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Chapter 15

Auxiliary Lanes

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Chapter 15 Amendments - April 2002

Revision Register

Issue/ Rev No.	Reference Section	Description of Revision	Authorised by	Date
1		First Issue.	Steering Committee	Aug 2000
2	15.3.3	Table 15.1 revised; clarification of text made.	Steering Committee	Feb 2002
	15.3.4	Additional paragraph added to provide for road train routes to adopt the normal maximum as the minimum; "Absolute minimum", "Desirable Minimum" terms introduced.		
	15.4	Figure 15.1 - note added regarding the use of VEHSIM for more accurate results.		
	15.6	Maximum length added in the fIrst paragraph; details of design clarified.		
	15.7	Consistent symbol used for "grade" and consistent definition adopted; appropriate changes to formulae made; second last paragraph of 15.7.5 amended.		
	15.7.4	Note added to section 'Arrester Beds'; added sentence re need to "fluff up" the material in the arrester beds.		
	15.8.1	1st paragraph - eye height changed to 1.15m; eye height - change back to 1.15m to be consistent with the rest of the manual; sight distance to start and end points - Additional material and changes to Table 15.8 (now 15.8A and 15.8B).		
	15.8.2	Formula for taper length should have a divisor of 3.6; Merge taper - formula changed to precise figures and changes made to Table 15.9.		
	15.8.3	Figure 15.6 modified; additional dot point provided to allow overlapping overtaking lanes and giving conditions; Figure 15.6 - Approach taper shoulders modified - no extra widening opposite the start of the diverge; additional note on Figure 15.6 reinforcing the need to adopt line marking from "Guide to Pavement Markings".		
	15.9	Right turns at overtaking lanes - New section to provide guidance on design of right turns associated with overtaking lanes.		
	15.9.1	Additions after 1st paragraph.		
	15.10.1 (old 15.9.1)	Signing and marking - Additional words to strengthen the section and to address marking between the two directions.		
	New	Relationship to Other Chapters.		
3	15.3.4	Table 15.3 revised.	Steering Committee	Apr 2002
	15.4.3	Table 15.9 revised.		
	15.8.3	Figure 15.6 modified.		

Chapter 15
Auxiliary Lanes

15.1 General

Auxiliary lanes are those added adjacent to the through lanes to enhance traffic flow and maintain the required level of service for the road in question. They are usually of relatively short length and can be referred to as speed change lanes, acceleration lanes, deceleration lanes, overtaking lanes, climbing lanes, descending lanes and passing bays. In addition, emergency escape ramps (runaway vehicle facilities) are included in this category. In this text, weaving lanes are not treated as auxiliary lanes but as part of the required cross section of a motorway where weaving conditions occur (see Chapter 4).

Auxiliary lanes are used to remove traffic that is causing disruption to the smooth flow of traffic in the through lanes to a separate lane to allow the through traffic to proceed relatively unhindered by the disruption. They are a means of separating the elements of the traffic stream on the basis of the speed difference between them, thereby improving the safety of the road as well as its capacity and the level of service provided.

15.2 Speed Change Lanes

15.2.1 Acceleration Lanes

Acceleration lanes are provided at intersections and interchanges to allow an entering vehicle to access the traffic stream at a speed approaching or equal to the 85th percentile speed of the through traffic. They are usually parallel to and contiguous with the through lane with appropriate tapers at the entering point. Acceleration lanes are almost always on the left-hand side of the through lanes although in certain circumstances, they can be on the right (seagull intersections, direct entry ramps at interchanges).

Details of the requirements for acceleration lanes are given in Chapter 13 Intersections, and Chapter 16 Interchanges.

15.2.2 Deceleration Lanes

Deceleration Lanes are provided at intersections and interchanges to allow an exiting vehicle to depart from the through lanes at the 85th percentile speed of the through lanes and decelerate to a stop, or the 85th percentile speed of the intersecting road, whichever is appropriate for the circumstances.

At intersections, the deceleration lane can be placed on either the right or the left of the through lanes, depending on the type of turn being effected. At interchanges, it is preferred that the exit be from the left side for most ramps and the deceleration lane will therefore be on the left in most cases.

Details of the requirements for deceleration lanes are given in Chapter 13 Intersections and Chapter 16 Interchanges.

15.3 Overtaking Lanes

Two lane two-way roads can only operate satisfactorily in most practical circumstances if adequate opportunities for overtaking are provided. These opportunities may occur through the geometric design providing adequate sight distance but as traffic increases, these opportunities gradually disappear and increasingly long queues (bunches) occur.

Overtaking lanes are provided to break up bunches and improve traffic flow over a section of road. They provide a positive overtaking opportunity and are sometimes the only real chance for overtaking to occur.

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15.3.1 Overtaking Demand

The demand for overtaking occurs each time a vehicle catches up with another and the driver desires to maintain the speed of travel. Provided there is no approaching traffic, this manoeuvre can occur at will where there is adequate sight distance. As traffic volume increases, the approaching traffic will restrict the available places where overtaking can occur and these will be further limited by the geometry of the road.

If demand is not met, enforced following occurs, queues or bunches form and drivers experience frustration and delay. The proportion of travel time spent following in bunches is a useful measure of quality of service as seen by the driver.

Typical situations that cause this to occur include slow trucks (frequently on grades) and that part of the traffic stream desiring to travel at a speed less than the other drivers do. Types are:

- Vehicles with fairly high desired speed of travel but which slow down appreciably on grades;
- Vehicles with low desired speeds, not affected by grades; and
- Vehicles with average speeds, but which are seen to be slow by those wishing to travel faster.

The type of slow moving vehicle influences the nature of the overtaking demand. Some vehicles can be overtaken easily anywhere along the route, while for others, an up grade opportunity is desirable. In deciding on the appropriate form of overtaking lane, the type of slow vehicles involved must be considered, as well as whether the overtaking demand is continuous along the route or whether it is confined to a specific location.

15.3.2 Overtaking Opportunities

On two lane roads overtaking opportunities depend on sight distance available as well as gaps in the approaching traffic stream. As opposing traffic volume increases, the availability of gaps declines and the chance of coincidence of the gap with an appropriate sight distance becomes increasingly remote. The apparent number of opportunities can also be reduced by the size of the vehicle in front obscuring the sight line, particularly on left-hand curves.

On an existing road, overtaking opportunities can be improved by improving the alignment or by providing an auxiliary lane. The latter is often the most cost effective, particularly if the additional lane can be constructed in an area of lower construction costs. In addition, even if the geometry is improved to increase the opportunities, the opposing traffic may prevent them being realised. Simulation studies by ARRB showed that providing auxiliary lanes at regular spacing often led to greater improvements in overall traffic operations than even major alignment improvements.

A two lane road with overtaking lanes provides a level of service intermediate between that of two lanes and four lanes. The overtaking lane therefore offers an economical and practical method of improving traffic flow and thus deferring the need for more extensive up grading to dual carriageways. Additional lanes are sometimes required on dual carriageways where traffic volumes have reached a level where the level of service is unduly affected by the performance of trucks and other vehicles on grades.

15.3.3 Warrants

In deciding on whether an overtaking lane is warranted, the analysis should be undertaken over a significant route length and not be isolated to the particular length over which the additional lane may be constructed. Overtaking opportunities outside the particular length can affect the result considerably. On multi lane roads, this may not apply since the reason for the extra lane will usually be confined to a specific location.

The following guidelines have been taken from Austroads (1989) and are based on research undertaken by ARRB using traffic simulation and cost benefit analysis. An alternative method is to base the decision on an analysis of level of service. A more detailed analysis can be undertaken by using traffic simulation (TRARR) and applying the Main Roads Cost Benefit Analysis Manual for Road Infrastructure Investment.

Traffic data for use in the simulation model must be in terms of hourly volumes at the minimum and in terms of half hourly volumes if possible to ensure that the peak conditions are properly modelled. In addition, this will give better knowledge of the directional split of traffic at the critical times of the analysis. It is common to use the hundredth highest hour as the design hour in these analyses but the actual pattern of traffic distribution should be examined to determine whether a different hour would more closely reflect the operations being considered.

These factors create the delays to drivers conveniently measured by the "percent time following" – the parameter used as the basis for assessing the level of service on the road. TRARR modelling will produce the expected level of service for the road being analysed and a judgement can be made as to the acceptability of that level of service.

Table 15.1 sets out the level of service for two-lane two-way roads that corresponds to 'percent time following' .These level of service criteria are taken from the Highway Capacity Manual (TRB 2000). They are also very close to the criteria that have been used for TRARR studies since 1998 (see Cox 1999, 2001). For rural roads, the desired level of service would be "C" for the peak conditions with a level of service of "B" for the rest of the day. For National Highways, level of service B should be provided for the 100th highest hourly volume in the design year.

When two-lane two-way roads have overtaking lanes or short sections of divided road that are nominally spaced at less than 10km, the proportion of the road with additional lanes starts to become significant. Certainly, this is the case when the nominal spacing is about 5km. At the same time, bunching is not the appropriate criterion for measuring level of service within the sections with an additional lane. Cox (2001) describes how a combined (or weighted) measure may be used for these roads. Typically, the combined (or weighted) measure will yield a better level of service and/or show that the level of service can be sustained over a larger traffic volume increase.

In the absence of a study based on the TRARR modelling, the approach described in Austroads (1989) may be used. In this case, the basis for adopting an overtaking lane is the traffic volume, the percentage of slow vehicles (including light trucks and cars towing) and the availability of overtaking opportunities on adjoining sections. The percentage of road allowing overtaking is described in Chapter 9 Sight Distance.

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Table 15.1 Percent Time Following Limits for Level of Service

Level of Service	Class 1 Roads (a), (b)		Class 2 Roads (a), (b)
	% Time Following TRB 2000	Average Travel Speed (km/h)	% Time Following TRB 2000
A	≤35	>90	≤40
B	≤50	>80	≤55
C	≤65	>70	≤70
D	≤80	>60	≤85
E	≤80	≤60	>85

(a) For Class 1 roads, both the % time following and the average speed criteria must be met for a given level of service. This means for example if the % time following is in the range of level of service B but the average speed is in the range of level of service C, then the level of service will be C. For Class 2 roads, only the % time following criterion applies.

(b) The classes of two-lane two-way roads closely relate to their functions. Most National Highways and State Strategic Roads will be Class 1. Most Regional Roads and District Roads will be Class 2. However, the primary determinant of the Class of a road will be the motorists' expectations. These may not agree with the formal classification. For example, a State Strategic road that passes through an area of rugged terrain may be considered to be Class 2 if motorists recognize that a high-speed route is not feasible.

Table 15.2 gives the current year volumes at which overtaking lanes would normally be justified. They are based on short, low cost overtaking lanes at a spacing of 10 to 15 km or more along a road in a given direction. If the spacing is less than this, a specific cost benefit analysis will be needed to justify the construction at the shorter spacing.

Table 15.2 Recommended Traffic Volume Guidelines for Providing Overtaking Lanes

Overtaking Opportunities over the preceding 5km (a)		Current Year Design Volume (AADT)		
Description	**% Length Providing Overtaking (b)**	**Percentage of Slow Vehicles (c)**		
		5	**10**	**20**
Excellent	70–100	5670	5000	4330
Good	30–70	4330	3670	3330
Moderate	10–30	3130	2800	2470
Occasional	5–10	2270	2000	1730
Restricted	0–5	1530	1330	1130
Very Restricted (d)	0	930	800	670

(a) Depending on road length being evaluated, this distance could range from 3 to 10km

(b) See Chapter 9

(c) Including light trucks and cars towing trailers, caravans and boats

(d) No overtaking for 3km in either direction

15.3.4 Length, Location, and Spacing

Length

The length of the overtaking lane must be sufficient to allow at least one overtaking manoeuvre and desirably allow queues to be dissipated. Experience shows that most of the overtaking occurs at the beginning of the overtaking lane and there is little point in making the lane longer than that required to accommodate this overtaking. Table 15.3 gives a range of lane lengths that are appropriate for all grades.

The minimum lengths provide for the majority of single overtaking manoeuvres but will not accommodate multiple overtaking or overtaking when there is only a small difference in speed. The desirable minimum values provide for multiple overtaking and the maximum lengths provide for extending the lanes to fit in with the terrain. There is little point, from an overtaking point of view, to extend the length beyond these maximum values. However, in areas where road trains operate, the normal maximum length shown in Table 15.3 should be used as the minimum.

It is generally more cost effective to construct two shorter lengths of overtaking lanes than expend all of the available funds on a single long lane. Several overtaking lanes at closer spacing will allow queues to dissipate before they become too long.

The length of overtaking lanes on grades is usually determined by the location of appropriate start and termination points. The start points must be clearly visible to the approaching drivers and the end point should be located so that the slower vehicles will have accelerated to the 85th percentile speed of the traffic stream. This will minimise the speed differential between vehicles in the traffic stream.

These requirements could result in lanes longer than the maxima shown in Table 15.3. This will cause the cost to be larger than envisaged in the development of warrants in Table 15.2 and a specific study (TRARR) and cost benefit analysis will be required. In these circumstances, the overtaking lane may take on more of the characteristics of a climbing lane and should be considered as such (see discussion below).

Table 15.3 Overtaking Lane Lengths

Design Speed (km/h) (a)	Total Taper Length (m) (b)	Overtaking Lane Length Including Tapers (m)		
		Absolute Min.	Desirable Min.	Normal Max. (c)
50	130	200	350	450
60	160	250	400	550
70	185	300	500	650
80	210	400	600	850
90	240	500	700	1000
100	265	600	800	1200
110	290	700	900	1350
120	315	800	1000	1500

(a) For the section on which the overtaking lane is constructed.

(b) See "Geometry" below.

(c) Adopt as minimum where road trains operate.

Location

The location of overtaking sites should be determined after considering the following:

- Strategic planning of the road in question and the long term objectives of that link – the spacing and consequently, expenditure, must be in accord with the strategy to obtain the best use of funds over the whole network;
- Nature of traffic on the section of road – if queuing occurs all along the route, then overtaking lanes at any location will be useful; if they occur at specific locations where slow vehicles cause the queue, the specific locations should be chosen;
- Location of grades – may be more effective to take advantage of the slower moving vehicles;
- Costs of construction of the alternative sites – may get a more cost effective solution by locating on the sites where construction is cheapest;
- Geometry of the road – when the sites are not on grades, sections with curved alignment and restricted sight distances may be preferable to long straight sections. These locations will make the location appear appropriate to the driver. However, sections with curves with reduced safe speeds are not suitable for overtaking lanes;
- Conflict with intersections/access - see Section 15.9.

If the conclusion is that the overtaking lane should be located on a grade, the length will be tailored to fit the grade. If the costs of the lane on the grade outweigh the benefits of being on the grade, the lane should be located to minimise the costs. Alternatively, a partial climbing lane could be considered (see "Climbing lanes" below).

Spacing

The factors already discussed must be taken into account in deciding the spacing of the overtaking lanes on a section. An analysis of the operating conditions over the whole link in the network, combined with the strategy for that link will establish the desired locations and therefore the spacing of the overtaking lanes. In general, if no auxiliary lanes exist, establishing the first ones at a larger spacing will provide better service than placing two lanes in close proximity.

In the first instance, a spacing of up to 20km may be appropriate, depending on the available overtaking opportunities. A more desirable spacing would be from 10 to 15km with the objective of providing overtaking opportunities every 5km in the long term. The intermediate lanes will be provided between the initial installations as required as the traffic grows.

There may be cases where the spacing is closer because of the proximity of long grade sections requiring treatment. A further case where the spacing may be close is where two partial climbing lanes are provided on the same long grade to reduce the total costs involved. In all these cases, the availability of overtaking opportunities on adjacent sections must be taken into account.

15.4 Climbing Lanes

15.4.1 General

Climbing lanes can be considered as a special form of overtaking lane but they are only provided on up grades. Where they are provided, they form part of the network of overtaking opportunities and will therefore have an effect on decisions on the location of other overtaking lanes. Unlike overtaking lanes, the location of a climbing lane is dictated by the specific conditions at a specific location i.e. an up grade.

On multi lane roads, there is no need to take account of the overall overtaking situation, as the effect is limited to the specific location of the grade in question. The decision on whether to add a climbing lane is based on level of service considerations only. Climbing lanes on multilane roads are specifically provided for slow moving vehicles and are therefore treated differently for signing and linemarking (see Section 15.9).

15.4.2 Warrants

Climbing lanes are warranted where:

- Truck speeds fall to 40km/h or less; and/or
- Traffic volumes equal or exceed those in Table 15.4.

In addition, climbing lanes should be considered where:

- Long grades over 8% occur;
- Accidents attributable to the effects of the slow moving trucks are high;
- Heavy trucks from an adjacent industry enter the traffic stream on the up grade; and
- The level of service on the grade falls two levels below that on the approach to the up grade or to level "E" (see Highway Capacity Manual, TRB 2000).

Table 15.4 Recommended Volume Guidelines for Providing Climbing Lanes

Overtaking Opportunities over the preceding 5km (a)		Current Year Design Volume (AADT)		
Description	**% Length Providing Overtaking (b)**	**Percentage of Slow Vehicles (c)**		
		5	**10**	**20**
Excellent	70–100	4500	4000	3500
Good	30–70	3500	3000	2600
Moderate	10–30	2500	2200	2000
Occasional	5–10	1800	1600	1400
Restricted	0–5	1200	1000	900
Very Restricted (d)	0	700	600	500

(a) Depending on road length being considered, this distance can range from 3 to 10km.

(b) See Chapter 9.

(c) Including light trucks and cars towing trailers, caravans and boats.

(d) No overtaking for 3km in either direction.

15.4.3 Length

The length of the grade and the start and end points of the lane dictate the length of the climbing lane. The theoretical start point is taken as the point at which the speed of the truck falls to 40km/h and decelerating. The end of the lane is determined by the point at which the truck has reached a speed equal to the design speed less 15km/h and accelerating. The starting point of the lane should be clearly visible to drivers approaching from that direction.

Truck speeds on grades can be assessed using the curves included in Figure 15.1 and the longitudinal section of the road. These curves assume an entrance speed to the grade of 80km/h. This is conservative as modern trucks can operate at highway speeds approaching those of cars. If more precise design is required, the conditions should be analysed using software designed to simulate truck performance and using entrance speeds based on the actual speed profile at the site.

The starting point should be located at a point before the warrant is met to avoid the formation of

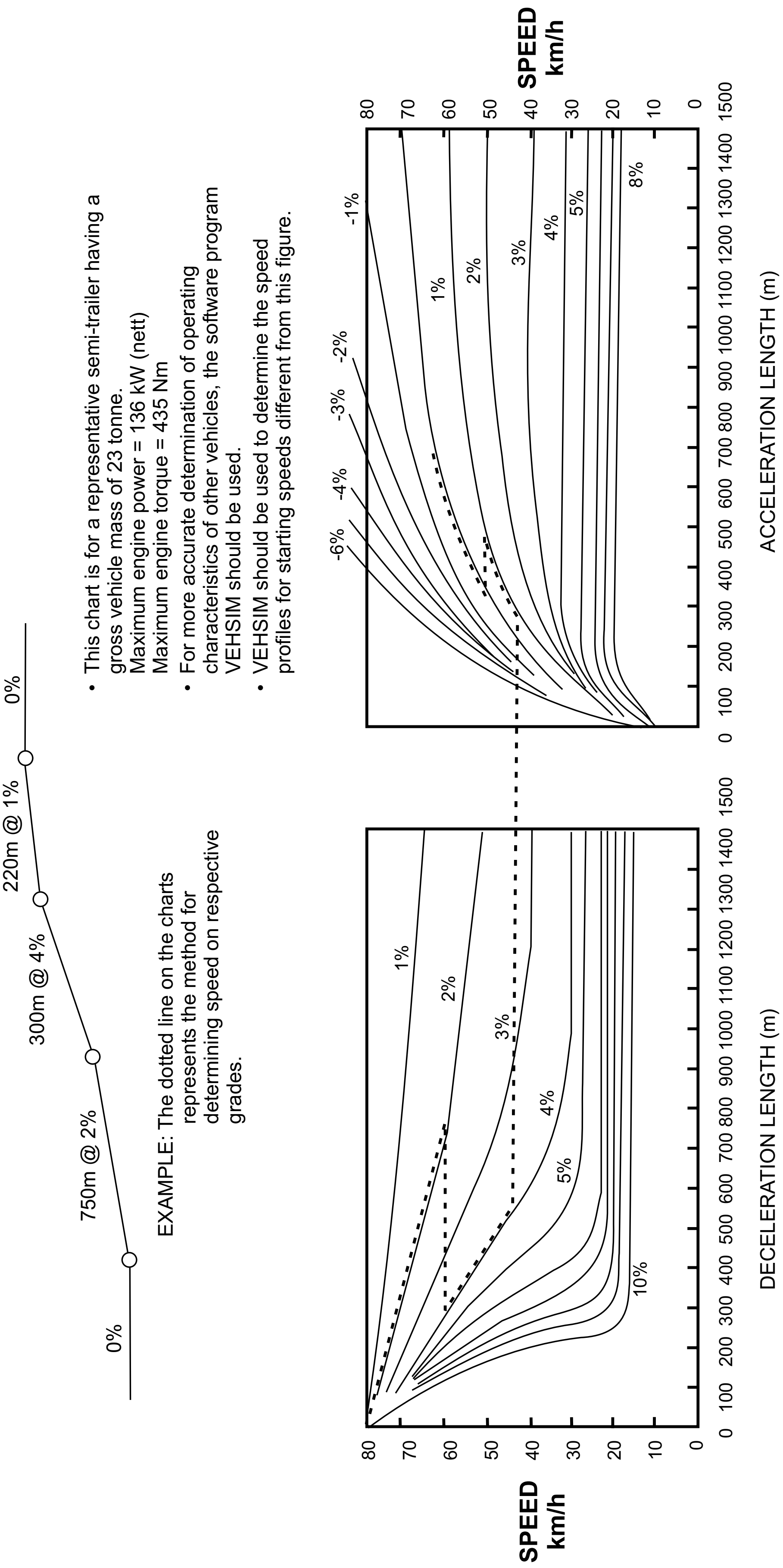

Figure 15.1 Determination of Truck Speeds on Grades

queues and possibly hazardous overtaking manoeuvres at the start of the lane (see Section 15.8 Geometry).

If the length of climbing lane exceeds 1200m, the design should be reconsidered. Options include:

- Partial climbing lane;
- Passing bay(s) in extreme conditions;
- Overtaking lane prior to the grade (where the delays on the grade are not excessive);
- Retention of the climbing lane where traffic volumes are sufficiently high.

15.4.4 Partial Climbing Lanes

While climbing lanes should preferably be designed to span the full length of the grade, there may be circumstances where it will be satisfactory to use a shorter lane on part of the up grade. The partial climbing lane may be appropriate if the traffic volumes are low or the construction costs are very high.

If a partial climbing lane is used, care must be taken to provide adequate sight distance and signing at the start and merge points to avoid unexpected merge locations. The minimum sight distance should be stopping distance for the design speed.

15.5 Descending Lanes

On steep down grades, the speed of trucks will be as low as on equivalent up grades with a similar effect on traffic flow if overtaking opportunities are not available. A descending lane will be appropriate in these circumstances.

If adequate sight distance is available and the traffic volumes are low enough, overtaking will be readily accomplished and a descending lane will not be needed. Similarly, if a climbing lane is provided in the opposite direction, and the sight distance is adequate, overtaking slower down hill vehicles can be safely done. A deceleration lane will not be needed.

Where the down grade is combined with tight horizontal curves, a descending lane will be appropriate to provide satisfactory traffic operation.

Design details are similar to those of climbing lanes and are discussed in Section 15.8 Geometry.

15.6 Passing Bays

On steep grades where truck speeds can reduce to a “crawl” speed less than 20km/h, and a full climbing lane can not be provided, passing bays may provide an improvement to traffic flow. A passing bay is a very short auxiliary lane (of the order of 100m but not more than 160m plus tapers) that allows a slow vehicle to pull aside to allow a following vehicle to pass. The passing bay provides for the overtaking of the slowest vehicles and is only appropriate if all of the following conditions are met:

- Long grades over 8%;
- High proportion of heavy vehicles;
- Low overall traffic volumes; and
- Construction costs too high for partial climbing lanes.

Passing bays must be properly signed to ensure their effectiveness. 300m advance warning of the location of the bay is required to allow heavy vehicle drivers to prepare for the overtaking manoeuvre and to alert other drivers to the approaching facility.

Details of the design of tapers for passing bays are provided in Section 15.8.2. Sight distance to the termination points should be in accordance with Section 15.8.1.

15.7 Runaway Vehicle Facilities

15.7.1 General

Where long steep grades occur it is desirable to provide emergency escape ramps at appropriate locations to slow and/or stop an out-of-control vehicle away from the main traffic stream. Out-of-control vehicles result from drivers losing control of the vehicle because of loss of brakes through overheating or mechanical failure or because the driver failed to change down gears at the appropriate time. Experience with the installation and operation of emergency escape ramps has led to the guidelines described in the following paragraphs for such ramps.

15.7.2 Types of Escape Ramps

Figure 15.2 illustrates four types of escape ramps.

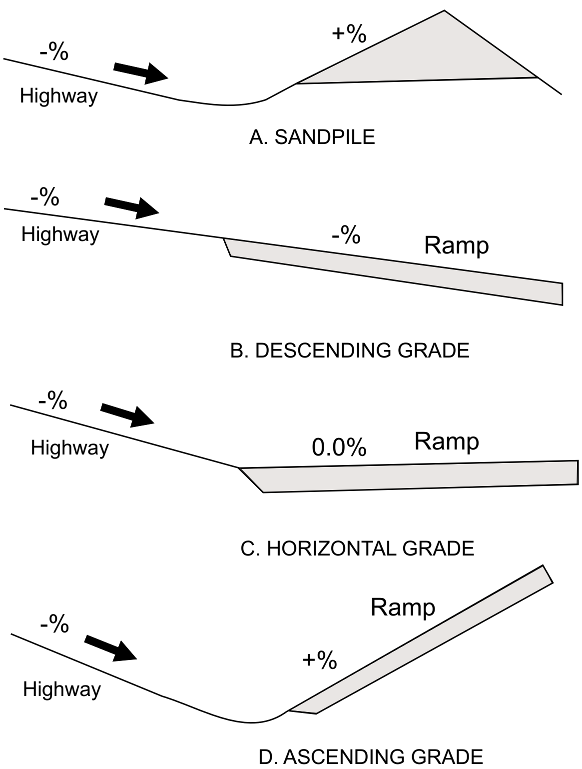

Figure 15.2 Types of Vehicle Escape Ramps

The sand pile types are composed of loose, dry sand and are usually no more than 130m in length. The influence of gravity is dependent on the slope of the surface of the sand pile. The increase in rolling resistance to reduce overall lengths is supplied by the loose sand. The deceleration characteristics of the sand pile are severe and the sand can be affected by weather. Because of these characteristics, the sand pile is less desirable than the arrester bed. It may be suitable where space is limited and the compact dimensions of the sand pile are appropriate.

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Descending grade ramps are constructed parallel and adjacent to the through lanes of the highway. They require the use of loose aggregate in an arrester bed to increase rolling resistance and therefore slow the vehicle. The descending-grade ramps can be rather lengthy because the gravitational effect is not acting to help reduce the speed of the vehicle.

For the horizontal-grade ramp, the effect of the force of gravity is zero and the increase in rolling resistance has to be supplied by an arrester bed composed of loose aggregate. This type of ramp will be longer than those using gravitational force acting to stop the vehicle.

The ascending-grade ramp uses both the arresting bed and the effect of gravity, in general reducing the length of ramp necessary to stop the vehicle. The loose material in the arrester bed increases the rolling resistance, as in the other types of ramps, while force of gravity acts downgrade, opposite to the vehicle movement. The loose bedding material also serves to hold the vehicle in place on the ramp grade after it has come to a safe stop. Designs on an ascending grade ramp without an arresting bed are not encouraged in areas of moderate to high commercial vehicle usage as heavy vehicles may roll back and jack-knife upon coming to rest.

Each one of the ramp types is applicable to a particular situation where an emergency escape ramp is desirable and must be compatible with the location and topography.

The most effective escape ramp is an ascending ramp with an arrester bed. On low volume roads of less than approximately 1000 vehicles per day clear run off areas without arrester beds are acceptable.

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15.7.3 Location of Runaway Vehicle Facilities

Runaway vehicle facilities should not be constructed where an out of control vehicle would need to cross oncoming traffic. On divided roadways where adequate space is available in the median, safety ramps can be located on either side of the carriageway with adequate advance warning signs prior to the safety ramp exit. (See Queensland Department of Main Roads - “Manual of Uniform Traffic Control Devices” for signing requirements.)

For safety ramps to be effective their location is critical. They should be located prior to or at the start of the smaller radius curves along the alignment. For example an escape ramp after the tightest curve will be of little benefit if trucks are unable to negotiate the curves leading up to it. Because brake temperature is a function of the length of the grade, escape ramps are generally best located within the bottom half of the steeper section of the alignment.

Because of terrain a lack of suitable sites for the installation of ascending type ramps may necessitate the installation of horizontal or descending arrester beds. Suitable sites for horizontal or descending arrester beds can also be limited particularly if the downward direction is on the outside or fill side of the roadway formation.

15.7.4 Design of Arrester Beds and Escape Exits

An arrester bed is a safe and efficient facility used to deliberately decelerate and stop vehicles by transferring their kinetic energy through the displacement of aggregate in a gravel bed. An escape exit consists of any surfacing used in the case of an emergency that will allow a runaway vehicle to exit the downgrade off the road and decelerate to a lower speed. For example, escape exits can be side streets, side tracks or accesses that are not normally signed as a safety ramp. An arrester bed is a particular kind of escape exit. The sections following list broad guidelines as to the design of arrester beds and escape exits.

Arrester Beds

From field tests and other research studies, rounded particles such as an uncrushed river gravel (single size) produce higher decelerations than the more angular crushed aggregate because the vehicles sink deeper into the river gravel, transferring more energy to the stones over a shorter length. The use of a material with low shear strength is desirable in order to permit tyre penetration. Sand is not ideal because it compacts with time and moisture ingress. Crushed stone has been used but is not recommended as to be effective it will require longer beds and will need regular fluffing or decompaction. **Note that regular maintenance of all arrester beds to “fluff up” or decompact the material in the beds is essential.**

Nominal 10mm river gravel has been used satisfactorily in testing. The gravel should be predominately rounded of single size free from fine fractions with a mean particle size ranging between 12mm and 20mm. In general gravels with a smaller internal friction angle will perform better than those with larger internal friction angles.

An appropriate crush test such as the Los Angeles abrasion test (or equivalent) should be used to evaluate durability of the stone. Stones with a high crush test will not deteriorate and will therefore not produce fines.

A variety of bed depths has been used and recommended throughout the world and more research and experimentation are required. The NSW Roads and Traffic Authority (RTA) have tested and constructed arrester beds at 350mm and 450mm deep. The 450mm deep beds provide higher decelerations. A typical section along the length of the bed is shown in Figure 15.3.

A gradual or staged increase of the depth of the bed should be provided over the 50m of the entry ramp. This is to ensure a gradual rate of deceleration when entering the ramp. The first 100 metres of the bed after the entry ramp should be 350mm deep. The bed depth should then increase over the next 25 metres to 450mm and remain at that depth for the rest of the bed. A bed

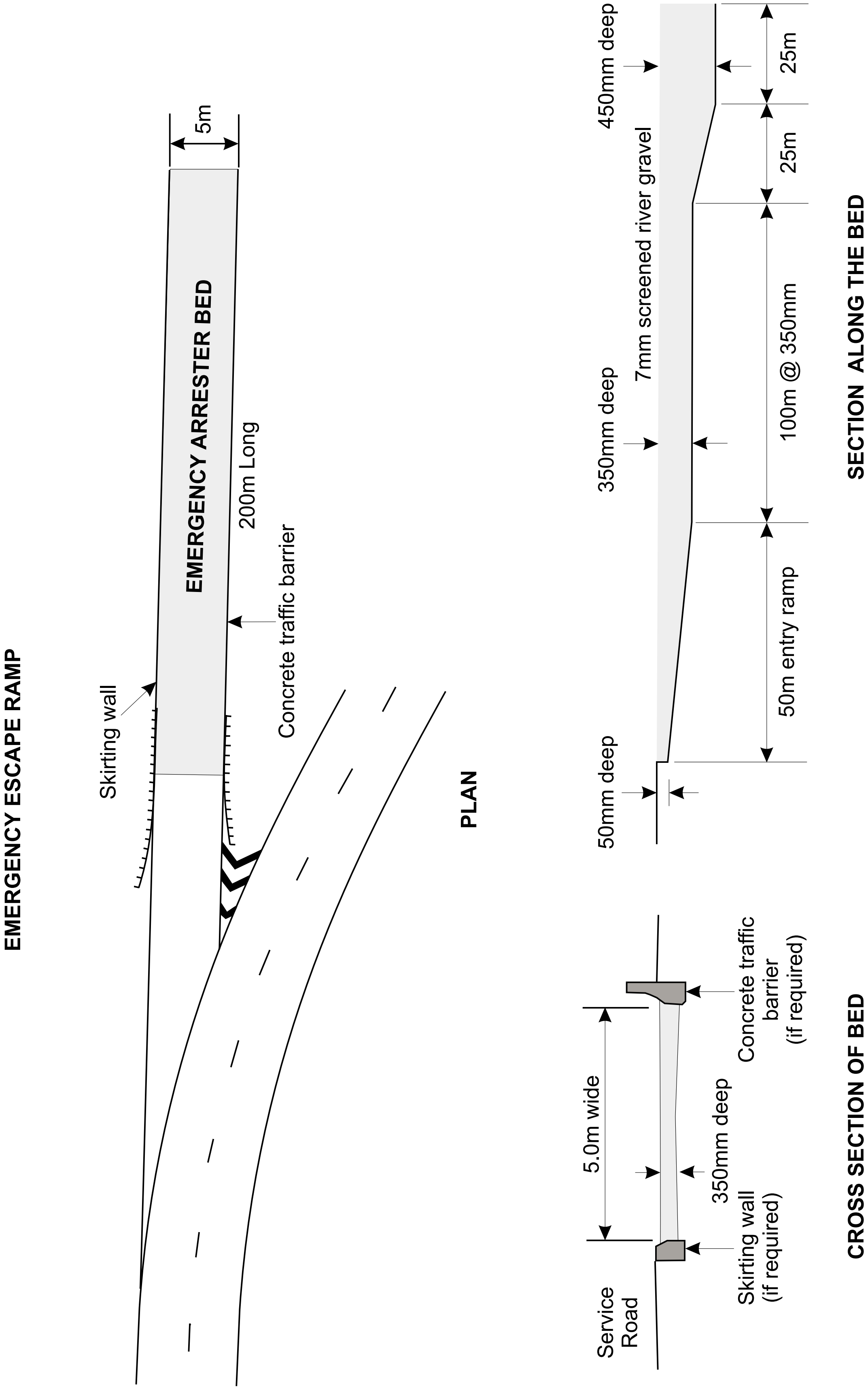

Figure 15.3 Typical Emergency Escape Ramp and Arrester Bed Layout

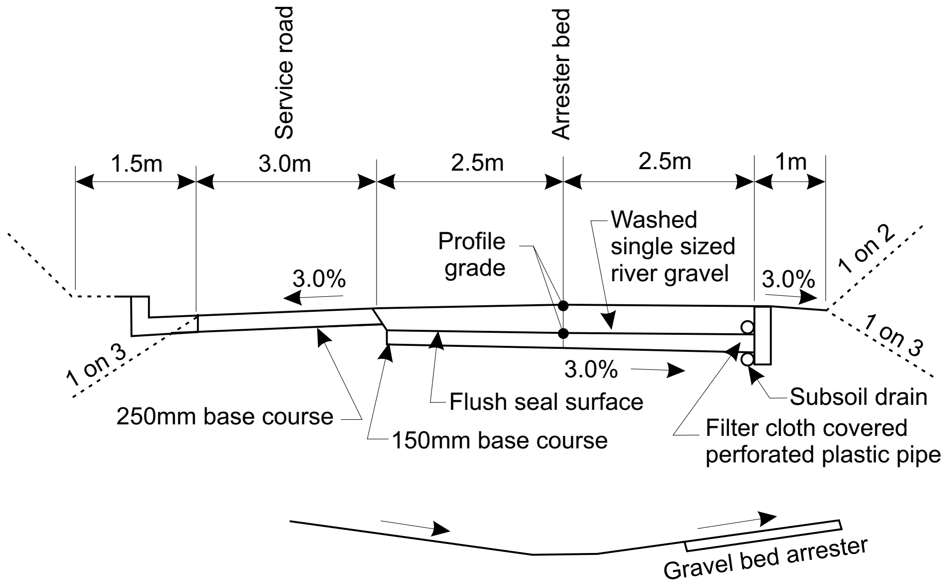

Figure 15.4 Typical Design for Gravel Arrester Bed System

constructed to this design would accommodate low speed entries within the 350mm deep section of the bed. Vehicles entering at higher speeds will slow down significantly before reaching the deeper section of the bed thus reducing the chances of the vehicle being damaged. Also see Figure 15.4 for a typical arrester bed cross section.

Following evaluation of the field tests by RTA, it has been determined that the following results can be applied in developing designs for arrester beds. This method is the preferred design method to be used when designing sand or gravel arrester beds.

- The average deceleration achieved in sand or gravel beds is:
  - Sand 350mm deep 2.8 m/sec
  - Sand 450mm deep 3.4 m/sec
  - Gravel 350mm deep 3.0m/sec
  - Gravel 450mm deep 3.7m/sec

These decelerations may be used in the following formula to calculate the length of an arrester bed:

$$L = V^2 / (26a + 2.55G)$$

Where

L = length of full depth bed excluding 50m transition at start (m)

V = entry speed (km/h)

a = deceleration (m/sec)

G = grade (%) - (positive for upgrade, negative for downgrade).

Note: The entry speed depends on:

- *weight of truck*
- *rolling friction resistance*
- *air resistance (frontal area of truck)*
- *initial speed*
- *length of grade*
- *slope of grade.*

This speed can be assessed using the Mx (Moss) add-in executable TRUCK.exe, which incorporates these factors.

- A 50m entry ramp provides a satisfactory and safe means of entering the full depth of the arrester bed; this entry ramp is not included in calculations for bed length.
- Where insufficient length is available at a particular site for stopping the vehicle at the anticipated entry speed, the bed depth should be increased in stages from 350mm up to 450mm. The increasing depth will provide greater deceleration toward the end of the bed allowing the vehicle to stop within the available length. Experience may indicate that a depth greater than 450mm will be required – each

case should be designed on its merits.

- From RTA's experience in the initial application of test results in designing and constructing arrester beds, 10mm diameter round uncrushed river gravel is the preferred material to use in the beds. Sand has problems of drainage, compaction and contamination and should not be used unless alternative materials are unavailable. Beds using sand will require a strict maintenance regime to ensure their continued effectiveness.

Escape Exits

Lengths will vary depending on the gradient of the facility and the surface material used (specific to the site). Wambold et al (1988) recommends the following formula to determine the length of a truck escape exit.

$$L = 0.004V^2 / (R + G/100)$$

Where

L = Distance to stop (m)

V = Entering velocity (km/h)

G = Percent grade

R = Rolling resistance expressed as equivalent percent grade divided by 100.

Values of R for several materials are given in Table 15.5.

Table 15.5 Rolling Resistance Values

Surfacing Material	Rolling Resistance (R)
Portland Cement Concrete	0.010
Asphaltic Concrete	0.012
Gravel Compacted	0.015
Earth, sandy and loose	0.037
Crushed Aggregate, loose	0.050
Gravel, loose	0.100
Sand	0.15

For escape exits, careful consideration of the land use adjacent to the exit is required. Normal streets should only be used at the top of steep grades where the truck has not generated any speed but the driver realises that the truck has developed a braking problem and wants to stop. Existing roads and streets used for property access should only be used where the traffic volume is very low and there is a very low probability of an escaping truck meeting another vehicle.

Spacing

For new projects Table 15.6 may be used as a guide when considering the need for safety ramps or exit routes on grades greater than 6% and with numbers of trucks exceeding 150 per day.

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Table 15.6 Approximate Distance from Summit to Safety Ramp

Grade (%)	Approximate Distance from the Summit to Ramp** (km)
6 – 10	3
10 – 12	2.5
12 – 15*	2.0
15 – 17*	1.5
>17*	1.0

* Grades > 12% require approval from the Regional Executive Director when designing new roadways.

** Actual distances will depend on site topography, horizontal curvature and costs.

The above distances are not absolute and greater distances could be acceptable, as site location is dependent on other factors. The need for a facility will be increased if the number of commercial vehicles is more than 250 per day.

Summary of Design Considerations

- The length of the escape ramp must be sufficient to dissipate the kinetic energy of the vehicle.
- The alignment of the ramp should be straight or of very gentle curvature to relieve the driver of undue vehicle control problems.
- The arrester bed material should be clean, not easily compacted and have a high coefficient of rolling resistance.

- The full depth of the arrester bed should be achieved in the first 50m of the entry to the bed using a tapering depth from 50mm at the start to the full depth at 50m.
- The bed must be properly drained and a positive means of effecting the drainage must be used.
- The entrance to the ramp must be designed so that a vehicle travelling at high speed can enter it safely. A 5° angle of departure or less is required, and as much sight distance as possible should be provided. The start of the arrester bed must be normal to the direction of travel to ensure that the two front wheels of the vehicle enter the bed simultaneously.
- Comprehensive signing is required to alert the driver to the presence of the escape ramp.
- Vehicles that enter the ramp will have to be retrieved, as it is likely that they will not be able to remove themselves from the arrester bed. An appropriate service road adjacent to the ramp is required to effect retrieval.
- When the location of the ramp is such that the length is inadequate to fully stop an out-of-control vehicle, a positive attenuation (or "last chance") device may be required. Care is required that the device does not cause more problems than it solves – sudden stopping of the truck can cause the load to shift, jackknifing or shearing of the fifth wheel, all with potentially harmful consequences to the driver and the vehicle. Judgement will be required on whether the consequences of failing to stop are worse than these effects. Crash cushions or piles of sand or gravel have been used as "last chance" devices.

15.7.5 Brake Check and Brake Rest Areas

A Brake Check Area is defined as an area set aside before the steep descent as distinct from a Brake Rest Area which is an area set aside for commercial vehicles part way down or at the bottom of the descent.

These facilities should be provided at least to an unsealed gravel condition on routes that have long steep downgrades and commercial vehicle numbers of around 500 per day, especially on National Highways and Principal State Roads. These areas, when used, will ensure that drivers begin the descent at zero velocity and in a low gear that may make the difference between controlled and out-of-control operation on the downgrade. It also would provide an opportunity to display information about the grade ahead, escape ramp locations and maximum safe recommended descent speeds.

These areas will need to be large enough to hold several prime mover and semi-trailer combinations, the actual numbers depending on volume and predicted arrival rate.

The location will need good visibility with acceleration and deceleration tapers provided. Adequate signage will be required to advise drivers in advance of the facilities. Special signs, specific to the site, will need to be designed for these areas.

15.8 Geometry of Auxiliary Lanes

15.8.1 Starting and Termination Points

The start and termination points of an auxiliary lane should be clearly visible to approaching drivers from that direction. The start point should be prior to the point at which the warrant is met to avoid potentially hazardous overtaking manoeuvres at the start of the lane. Visibility to the start of the taper should be sufficient for the driver to assess the situation and make a decision on the course of action to take. The desirable visibility to this point is given in Table 15.7 and should be measured from an eye height of 1.15m to an object height of 0.6m (tail light). The object height is based on the assumption that the course of action will be determined by the action of the preceding vehicle.

Table 15.7 Sight Distance to Start of Auxiliary Lane

Design Speed (km/h)	Braking Distance (m)	Distance for 5 sec. of Travel (m)	Rounded Visibility Distance (m)
50	20	70	90
60	30	83	115
70	43	97	140
80	59	111	170
90	78	125	200
100	101	140	240
110	129	153	280
120	162	167	330
130	202	181	390

The termination of the auxiliary lane should desirably be at a point where there is sufficient sight distance for the driver in the faster lane to decide whether to complete or abandon the overtaking manoeuvre. Tables 15.8A and 15.8B set out these values.

The sight distance should be measured from an eye height of 1.l5m to an object height of zero in the middle of the through lane and 20m past the start of the merge taper. The sight distances for the completion of overtaking of cars and prime mover and semi-trailer combinations match reasonably well with the position from which the 'left lane ends, merge right' sign can be read (see Manual of Uniform Traffic Control Devices).

As an absolute minimum, stopping sight distance should be provided, measured from an eye height of 1.15m to an object height of zero at the start of the merge. Completion of any overtaking then relies on the standard warning signs at the end of the auxiliary lane. The positioning of these signs as specified in the Manual of Uniform Traffic Control Devices supports the completion of overtaking of cars and prime mover and semi-trailer combinations.

In all cases, a further check should be made that stopping sight distance is provided, measured from an eye height of 1.l5m to an object height of zero in the middle of the traffic lane at the end of the merge.

Table l5.8A Sight Distance to End of Climbing Lane

Design Speed (km/h)	Car & PM & semi operation	B-double routes	Type 1 Rd Train routes	Type 2 Rd Train routes
50	100	100	105	120
60	130	130	135	155
70	150	160	175	205
80	185	200	220	260
90	230	250	280	325
100	285	305	345	400
110	350	350	350	400
120	385	385	385	400
130	400	400	400	400

Notes:

1. Distances derived from analysis of the length required to complete the overtaking of relevant vehicles using the Troutbeck model for overtaking but with no approaching vehicle.
2. Heavy vehicle speeds assumed to be the lesser of 15 km/h below the design speed or typical maximum vehicle speed.
3. Overtaken car speeds > mean free speed but slightly < design speed.
4. At the higher design speeds, the speed of overtaken cars is more dominant than the speed of the overtaken trucks.
5. The sight distance should be measured from an eye height of 1.15m to an object height of zero in the middle of the through lane and 20m past the start of the merge taper. Distances include an extra 30m to provide clearance and perception of the merge taper. This is why the object point is located 20m past the start of the merge taper.

Table 15.8B Sight Distance to End of Overtaking Lane

Design Speed (km/h)	Car & PM & semi operation	B-double routes	Type 1 Rd Train routes	Type 2 Rd Train routes
50	110	120	130	145
60	135	145	160	180
70	165	180	195	225
80	200	220	245	285
90	250	270	305	355
100	300	330	345	400
110	375	410	410	435
120	430	430	430	435
130	450	450	450	450

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Notes:

1. Distances derived from analysis of the length required to complete the overtaking of relevant vehicles using the Troutbeck model for overtaking but with no approaching vehicle.
2. Heavy vehicle speeds assumed to be the lesser of typical truck speeds for the design speed (see Table 6.3) or typical maximum vehicle speed.
3. Except for 130km/h design speed, overtaken car speeds match the design speed.
4. At the higher design speeds, the speed of overtaken cars is more dominant than the speed of the overtaken trucks.
5. The sight distance should be measured from an eye height of 1.15m to an object height of zero in the middle of the through lane and 20m past the start of the merge taper. Distances include an extra 30m to provide clearance and perception of the merge taper. This is why the object point is located 20m past the start of the merge taper.

It is desirable for the termination point to be on a straight to give drivers a better visual appreciation of the approaching merge. Termination on a left-hand curve should be avoided because slow vehicles are seriously disadvantaged by lack of rear sight. It is also desirable that the termination point be on a down grade to minimise the speed differential between vehicles.

15.8.2 Tapers

Diverging Taper

The widening of the pavement at the start of the auxiliary lane is achieved with a taper. The length of the taper should be sufficient to permit easy diverging of traffic with the slower traffic moving to the left and the faster traffic going to the right lane. This length depends on the speed of the approaching traffic and the width of the through lane. The rate of lateral movement is assumed to be 1.0m/sec, giving the following formula for taper length:

$$TD = V\,W / 3.6$$

where

TD = Diverge Taper Length (m)

V = 85th Percentile approach speed (km/h)

W = Amount of pavement widening (m)

If convenient, developing the widening around a horizontal curve can improve appearance and contribute to an easier divergence of the traffic into the fast and slow streams.

Merging Taper

At the termination of the auxiliary lane, the pavement width should be reduced by a taper that allows the two streams to merge into one. Since this situation is equivalent to the dropping of a lane, drivers will be less prepared for the merging action than they would be if merging from an acceleration lane. It is therefore necessary to adopt a lesser rate of merging than for the tapers on acceleration lanes and a rate of 0.6m/sec is used (as opposed to a rate of 1.0m/sec for acceleration lanes - see Chapter 13 – Intersections at Grade). The minimum length depends on the speed of the approaching traffic and the width of the lane and is determined from the following formula:

$$TM = V\,W / 2.16$$

where

TM = Merge Taper length (m)

V = 85th Percentile approach speed (km/h)

W = Amount of pavement widening (m)

(This formula has been derived on the basis of a merging rate of 0.6m/sec of lateral movement.)

A “run out” area should be provided through the merge area to accommodate those vehicles prevented from merging as they approach the narrowed section. This can be achieved by maintaining a total pavement width in the direction of travel equal to at least the sum of the full lane width plus a shoulder width of 3.0m over the full length of the taper plus 30m (see Figure 15.6).

Table 15.9 Tapers for Diverges and Merges

Design Speed (km/h)	Taper Lengths (m) Diverge	Merge
50	50	80
60	60	100
70	70	115
80	80	130
90	90	150
100	100	165
110	110	180
120	120	195

15.8.3 Cross Section

Pavement Width

The width of the auxiliary lane should not be less than the normal lane width for that section of road.

Shoulder Width

Because the total pavement has been widened over the section with an auxiliary lane, a shoulder width of 1.0m is often satisfactory. This width will have to be increased in areas of restricted visibility (e.g. around curves) and in the merge area at the end of the lane (see above).

Crossfall

The crossfall of the auxiliary lane will usually be the same as the adjacent lane. Because of the additional width of pavement, the depth of water flowing on the pavement should be checked to ensure that aquaplaning does not occur. It may be necessary to change the crown line to overcome this type of problem.

Lane Configurations

The specific circumstances of each design will dictate the preferred treatment for individual locations but the following considerations should be taken into account when deciding on the layout of the design:

- If duplication is a longer term goal, providing a section of four lane divided road may be a logical first stage;
- Providing a four lane section of divided road is applicable when the analysis of the road shows that a spacing less than 5km is required and the topography is suitable;
- The merge areas of opposite overtaking lanes should be in accordance with Figure 15.5;
- Diverges may occur opposite each other without any special requirements. At locations where additional definition is required, a painted median may be installed as shown in Figure 15.5;
- Overtaking lanes in opposite directions may be overlapped provided the start and ends are arranged in accordance with Figure 15.6 and a 1m painted median is included (see also Section 7.4.2).

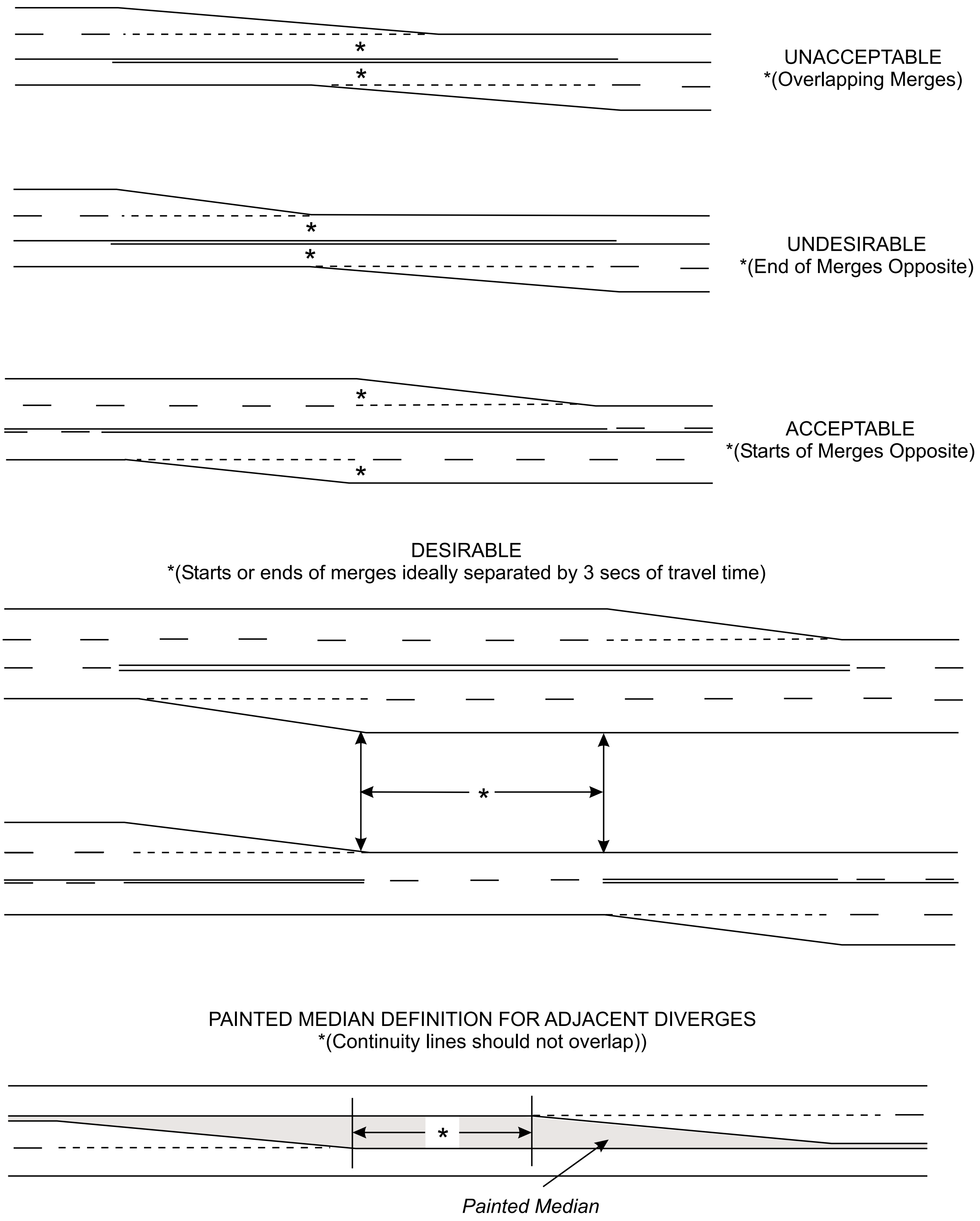
The general development of overtaking lanes is shown in Figure 15.6. Details of the linemarking and signing are discussed in Section 15.9.

15.9 Overtaking Lanes and Accesses or Turnouts on the Right

Overtaking lanes are constructed to provide road users with an opportunity for unhindered overtaking of slower vehicles. There is an expectation by drivers that slowing or stopped vehicles will not obstruct this overtaking manoeuvre. For this reason it is highly undesirable to have right turning vehicles from the overtaking lane.

Slowing or turning vehicles should not compromise vehicle use of overtaking lanes.

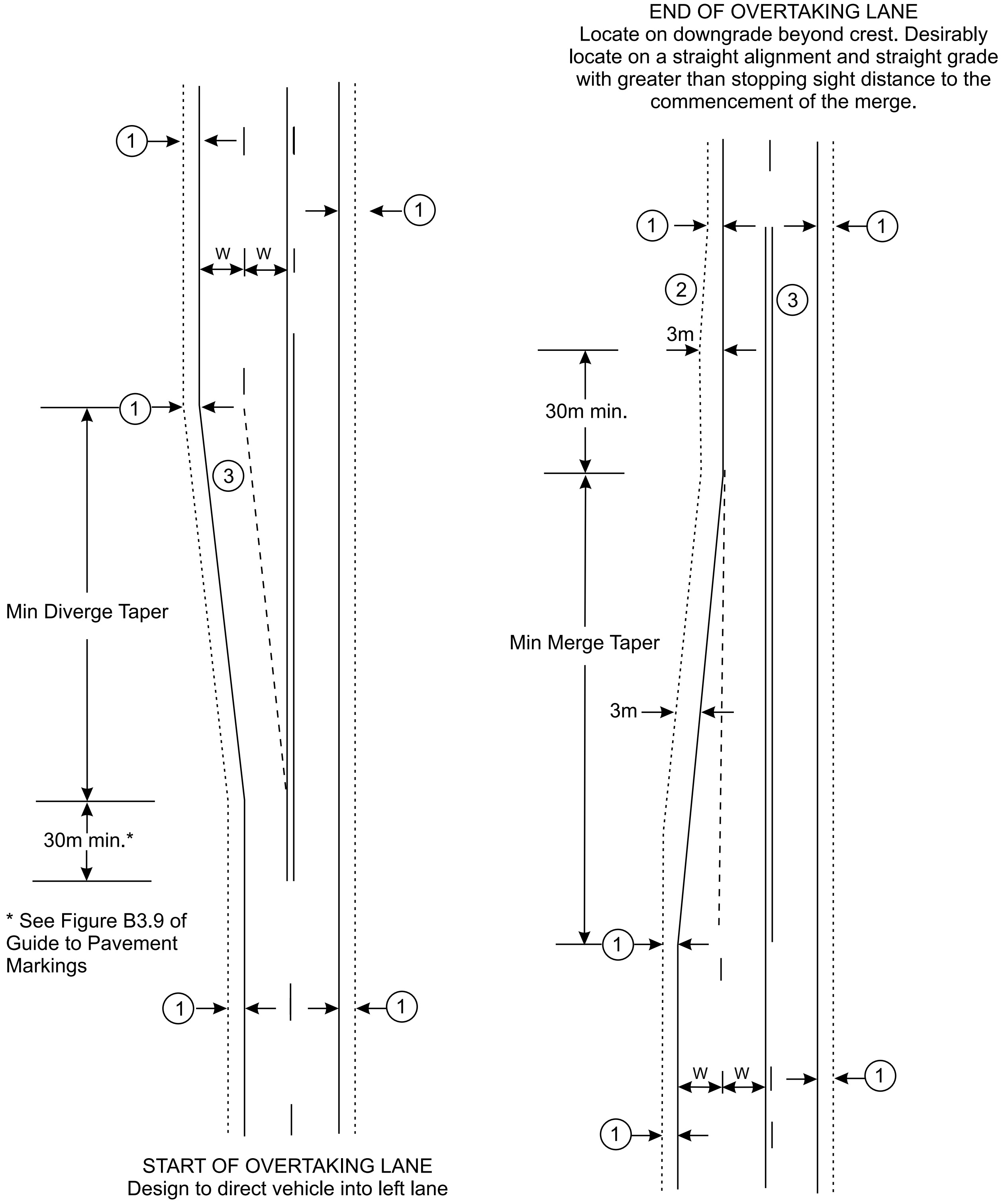
When siting overtaking lanes the presence and location of accesses and turnouts needs to be considered and appropriate facilities provided. When accesses or turnouts are located to the right of the overtaking lane the following steps need to be followed.



Notes:

1. The actual location of the start or end of merges to be determined in conjunction with vertical alignment.
2. Linemarking to be in accordance with Guide to Pavement Markings.
3. Drawing Not to Scale.

Figure 15.5 Overtaking Lane Configurations



Notes:

1. Shoulder widths to be in accordance with Chapter 7 (Section 7.3) and Section 15.8.2.
2. Shoulder tapers should be 1:50.
3. Signposting and linemarking should be in accordance with the Guide to Pavement Markings.

Figure 15.6 Development of Overtaking Lane

1. Assess the access/turnouts usage. (Volume and vehicle type, seasonal or slow).
2. Consult with owner or LGA on current usage and future potential.
3. Assess the risk of right turn to the access/ turnout from the overtaking lane.
4. Can the overtaking lane be relocated to avoid the access/turnout? If so determine a more viable location.
5. Can the access or turnout be closed to use? If so close the access/turnout following consultation.
6. Can right turn access be prevented by linemarking or median? If so provide appropriate barrier and construct a u-turn facility clear of the overtaking lane. Consideration needs to be given to the amount of extra travel to carry out this manoeuvre. 1.5 minutes of travel with a maximum distance of 1.5km is considered to be acceptable ((a), (b) and (c) in Figure 15.7)
7. Can the access or turnout be relocated beyond the overtaking lane? If so construct in new location.
8. Can the accesses or turnouts be rationalised and collected by a service road with the egress relocated beyond the overtaking lane? Construct service road and new entry beyond the overtaking lane.
9. Even after all those considerations it may still be necessary for the overtaking lane to remain at this location. Should this be the case then appropriate right turn protection (Figure 15.7(e)) or pull over to the left (Jug Handle Figure 15.7(d)) to create a road crossing is to be provided. The jug handle facility within the overtaking lanes is for passenger and light commercial vehicles only. It is not suited to the larger heavy and slow moving vehicles due to the time to cross the lanes. Note that sight distance to this facility must be at least safe intersection sight distance. Locating these lanes on left hand curves should be avoided because of the difficulty of providing adequate visibility.

Service road collection, u-turn facilities and left pull overs are shown in Figure 15.7. Figure 15.8 provides a flow chart for this process.

Right turns that are downstream of an overtaking lane can also cause problems for the traffic flow. At worst, they can provide a higher degree of hazard due to the combination of a vehicle that is stopped while waiting to turn and the increased speed of the through traffic. Right turning vehicles may also cause traffic bunching to reform prematurely.

The desirable minimum spacing is 15 seconds of travel past the end of the merge taper. This is based on:

- 5 seconds travel time until the driver is faced with a new decision after the merge;
- 3 seconds travel time to see and comprehend a right turn sign;
- 7 seconds travel time to accommodate the standard spacing of the right turn sign before the intersection.

At this spacing, even though traffic flow may initially be compromised when there is a turning vehicle, the right turn is still likely to be within the zone where headways are being re-established after the overtaking lane. This means that it is unlikely that bunching will reform prematurely.

15.10 Linemarking and Signing

15.10.1 Overtaking Lanes

The general linemarking and signing requirements are given in the Guide to Pavement Markings, Figures B3.9 and B3.10. Taper dimensions should be taken from Table 15.9 above.

The provision of advance signs for auxiliary lanes promotes road safety and improves the quality of service as perceived by the driver. Having seen such a sign, a driver wishing to overtake may relax his search for overtaking opportunities and is less likely to accept gaps with low safety

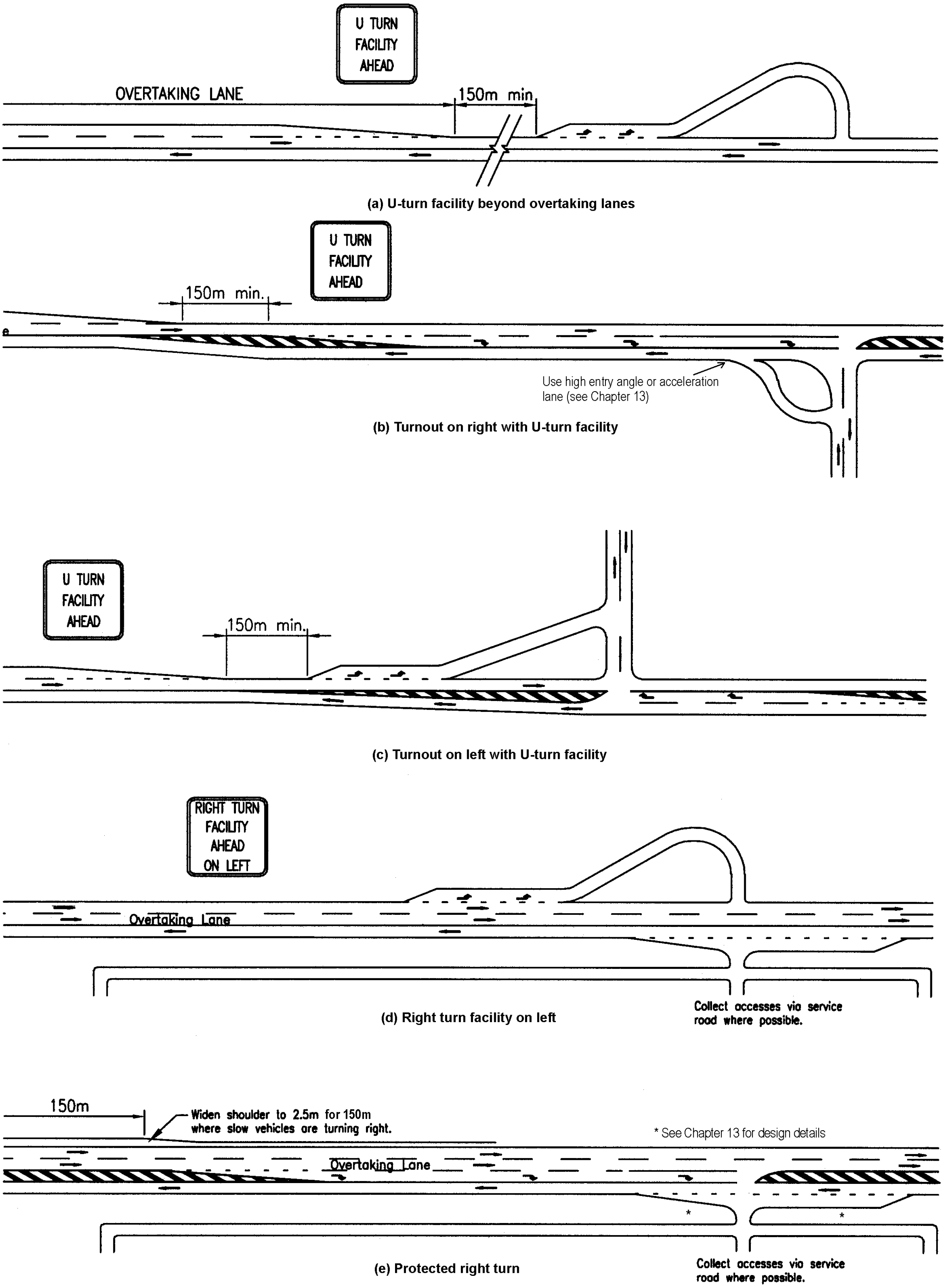


Figure 15.7 Overtaking Lanes and Accesses or Turnouts on Right

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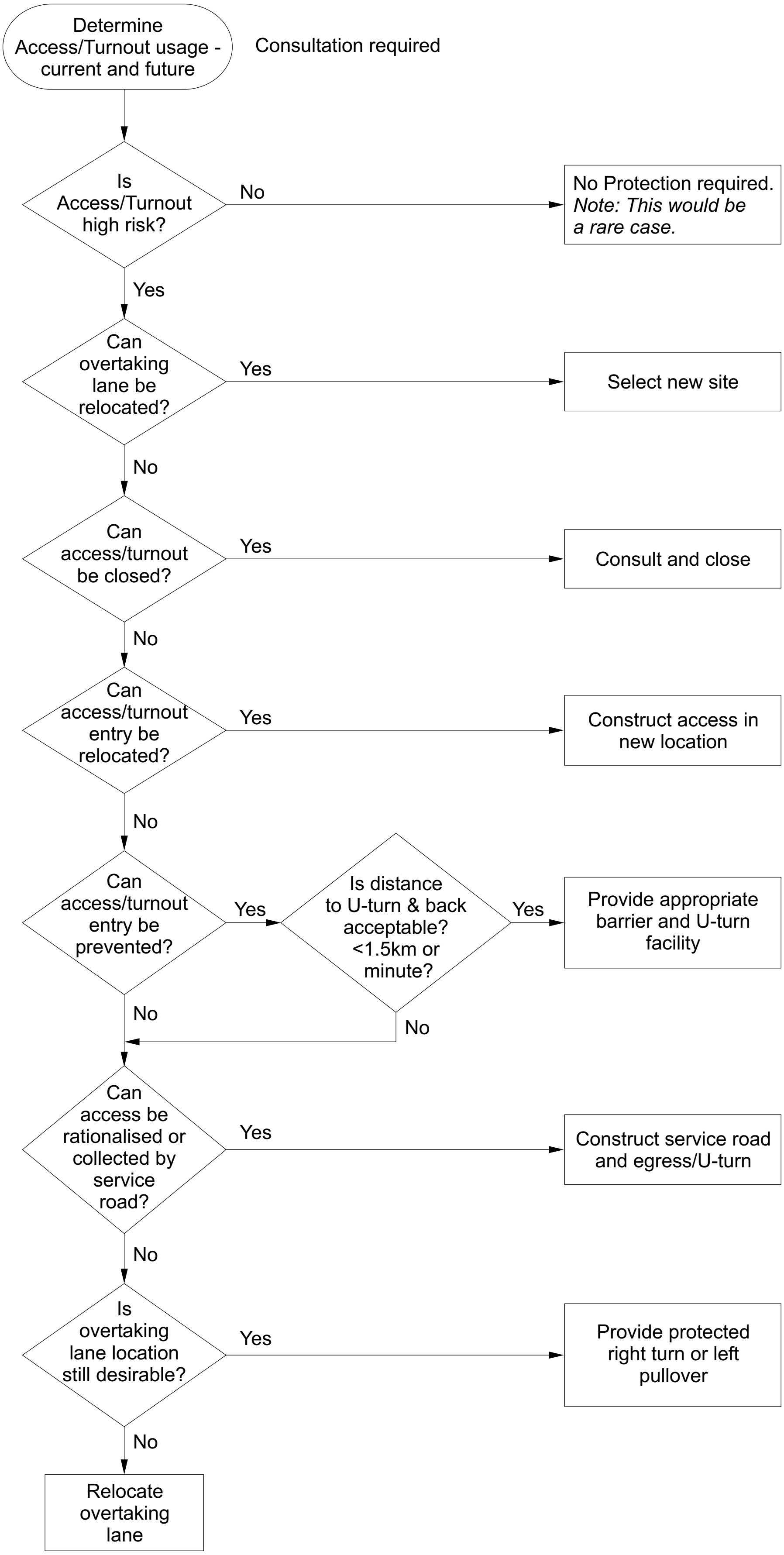

Figure 15.8 Flow Chart - Overtaking Lanes and Accesses or Turnouts on Right

margins. Advance signs are particularly appropriate when significant bunching occurs for 3 minutes of driving time (at the slow vehicle's speed) before the commencement of an auxiliary lane.

General practice for marking overtaking barrier lines on rural roads is described in the Guide to Pavement Markings. For auxiliary lanes constructed as three-lane road sections, three particular aspects are of relevance:

- In the direction of the auxiliary lane (direction 1) it is normal practice to provide a continuous barrier line over the full auxiliary lane length - including tapers - to prohibit any use by direction 1 vehicles of the third or opposing traffic lane. This also serves to define the centreline of the road and indicate that the centre lane is primarily for direction1 traffic.
- For direction 2 traffic a barrier line is generally provided adjacent to the auxiliary lane diverge and merge tapers.
- For direction 2 traffic adjacent to an auxiliary lane in direction 1, the direction 2 lane separation line marking should follow normal practice for two lane roads. This means that, if sight distance permits, direction 2 vehicles may be permitted to use the centre lane as an opposing traffic lane provided no vehicles are encountered in that lane.

Some use of auxiliary lane sections by opposing traffic is allowed, particularly when traffic volumes are low. However there may be cases where more restrictive line marking is appropriate. These will generally arise when there exists a combination of the following factors:

- short auxiliary lane length;
- moderate to heavy traffic volumes;
- sight distances only marginally adequate for overtaking; and
- perceived operational or safety problems on a given road section.

The use of more restrictive line markings should not be too widespread, however, since the presence of apparently unnecessary barrier lines can lead to driver frustration and a reduced quality of service on a road.

15.10.2 Climbing Lanes

On two lane roads, climbing lanes should be treated as an overtaking lane and marked accordingly.

On multilane roads where a climbing lane is required, only the slow moving vehicles are required to enter the climbing lane. In these circumstances, the general requirements for the layout of the climbing lane are shown in Figure 15.9. Details of the signing and marking are given in the Guide to Pavement Markings, Figure B3.8. Taper dimensions should be taken from Table 15.9.

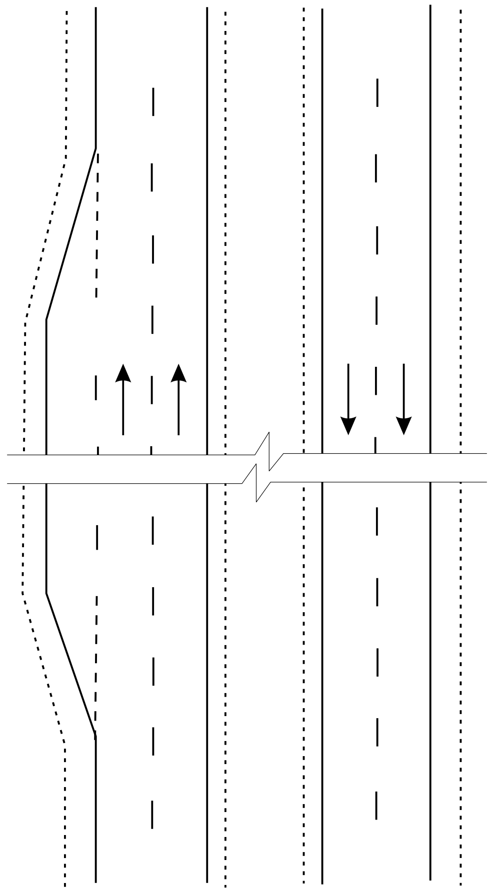

Figure 15.9 Development of Climbing Lane on Divided Road

Notes:

1. Refer Section 15.8 for design details of merge and diverge areas.

2. Shoulder widths in accordance with Chapter 7.
3. Shoulder Tapers shoulder be 1.50.
4. Signposting and linemarking in accordance with the Guide to Pavement Markings and MUTCD

15.10.3 Descending Lanes

Linemarking should be provided in the same way as for overtaking lanes with appropriate modifications of the signing to suit the circumstances.

15.10.4 Passing Bays

Signs and marking for passing bays is provided as shown in Figure B3.8 of the Guide to Pavement Markings.

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Relationship to Other Chapters

- Relies on Chapter 13 for details of acceleration and deceleration lanes;
- Sight distance requirements rely on Chapter 9 to some extent;
- Cross section details are taken from Chapter 7;
- Chapter 5 has additional discussion on overtaking requirements;
- Overtaking opportunities are discussed in more detail in Chapter 12.