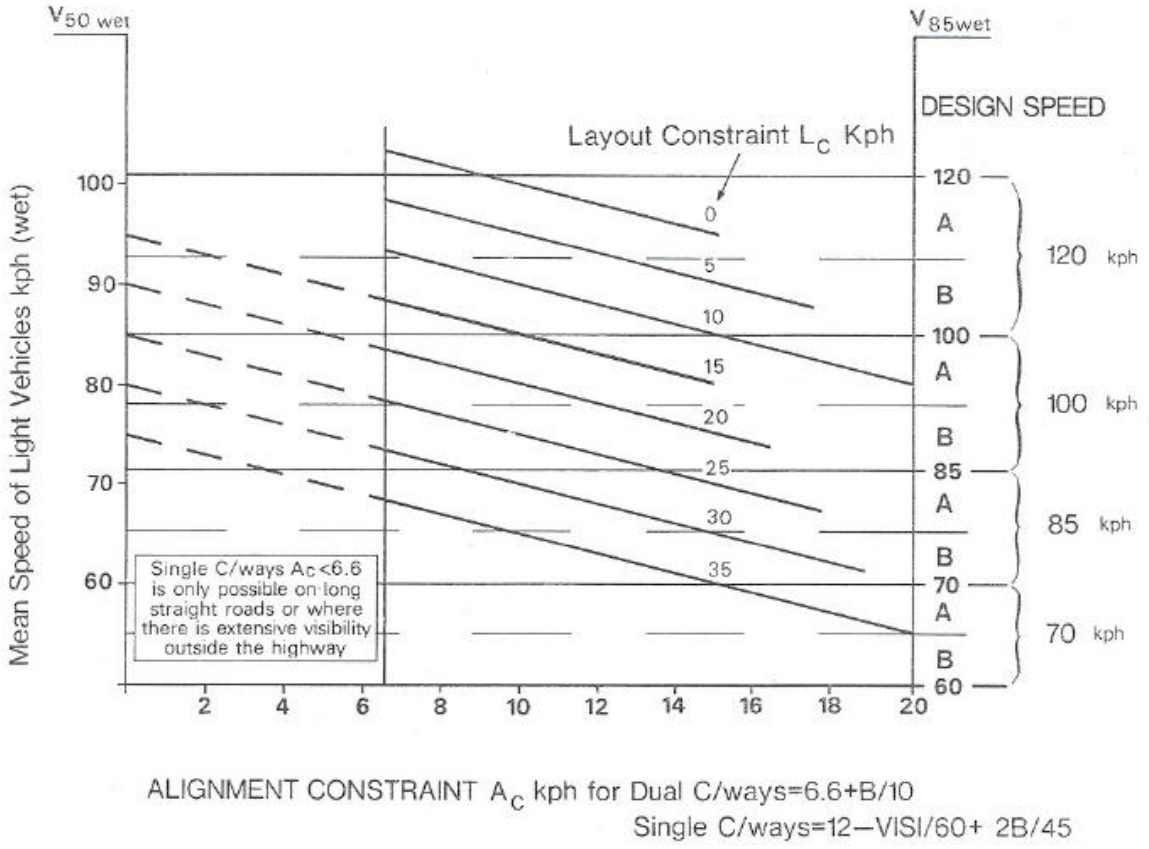


Figure 1/1

Design Speed

- Desirable Minimum Standards for Stopping Sight Distance (SSD), Horizontal Curvature, Vertical Curvature
- Relaxations at discretion of Designer where safe and justified
- Relaxation effectively is the Desirable Minimum Standard for the next lower Design Speed

Table 1/3

DESIGN SPEED (km/h)	120	100	85	70	60	50	V^2/R
STOPPING SIGHT DISTANCE m							
Desirable Minimum Stopping Sight Distance	295	215	160	120	90	70	
One Step below Desirable Minimum	215	160	120	90	70	50	
Two Steps below Desirable Minimum	160	120	90	70	50	50	
HORIZONTAL CURVATURE m							
Minimum R+ without elimination of Adverse Camber and Transitions	2880	2040	1440	1020	720	510	5
Minimum R+ with Superelevation of 2.5%	2040	1440	1020	720	510	360	7.07
Minimum R with Superelevation of 3.5%	1440	1020	720	510	360	255*	10
Desirable Minimum R with Superelevation of 5%	1020	720	510	360**	255**	180*	14.14
One Step below Desirable Min R with Superelevation of 7%	720	510	360	255**	180**	127*	20
Two Steps below Desirable Min R with Superelevation of 7%	510	360	255	180**	127**	90*	28.28
Three Steps below Desirable Min R with Superelevation of 7%			180	127**	90**	65*	40
Four Steps below Desirable Min R with Superelevation of 7%			127	90**	65**	44*	56.56
VERTICAL CURVATURE – CREST							
Desirable Minimum Crest K Value	182	100	55	30	17	10	
One Step below Desirable Min Crest K Value	100	55	30	17	10	6.5	
Two Steps below Desirable Min Crest K Value	55	30	17	10	6.5	6.5	
VERTICAL CURVATURE – SAG							
Desirable Minimum Sag K Value	53	37	26	20	13	9	
One Step below Desirable Min Sag K Value	37	26	20	13	9	6.5	
Two Steps below Desirable Min Sag K Value	26	20	13	9	6.5	6.5	
*** Absolute Minimum Vertical Curve Length to be used on Dual Carriageways	240	200	-	-	-	-	
OVERTAKING SIGHT DISTANCES							
Full Overtaking Sight Distance FOSD m.	N/A	580	490	410	345	290	
FOSD Overtaking Crest K Value	N/A	400	285	200	142	100	

Notes

+ Not to be used in the design of single carriageways (see Paragraphs 7.25 to 7.30).

The V2/R values simply represent a convenient means of identifying the relative levels of design parameters, irrespective of Design Speed.

K Value = Desirable Minimum curve length divided by algebraic change of gradient (%). Or Desirable Minimum curve length multiplied by the algebraic change of gradient (%) = K Value See Paragraph 4.5.

* For roads of design speeds 50km/h and less, a maximum superelevation of 3.5% shall apply.

** For roads of design speeds 60 km/h and 70km/h, a maximum superelevation of 5% shall apply.

*** Notwithstanding the minimum vertical curve K values contained in Table 1/3 for dual carriageways the selected K value shall be sufficiently large to ensure compliance with the Absolute Minimum Vertical Curve length indicated.

UK studies aimed at correlating personal injury accidents rates with geometric parameters show that accident rates do not significantly increase until difference from Desirable Minimum was considerable.

Desirable Minimum Standards may lead to disproportionately high construction costs or severe environmental impacts.

Desirable Minimum Standards design – produce a high standard of road safety and should be initial objective.

Hierarchy
- Desirable Minimum
- Relaxation
- Departure

Relaxations

- Limit defined by a given number of Design Speed steps below Desirable Minimum
- Vary according to type of road
- At discretion of designer, recorded, endorsed
- Combinations of Relaxations only permitted in certain circumstances set out in NRA TD 9
- Relaxations not permitted on immediate approaches to junctions (1.5 x Des Min SSD)

Departures from Standard

- In situations of exceptional difficulty which cannot be overcome by Relaxations, it may be possible to overcome them by adoption of Departures from Standard (third tier of hierarchy)

- Proposals to adopt Departures from Standard must be submitted to TII for approval before incorporation into a design layout

Sight Distance

- Stopping Sight Distance (SSD) – forward sight distance required by a driver to stop if encounters unexpected object/hazard on carriageway

- Full Overtaking Sight Distance (FOSD) – single carriageways, forward sight distance required for an overtaking vehicle when using the opposing carriageway

- Horizontal SSD – measured between any 2 points in the centre of the lane on the inside of the curve (for each carriageway on dual carriageways)

- Vertical SSD – Envelope of visibility is measured from a driver's eye height of between 1.05m and 2.00m, to an object height of between 0.26m and 2.00m above the road surface

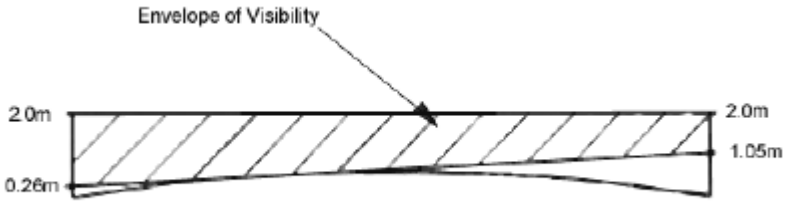


Figure 2/1

Sight Distance

Calculation of minimum distance required to stop a vehicle is based on evaluation of:

- Perception time – time which elapses from driver seeing object/hazard on carriageway to when he realises that he has to stop
- Reaction time – time taken to apply brakes
- Braking distance – distance travelled when braking

Sight Distance

Basic formula $SSD = vt + \frac{v^2}{2d}$

v = speed in m/s

t = driver perception time and reaction time (seconds)

d = deceleration (m/s^2)

NRA DMRB – desirable minimum SSD based on 2s perception – reaction time and deceleration rate of 0.25g ($g=9.81m/s^2$)

Sight Distance

FOSD – envelope of visibility measured between points 1.05m and 2.00m above the centre of the carriageway

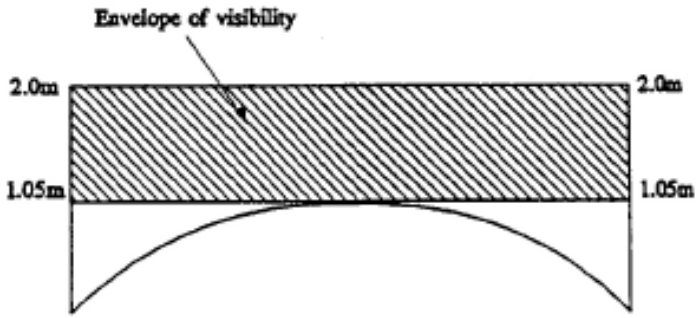


Figure 2/2

FOSD – provides a reasonable degree of safe overtaking for 85%ile

Sight Distance

Obstructions to sight distances

- Substantial fixed obstructions such as road signs
- Momentary obstructions such as lamp columns, sign supports, slim bridge supports (<550mm wide) can be ignored
- Lay-bys where possible to be sited on straights or outside of curves
- Safety barriers or bridge parapets on horizontal curves may obscure SSD to 0.26m object height although sight distance to high object is available above the barrier/parapet (relaxations permitted)

Horizontal Alignment

- Maximum comfortable speed on a horizontal curve is primarily dependent on radius of curve and superelevation of carriageway
- Vehicle speeds and safety on high speed roads are aided by features such as extra carriageway widths at curves and the insertion of transition curves between straights and curves

Any body moving rapidly along curved path is subject to outward reactive force called centrifugal force. On road curves this force tends to cause vehicles to overturn or to slide outward from the centre of the road curvature.

Centrifugal force also tends to cause a vehicle to overturn, acting through the centre of gravity of vehicle causes an overturning movement about points of contact between the outer wheels of the vehicle and carriageway surface. Overturning moment is resisted by a righting moment caused by weight of vehicle acting through its centre of gravity.

Superelevation

- In order to resist outward acting centrifugal force it is usual to superelevate or slope the carriageway

- For every combination of curve radius and design speed there is a superelevation rate to balance the centrifugal force

$$S = \frac{V^2}{2.828 \times R}$$

- Rural roads, superelevation shall not exceed 7%

- Urban roads with at-grade junctions, superelevation is limited to 5%

- Regional and local road limits identified in Table 11/3

Superelevation

- Not be introduced so gradually as to create large almost flat areas of road pavement, nor so sharply as to cause discomfort or to kink the edges of the road pavement
- Carriageway edge profile not to vary in grade by more than 1% from that of the line about which the carriageway is pivoted (0.5% for motorways and dual carriageways)
- Ensure a minimum longitudinal gradient of 0.5% min along length of road pavement where superelevation is to be applied or reversed
- Where superelevation is applied against longitudinal gradient:
  - May be necessary to modify the horizontal alignment to move the superelevated area
  - Increase the variation in grade of edge profile
  - Apply a rolling crown

Horizontal Alignment

- Pavement widening at horizontal curves is required on low radius curves to allow for swept path of long vehicles
- Standard carriageway width (3.5, 3.65 or 3.75m), each lane shall be widened to 3.95m where radius is between 90m and 150m
- Standard carriageway lane width, each lane shall be widened 0.15m where radius between 150m and 1000m up to 3.65m max lane width
- Less than standard carriageway widths, all lanes widened 0.6m if radius between 90m and 150m, 0.5m where radius is between 150m and 300m or 0.3m per lane where radius between 300m and 400m subject to maximum carriageway widths
- No widening at curves is to be provided on narrow two way roads without lane markings (<5.3m) as may encourage passing on the bend.

Radii less than 90m on the mainline are Departures from Standard

Extra width shall be applied uniformly along transition curve

Transitions

- A vehicle cannot instantaneously change from a straight path to a circular path of constant radius
- Usual practice to use a transition curve changing radius from infinity at start to that of the circular curve at the end
- Enable vehicles moving at high speeds to make the change from the straight section to the curved sections in a safe and comfortable manner
- Proper introduction of transition curves will provide a natural path for motorists so that the centrifugal force increases gradually as the vehicle enters the circular curve

Transitions

- Required for radii less than ‘Minimum R without elimination of adverse camber and transitions’ in Table 1/3

- Superelevation or elimination of adverse camber shall generally be applied on or within length of the transition curve

- If transition length cannot accommodate superelevation turnover, then longer transitions should be provided to match superelevation design

Vertical Alignment

Series of gradients connected by vertical curves. Gradients normally expressed by %, positive ascending to right and negative when descending to right.

Desirable max gradients are:

3% - Motorways and Type 1 Dual Carriageways

4% - Type 2 and 3 Dual Carriageways

5% - Type 1 and 2 Single Carriageways

6% - Type 3 Single Carriageways

7% - Other local roads

- Maximum grade with Relaxation is 1% higher
- Departure from Standard required to use steeper gradients
- Minimum gradient for effective drainage with kerbed roads is 0.5%
- In flatter areas, false channels, surface water channels, filter drains or over the edge drainage should be used. Vertical alignment should not be manipulated by introduction of vertical curvature simply to achieve adequate surface water drainage

Vertical Alignment

- Vertical curves used to change from one gradient to another, large enough to provide for comfort and sight distance
- Use of permitted vertical curve parameters in Table 1/3 will normally meet the requirements of visibility. SSD shall always be checked because horizontal alignment, crossfall, superelevation, verge treatment and other features adjacent to carriageway will affect interaction between vertical curvature and visibility
- Vertical curves expressed as ‘K values’ where 100K ≈ curve Radius
- Minimum curve length is determined by multiplying K value by algebraic change of gradient (%)
- Crest curves – choice affected by visibility and comfort - Table 1/3 Des Minimum Crest will restrict forward visibility to the Des Min SSD before minimum comfort criteria are approached

Vertical Alignment

- Use of crest curves with K values greater than Des Min but less than FOSD on a single carriageway in combination with straight or nearly straight horizontal alignment is a Departure from Standard
- Sag curves – can affect night-time visibility on unlit roads
- Relaxations below Desirable Minimum permitted set out in paras 4.9-4.19
- Relaxations below Desirable Minimum not permitted on immediate approaches to junctions.

Climbing Lanes

- Additional lane to improve capacity and/or safety because of presence of steep gradient

- Single carriageway roads, consider if can be justified on hills with gradients >2% and longer than 500m

- Dual Carriageway roads, consider if can be justified on hills with gradients >3% and longer than 500m

- Need for and justification, appraisal of effects should consider economy, environment and safety

- Major/minor junctions & direct accesses onto National Roads shall not be located on climbing lane sections

Climbing Lanes - Criteria for Provision:

- Single carriageway without hard shoulders or with narrow hard shoulders use Figure 5/1

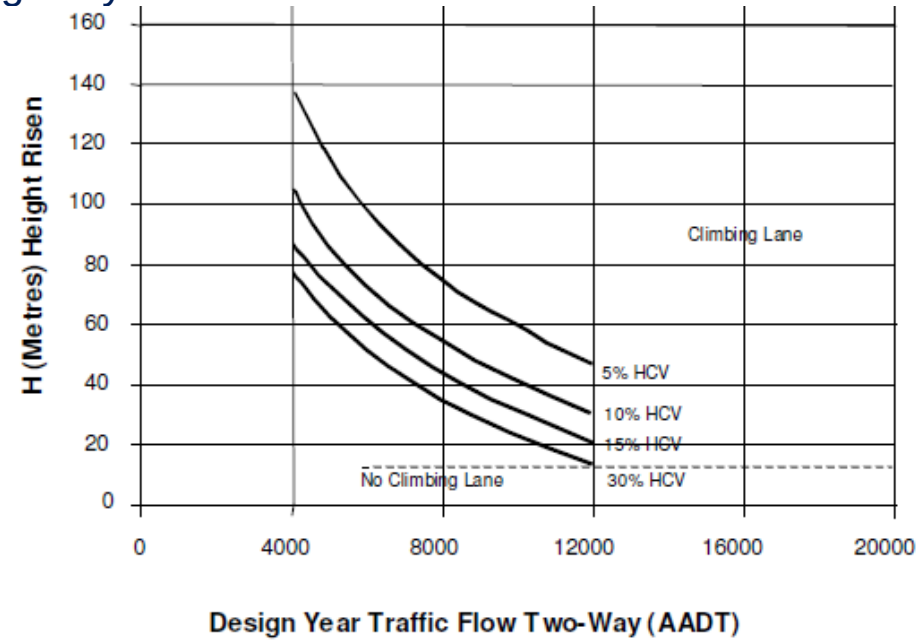
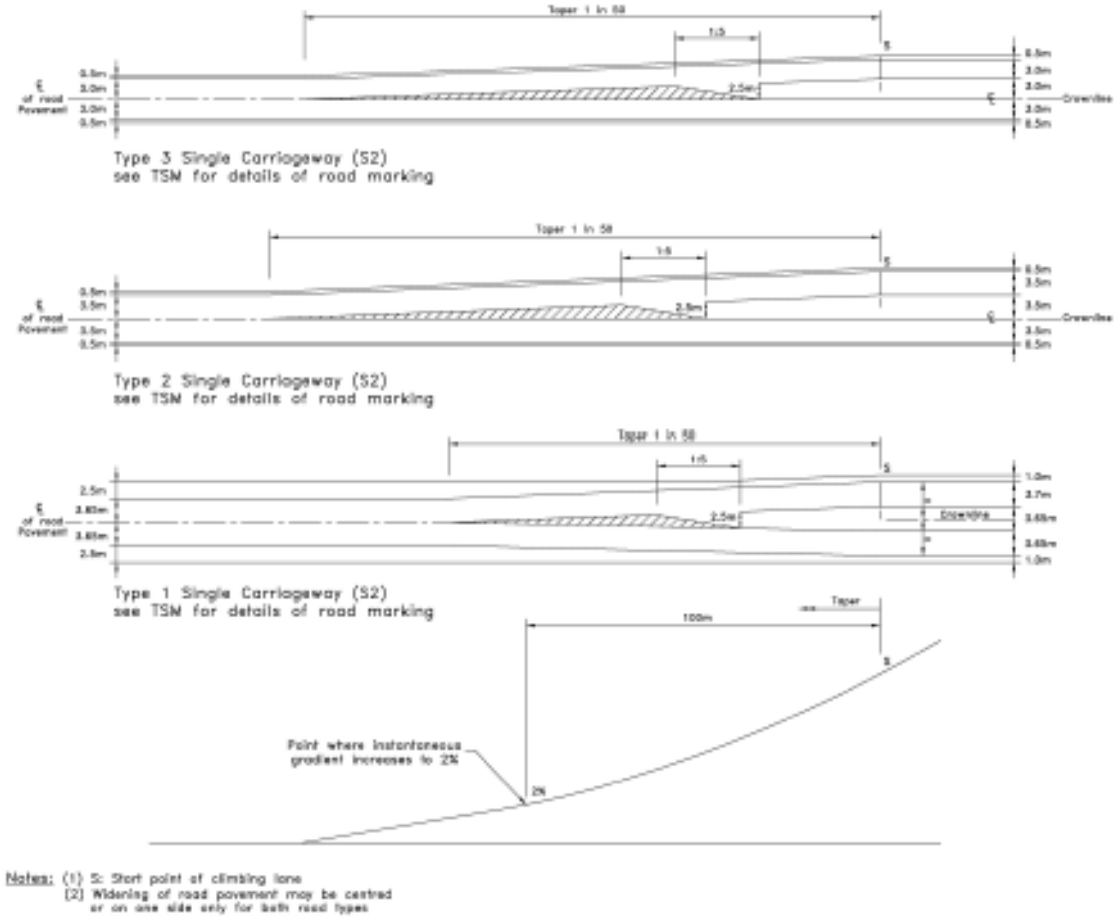


Figure 5/1

- Single carriageway with full width hard shoulders (2.5m or more), the climbing lane should replace the hard shoulder – generally provided where gradient >2% and risen height exceeds 15m and design year traffic flow >6,000 AADT

Climbing Lane

- Alignment at commencement shall encourage drivers to follow the nearside channel unless overtaking



Notes: (1) S: Start point of climbing lane
(2) Widening of road pavement may be centred or on one side only for both road types

Figure 5/4

Climbing Lane

- End of climbing lane – full width maintained until point ‘F’ at least 200m beyond the point where gradient reduces to 2% at crest curve, then 1:150 taper for lane marking with greatest lateral shift

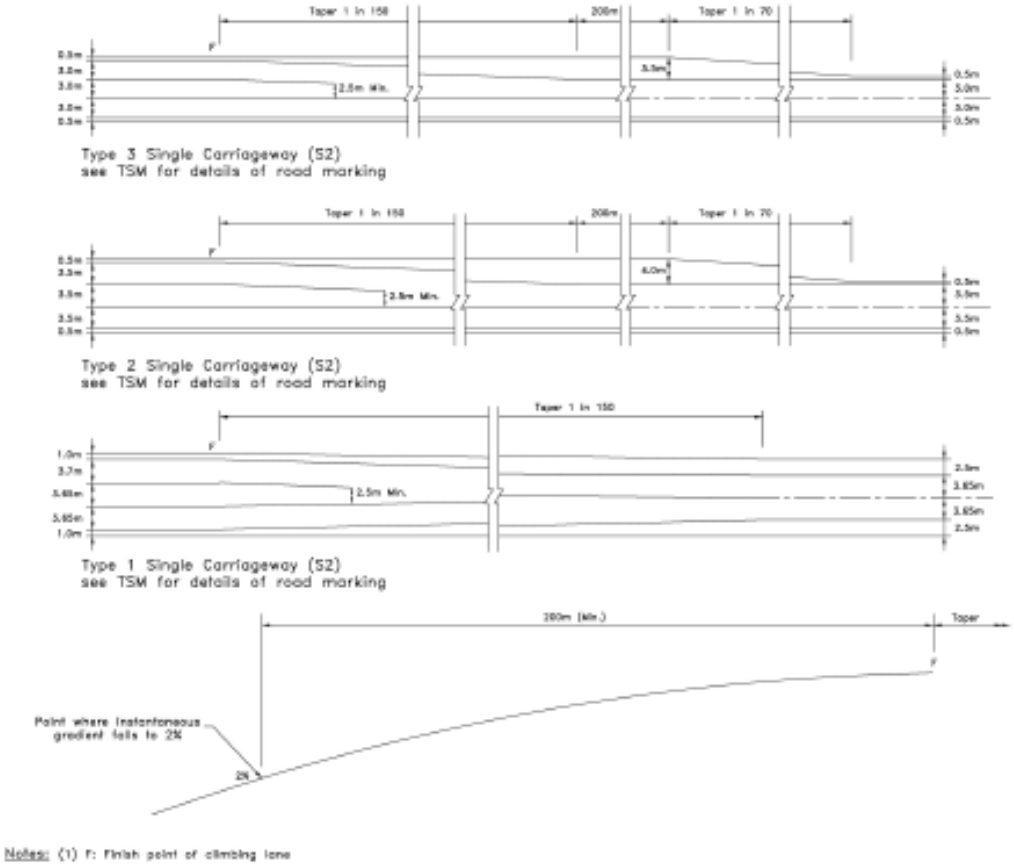


Figure 5/5

Climbing Lanes

- Alignment at end shall place onus on the driver in the right hand lane to re-join the continuing lane

- Return to single lane should not coincide with junctions or a sharp curve

- Climbing lanes on single carriageways do not require FOSD but Desirable Minimum SSD shall be provided (1 step relaxation may be provided in difficult circumstances)

- Criteria for climbing lanes for Dual Carriageways and Motorways see paragraphs 5.39 to 5.47 of NRA TD 9

Recommended Rural Road Layouts

Type of Road [1]	Capacity[2] (AADT) for Level of Service D	Edge Treatment	Access Treatment	Junction Treatment at Minor Road	Junction Treatment at Major Road
Type 3 Single (6.0m) Carriageway (S2)	5,000	0.5m hard strip. Footways/Cycle Tracks where required,	Minimise number of accesses to avoid standing vehicles and concentrate turning movements.	Simple Priority Junctions	Priority junctions, with ghost islands where necessary.
Type 2 Single (7.0m) Carriageway (S2)	8,600	0.5m hard strips. Footways/Cycle Tracks where required	Minimise number of accesses to avoid standing vehicles and concentrate turning movements.	Priority junctions, with ghost islands where necessary.	Ghost islands
Type 1 Single (7.3m) Carriageway (S2)	11,600	2.5m hard shoulders Footways/Cycle Tracks where required	Minimise number of accesses to avoid standing vehicles and concentrate turning movements.	Priority junctions, with ghost islands where necessary.	Ghost islands or roundabouts [3]
Type 3 Dual [4] (7.0m + 3.5m) Divided 2+1 lanes Primarily for retro fit projects	14,000	0.5m hard strips.	Minimise the number of accesses to avoid standing vehicles and concentrate turning movements.	Restricted number of left in/left out or ghost priority junctions.	Priority junctions or at-grade roundabouts.
Type 2 Dual [4] Divided 2 +2 Lanes (2x7.0m) Carriageways. ()	20,000	0.5m hard strips	No gaps in the central reserve. Left in / Left out	No gaps in the central reserve. Left in / Left out	At-grade roundabouts and compact grade separation
Type 1 Dual Divided 2+2 Lanes (2x7.0m) Carriageways ()	42,000	2.5m hard shoulders	No gaps in the central reserve. Left in / Left out	No gaps in the central reserve. Left in / Left out	At-grade roundabouts and full-or compact grade separation.
Standard Motorway Divided 2 +2 Lane (2X7.0m) (D2M)	52,000	2.5m hard shoulders	Motorway Regulations	No gaps in the central reserve.	Motorway standards Full-grade separation.
Wide Motorway Divided 2+2 Lane (2X7.5m) (D2M)	55,500	3m hard shoulders	Motorway Regulations	No gaps in the central reserve	Motorway standards Full-grade separation.

Notes:

1. For details of the standard road cross-sections, see NRA TD 27, NRA TD 10 'Type 2 and Type 3 Dual Carriageways' and Road Construction Details Series 000.
2. Capacity figures are indicative for general guidance. The appropriate cross section shall be selected in accordance with the NRA Project Appraisal Guidelines
3. Single lane dualling may be appropriate in some situations, but would be a Relaxation (see NRA TD 41-42).
4. See NRA TD 10 'Type 2 and Type 3 Dual Carriageways'
5. Refer to TA 79 for Urban Road capacities.

Table 6/1

Two-way Single Carriageway Roads

- Objectives of safety and uncongested flow

- Provision of frequent overtaking sections for either direction of travel enables vehicles to maintain design speed in off-peak conditions

- Use of mid-large radius curves produce long dubious overtaking conditions for vehicles travelling in the left hand curve direction

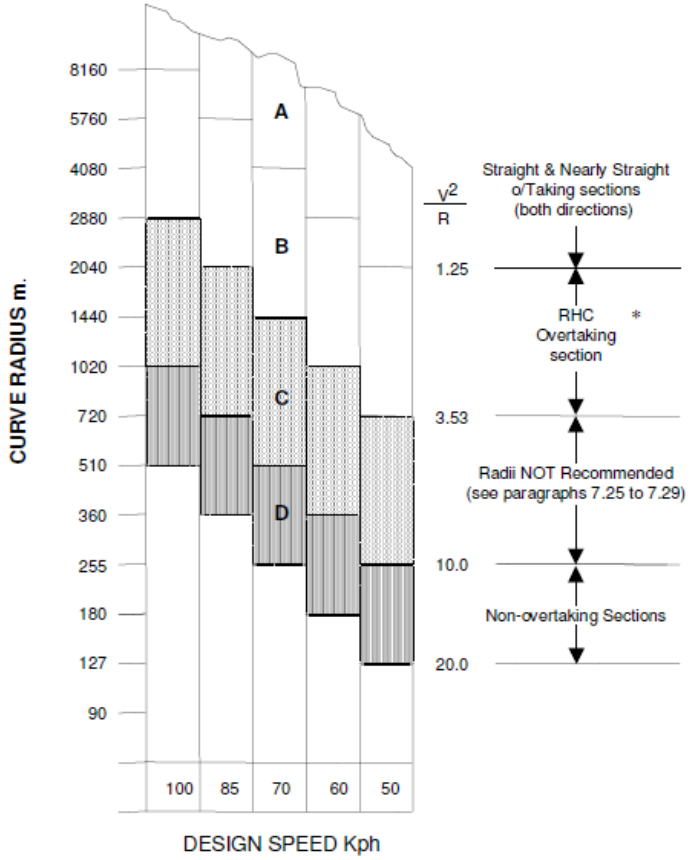


Figure 7/6

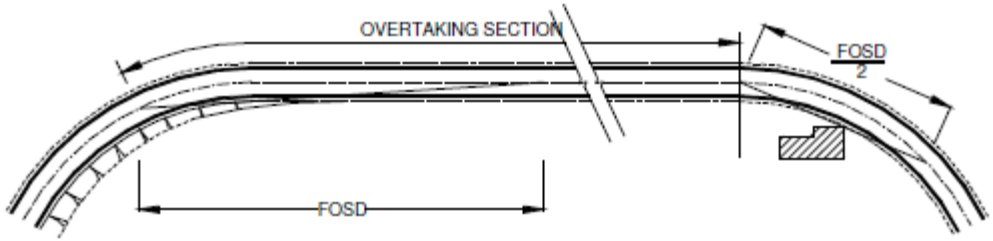
- Wherever possible overtaking sections should be provided as straight or nearly straight (Band A), overtaking section for both directions
- Band B curves will result in right hand curve overtaking sections
- Band C curves not recommended, provide long sections with dubious overtaking conditions for LHC traffic
- Band D – non overtaking sections

Two-way Single Carriageway Roads

- Vertical alignment shall be co-ordinated with horizontal alignment to ensure most efficient overtaking provision
- Vertical curvature shall be sufficient to provide FOSD on overtaking sections
- Unless FOSD is provided, crest K value shall not be greater than that for 1 step below Des Min
- Use of crest K greater than 1 step below Des Min and up to Des Min is not preferred but may be used as a Relaxation
- Use of crest K values greater than Des Min but less than FOSD overtaking crest is considered to be a Departure from Standard – provides dubious visibility for overtaking
- Crest K on immediate approaches to junctions shall not be less than the Des Min

Overtaking Sections

- Combination of HA and VA, visibility or width provision is such that clear opportunities for overtaking will occur
- Commence when FOSD is achieved or width provision is sufficient for overtaking without crossing dividing line between opposing carriageways
- Terminate where sight distance reduces to FOSD/2 when approaching a non-overtaking section or at a distance of FOSD/4 prior to an obstruction to overtaking (major/minor junctions with ghost islands, single lane dualling or roundabouts)



For details of road markings at non-overtaking curves see Paragraph 7.43

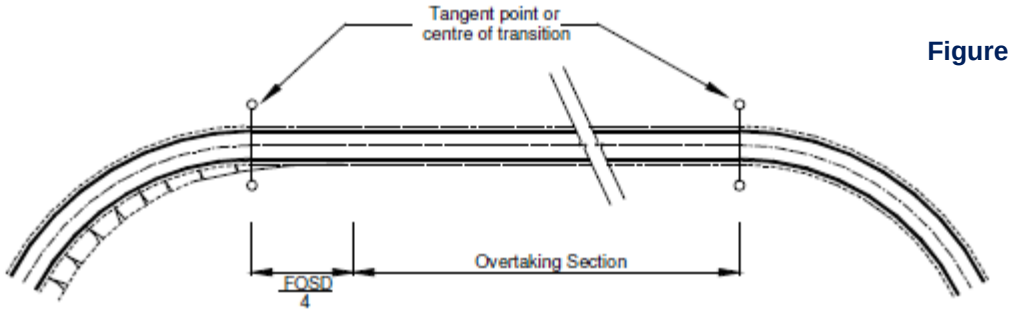


Figure 7/1

Overtaking Sections

- Overtaking value on Rural Roads shall be a minimum of 15% on Types 2 and 3 single carriageways and 30% on Type 1 single carriageway

- Sight distance analysis carried out for each direction of travel. Total length of overtaking sections for each direction summed and divided by total length of road improvement to obtain the value in each direction

- Distributed along scheme so that no Non-overtaking section exceeds 3km

Overtaking

Possible means of improving overtaking value:

- Modify junction strategy by stopping up, bridging or diverting side roads
- Adjust alignment to produce more straight sections
- Introduce climbing lanes on hills previously not considered justified
- Introduce roundabouts at more heavily trafficked priority junctions to create sharper changes in direction
- Introduce more extensive sections of single 4 lane or dual carriageway
- Existing roads without hard shoulders, introduce lengths of Type 1 single carriageway with hard shoulders at suitable locations

Dual Carriageways & Motorways

- Designed to permit light vehicles to maintain Design Speed

- Light vehicles can overtake slower moving vehicles without conflict with opposing traffic

- No limitation on use of horizontal or vertical curves in excess of values for 1 step below Des Min

- Co-ordination of design elements mainly involves the design and optimisation of aesthetic alignments

- Smooth flowing alignment required for sustained high speeds

Dual Carriageway and Motorway - Principles

- Embankments and cuttings should not make severe breaks in the natural skyline
- Road should be on a curve when negotiating a ridge in cutting or passing through a woodland so as to preserve unbroken background
- Short horizontal curves and short straights should not be used, need to be reasonably long to avoid disjointed appearance
- Adjacent curves should be similar in length
- Small changes in direction should not be made as they give the perspective of the road ahead a disjointed appearance
- Curves of same or opposite sense which are visible from one another should not be connected by a short straight

Dual Carriageway and Motorway - Principles

- Changes in horizontal and vertical alignment should be phased to coincide whenever possible (HA <2000m, VA <15,000m)
- Flowing alignment can most readily be achieved by using large radius curves rather than straights
- Profile of road overbridges must form part of the easy flowing alignment
- At start of horizontal curves, superelevation must not create flat areas and must not create kinks in the vertical alignment
- Horizontal and vertical curves should be as generous as possible at interchanges to enhance sight distances
- Sharp horizontal curvature should not be introduced at or near top of pronounced crest – hazardous especially at night because driver cannot see change in HA
- View of road ahead should not appear distorted by sharp horizontal curvature introduced near low point of sag curve

Motorways

- Same principles apply

- Horizontal and vertical curves should be as generous as possible throughout

- To relieve monotony of driving on a road with good extensive forward visibility, long sections of the road should be aligned to give a view of some prominent feature ahead

Emergency Accesses

- Motorways and Type 1 Dual Carriageways
- Minimum frequency specified in Table 8/1 based on AADT, distance between junctions
- Either break in central reserve barrier as Emergency Crossing Point (ECP) or Emergency Access Link (EAL) to connect to local road

Design Year AADT	Distance between Junctions (km)						
		<5	≥5<10	≥10<15	≥15<20	≥20<25	≥25<30
≥50,000	Emergency Access Provisions	1	2	3	4	5	6
		<5	≥5<10	≥10<15	≥15<20	≥20<25	≥25<30
<50,000	Emergency Access Provisions	0	1	2	3	4	5

Table 8/1

Regional and Local Roads

- To improve safety, overtaking is discouraged for Regional and Local Roads with design speed ≤ 50km/h – no overtaking sight distances included in Table 11/3
- Max gradients same as previously
- In general the policy for Relaxations and Departures shall be that adopted for national roads as set out in NRA TD 9, except for:
    - Crest curve K value Relaxation of 1 design step below Des Min will generally result in reduction in SSD to a value 1 design step below Des Min, which would also require a relaxation. This is permitted and will not require a departure when applied on Regional and Local Road
    - Where site specific circumstances dictate, transitions may be omitted at low speeds ≤ 60km/h – not considered a relaxation

Regional and Local Roads

- Progressive superelevation be achieved over or within length of transition curve from arc end. Roads without transitions, between $^{1}l_{2}$ and $^{2}l_{3}$ shall be introduced on approach straight and remainder at beginning of curve use of ‘q’ value of 0.6 permitted on Regional and Local Roads – not a relaxation
- Relaxations below Des Min R, no. of steps permitted is 4 steps