



Chapter 18

Interchanges

18 Grade Separations and Interchanges

18.1 General

A bridge or underpass may be used to enable two roads to cross each other without interconnection, this arrangement being known as a **Grade Separation**. The main factor for the designer of the road geometry is the choice of “over” or “under”, and this will generally be determined by the design characteristics of the more important of the two roads. A secondary consideration is the form of the resultant grade-separation structure, and some guidance is contained in Sections 7.13.3 and 7.13.4 of this manual.

Interchanges use one or more bridge or underpass to separate vertically some or all of the conflicting streams of traffic. Where all conflicts are eliminated in this way, leaving only merging and diverging movements which occur at ramp terminals, the interchange is known as a **Fully Grade-separated** (or Free Flow) **Interchange**.

Grade Separations and Interchanges are warranted by the following factors.

(a) **Design Designation**

The decision that a road should have full control of access is a warrant for providing grade separations, with interchanges at all intersecting roads. Interchanges are the only type of intersection provided on Freeways and Expressways (the highest classes of road provision) regardless of traffic volume considerations. This is to ensure a consistent standard of provision for the users of these longer-distance facilities, and to provide the maximum level of safety appropriate for the high operating speeds which pertain.

(b) **Reduction of intersection congestion**

Where an at-grade intersection is subject to congestion greater than others along its route, introduction of grade-separation may eliminate the bottleneck. On arterial roads, interchanges are appropriate where levels of conflicting traffic are high, but it should be noted that uniformity of intersection type on this class of road is unimportant. Interchanges will rarely be warranted on roads of a lower class than Arterial.

(c) **Safety improvement**

Certain at-grade intersections may prove to have a high proportion of serious and fatal accidents. In the absence of other, less costly means of safety improvement, grade separation may be warranted.

(d) **Topography**

In hilly terrain, it is possible that grade separation may offer a more cost-effective solution than an at-grade intersection.



(e) **Road User Benefits**

An interchange can reduce delays very considerably, and a cost-benefit analysis may warrant the provision of one.

(f) **Traffic levels**

Where design flows are greater than the capacity of an at-grade intersection, an interchange is clearly warranted. Lower flows may also be sufficient to justify one, particularly if the volume of cross traffic is significant. It will sometimes prove economic to make an initial provision of an at-grade intersection, laid out in such a manner that future grade-separation of a main traffic movement can be achieved at a later date, when volumes have increased to an appropriate level, by means of a flyover or underpass.

18.2 Types of Interchange

Interchanges can be grouped under the headings shown in Table 18.1, the numbers in brackets indicating the Figure Numbers which refer.

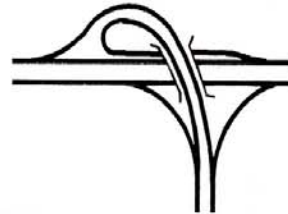
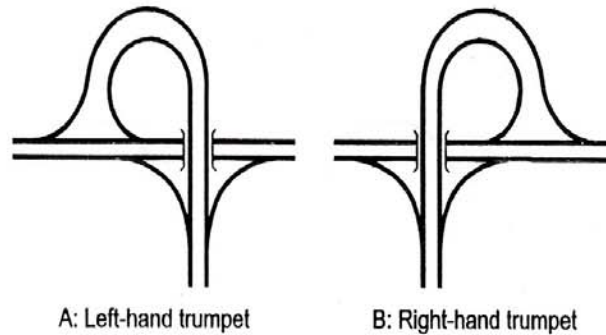
Table 18.1 : Types of Interchange

Number of legs	Number of bridges	Free-Flow Interchanges (fully free-flow)	Other Interchanges (some at-grade elements)
3-leg	single	● Trumpet (18.1) ● Half-cloverleaf (18.2)	
	multiple	● 3-leg direct (18.3)*	
4-leg	single	● Cloverleaf (18.4)	● Partial Cloverleaf (18.7) ● Diamond (18.8) ● Dumbbell (18.9)
	multiple	● 4-leg direct (18.5) ● 4-leg hybrid (18.6)	● Grade-separated roundabout (18.10)

* May incorporate a major fork - see section 18.6.7.

The layout of each of these, together with their advantages and disadvantages, is set out in Figures 18.1 to 18.10 on subsequent pages, following which there is general design guidance applying to all types of interchange.

Interchanges can also be designed to cater for more than four legs, and in such cases should be arranged to cater for the unique circumstances which exist. Elements within the interchange should conform to relevant guidance given in this Chapter.



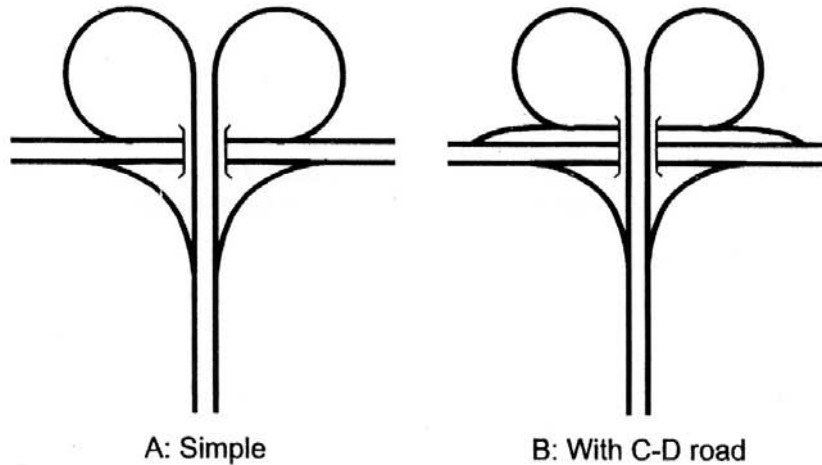
C: Preferred left-hand trumpet with skew bridge

Arrangement (A) depicts a **left-hand trumpet**, while arrangement (B) shows a **right-hand** one. As there is no straight-ahead escape route in either layout for a driver approaching at speed up the "stem of the T", often over a crest curve, arrangement (A) is slightly preferable in that such vehicles have a somewhat larger radius curve to negotiate.

Arrangement (C), which is a **left-hand trumpet**, improves on (A) by providing an even greater radius for the left-hand curve termination of the route approaching up the "stem of the T", although at the expense of a tighter loop for vehicles leaving the main line.

Positive attribute	Negative attributes
● Requires only one bridge. ● Provides relatively high-speed direct or semi-direct links for all movements. ● Layouts are simple to sign. ● Moderate land-take. ● Exit precedes entry, so no weaving movements.	● Right-hand trumpet (B) unsuitable for termination of a high-speed route; Left-hand skew trumpet (C) may be acceptable. ● U-turning by emergency and maintenance vehicles is not possible.

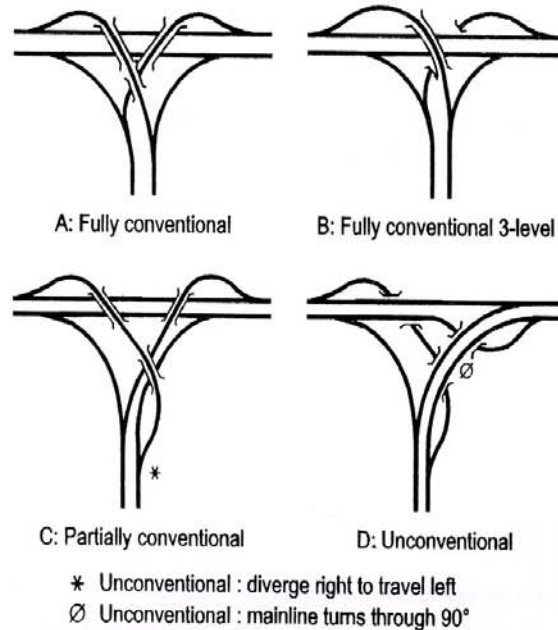
Figure 18.1 : Trumpet Interchange



The half-cloverleaf is a 3-leg interchange, but it has little to commend it over the trumpet interchange. It introduces apparently unnecessary weaving of the South to West and the East to South movements, and its sole advantage is its ability to allow the intersecting road to be extended Northwards at some future date.

Positive attributes	Negative attributes
● Provides moderate speed direct or semi-direct for all movements. ● Layouts are simple to sign. ● Only one bridge required. ● Moderate land-take. ● Permits future expansion into 4-leg interchange. ● Provides U-turning for emergency and maintenance vehicles approaching on the "stem of the T".	● Not suitable for the termination of a high-speed route. ● Introduces significant weaving movements; C-D Road arrangement (B) is preferred, but weaving still exists. ● U-turning not possible for vehicles on the main line.

Figure 18.2 : Half-cloverleaf Interchange



Arrangement (A) is the **conventional** layout. Traffic on the main line leaves by a conventional ramp located on the right side of the road, and traffic joining the main line does so from the right. Traffic approaching the main line along the “stem of the T” diverges to the right if wishing to travel to the right along the main line, and similarly to the left if traveling left.

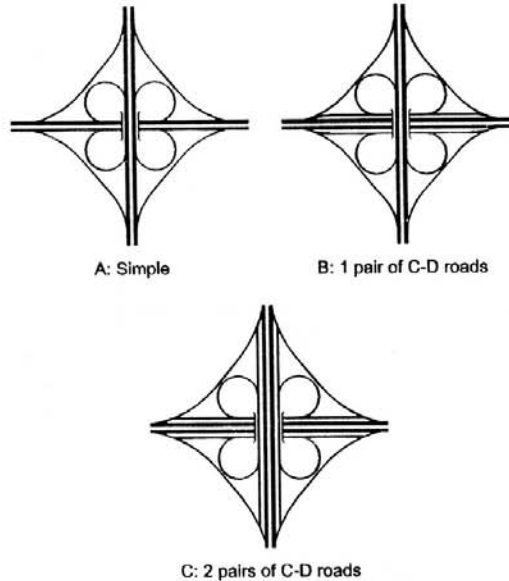
Arrangement (B) is a **conventional** layout, but on **three levels**.

Arrangement (C) is somewhat **unconventional**, in that traffic approaching along the “stem of the T” diverges to the right to travel left along the main line, and vice-versa. Such an arrangement might be considered appropriate where there is a heavier flow in the SE quadrant than the SW quadrant of the intersection, but where both these flows are exceeded by the through flow on the main line.

Arrangement (D) is **unconventional**, in that the main line is designed to turn through 90 degrees in the SE quadrant. This layout could be appropriate in circumstances where the flow in the SE quadrant is the dominant one, and that in the SW quadrant the lowest.

Positive attributes	Negative attributes
● Provides high-speed direct links for all movements. ● Conventional layouts are simple to sign. ● Suitable for the termination of a high-speed route. ● No weaving movements.	● Requires two or three bridges. ● Relatively high land-take. ● U-turning by emergency and maintenance vehicles is not possible.

Figure 18.3 : 3-leg Direct Interchange



The standard form (A) provides the driver on both main alinements with the following sequence of elements:

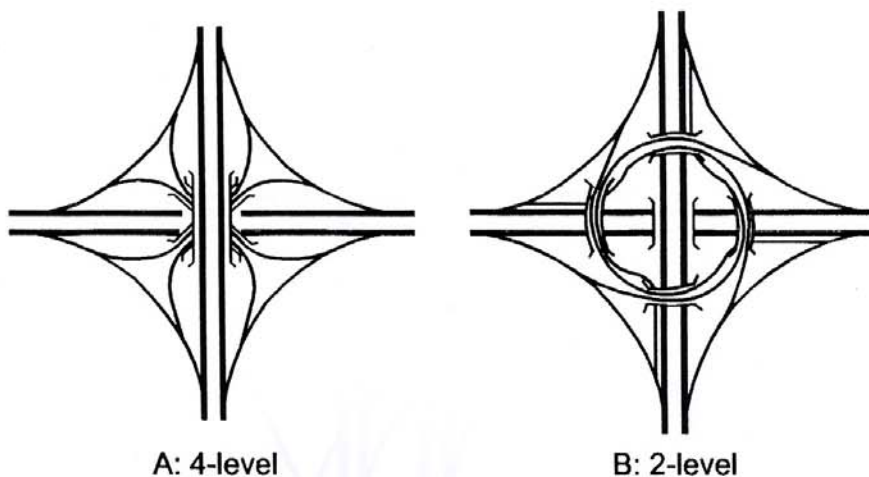
1. An off-ramp (for the leaving right-turn traffic)
2. An on-ramp (for the joining left-turn traffic from the loop)
3. A weaving section, often relatively short
4. An off-ramp (for the leaving left-turn traffic to the loop)
5. An on-ramp (for the joining right-turn traffic)

This can be difficult to sign, because there are two exits in succession, and drivers have to decide in advance on, usually, their compass direction - for example, do they want Route E3 North or E3 South? It also leads to turbulence in the weaving area, even in through lanes which theoretically do not have any need for lane-changing. For these reasons, a C-D Road is normally provided, as shown in (B) and (C). This simplifies the signing (just one exit, followed by a compass decision, for example north or south) and ensures that all weaving takes place away from the main line - on a C-D Road where every vehicle weaves.

The further advantages and disadvantages of the cloverleaf are given in the table.

Positive attributes	Negative attributes
- Provides moderate speed direct or semi-direct links for all movements. - Requires only one bridge. - Allows U-turning for emergency and maintenance vehicles.	- Entails significant weaving; C-D roads normally required, as in arrangements (B) + (C). - Difficult to sign. - Left-turning traffic leaves by the second exit on the right - Considerable land-take

Figure 18.4 : Cloverleaf Interchange



The 4-leg direct interchange provides high speed connections for all movements.

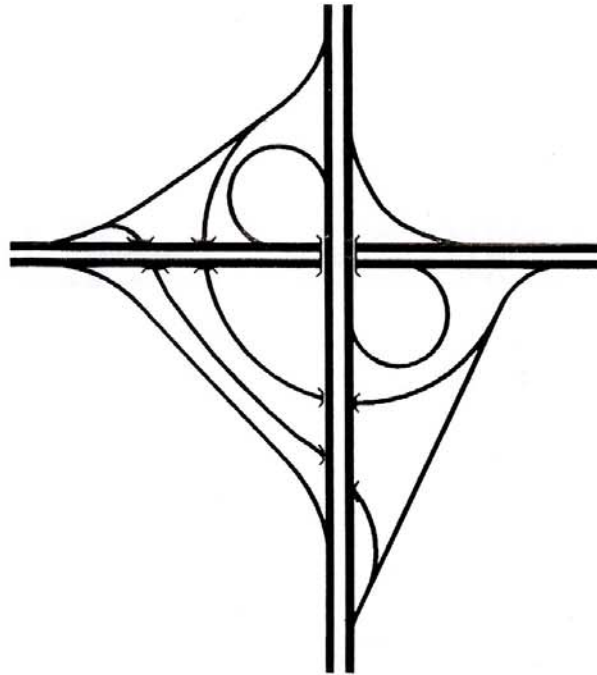
Layout A locates three structures at a single location, which minimises landtake but requires considerable earthworks to achieve the necessary level differences for this four-level crossing.

Layout B restricts all the crossings to two-level, but as a consequence requires five structures. Landtake is greater, but earthworks are considerably reduced.

Many other arrangements, symmetrical and asymmetrical, are possible.

Positive attributes	Negative attributes
● Provides high-speed direct links for all movements. ● Layouts are simple to sign. ● With the 2-level layout (B), it is possible to provide an emergency U-turn facility.	● Requires three, four or five bridges. ● Relatively high land-take. ● 4-level layout (A) is difficult to integrate into a flat landscape.

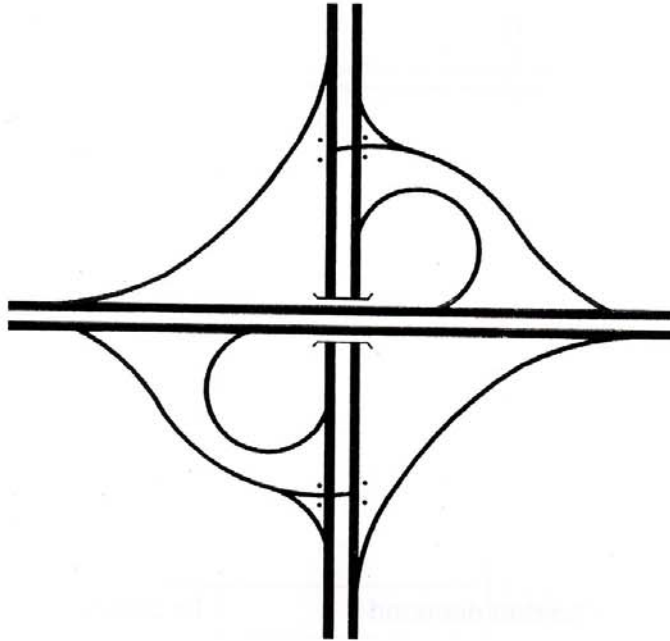
Figure 18.5 : 4-leg Direct interchange



It is possible to produce designs which incorporate features of several types of interchange. This figure shows one such hybrid, which uses the direct form, but replaces two of the direct connections by loops.

It is not possible to comment on the generic advantages and disadvantages of hybrid junctions, as each will have its unique attributes.

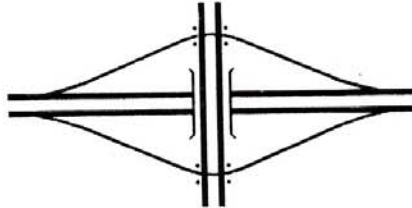
Figure 18.6 : 4-leg Hybrid Interchange (example)



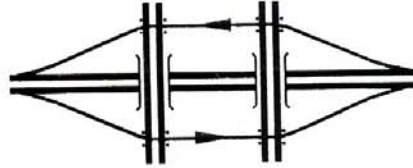
Many forms of partial cloverleaf are possible, with one to three loops in various quadrants. The one illustrated (with two loops in opposite quadrants) eliminates weaving on the main line, albeit by accepting at-grade left turning on the minor road.

Positive attributes	Negative attributes
● Provides moderate speed semi-direct links for some movements. ● Requires only one bridge. ● Can enable the elimination of weaving (as in the layout shown in Figure 18.7) ● Layouts are simple to sign if weaving is eliminated.	● Introduces at-grade movements, normally at signalized intersections. ● Requires more land than Diamond Interchanges. ● Left-turning traffic leaves the minor road by the second exit on the right - danger of wrong-way travel by left-turning at signals.

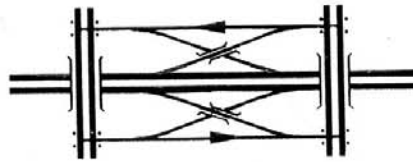
Figure 18.7 : Partial Cloverleaf Interchange



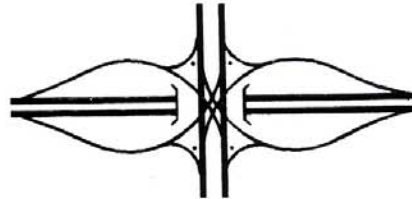
A: Full diamond



B: Split diamond



C: Overlap diamond



D: Single-point diamond

The Diamond Intersection is probably the most common form of grade-separated intersection, in which the ramps connect to the lower-category road by means of signalized at-grade intersections.

Arrangement (A) is the conventional **full diamond**, with two sets of signals.

Arrangement (B), the **split diamond**, is sometimes adopted where the spacing of adjacent cross-arterials is too close to allow the ramps to effect the necessary level difference. This layout, in which there are four sets of signals, is particularly suited to situations where the cross-arterials are one-way streets operating in opposite directions.

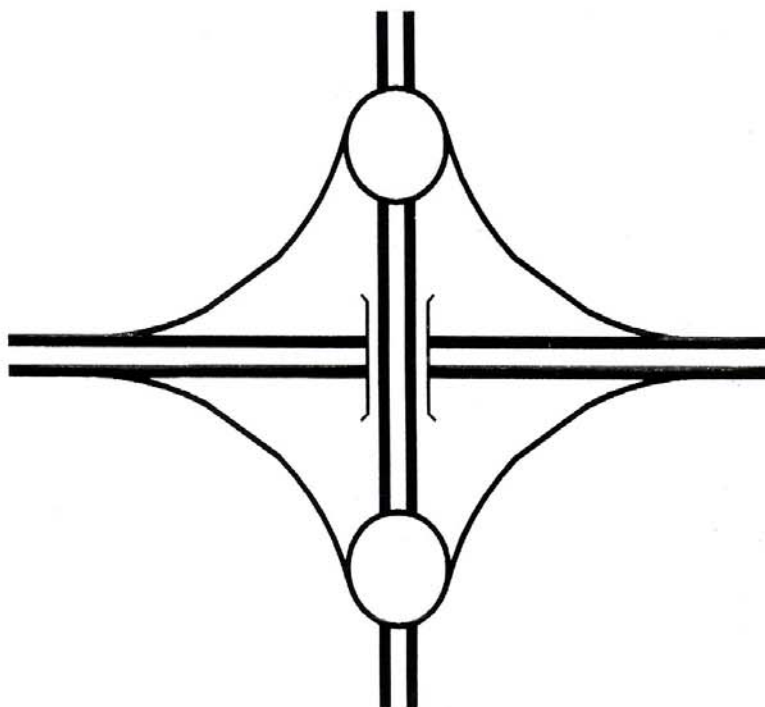
Another solution to this situation is the **overlapping diamond** shown in arrangement (C). This layout requires two additional bridges, and retains the four sets of signals. Again this works well with one-way cross-arterials.

A major difficulty with arrangement (A) is the fact that all the left turns "hook" with their opposites, rather than "sliding" past them. This can impose a significant capacity limitation on the intersection, generally necessitating four-stage signal operation. Arrangement (D), the **single point diamond**, gets around that difficulty by allowing all left turns to "slide", albeit at the expense of a layout which requires more space and is potentially more prone to driver misunderstanding. With such slide turns, the signal operation can be reduced to three-stage.

Attribute	Full Diamond	Split Diamond	Overlap Diamond	Single Point Diamond
Positive:				
• Very small land-take	✓	✓	✓	✓
• Easy to sign	✓	✓	✓	✓
• Conventional at-grade intersections	✓	✓	✓	
• Single bridge only	✓	••		✓
• U-turning possible for main line traffic	✓	✓	✓	•••
• No weaving sections on main line	✓	✓	✓	✓
• Maximizes spacing between intersections on main line			✓	
Negative				
• Lower capacity on minor road	X	X	X	X
• Left-turns interact	X	X*	X*	
• Weaving on frontage road			X	
• Greater possibility of wrong-way entry to ramp	X	X	X	XXX
• Difficult to expand the intersection in the future	X	X	X	XX

- Second bridge probably required in any event
 ••• May be possible, but difficult to sign and control
 * Not if cross-streets are one-way

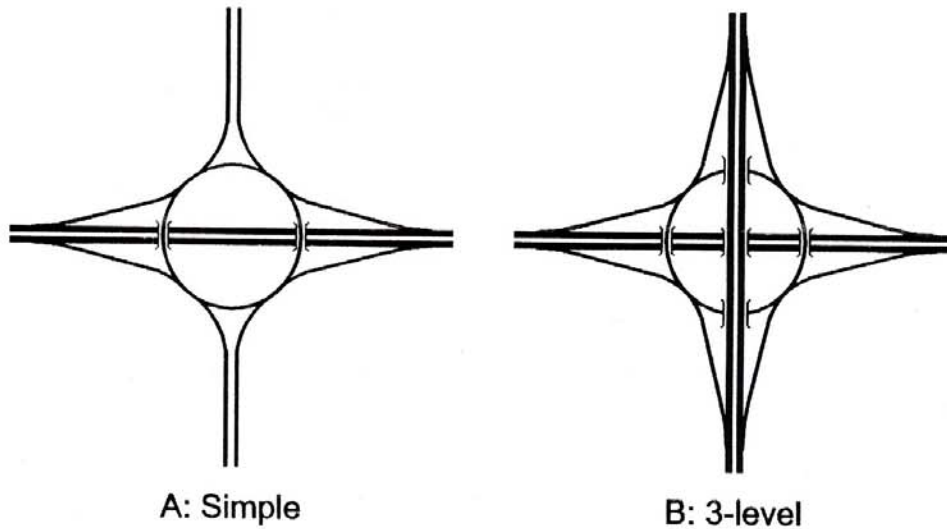
Figure 18.8 : Diamond Interchange



The advantages and disadvantages of the dumbbell intersection are similar to those of the full diamond. Additionally, the dumbbell scores by eliminating problems arising from the interaction of left turns, but has the disadvantage that queues may develop on the off-ramp as other traffic always has priority.

Note that, as there is no traffic likely to use that side of the roundabout circulating pavement adjacent to the bridge, it is feasible to join the two roundabouts and the median on the bridge to form a single "bone-shaped" island.

Figure 18.9 : Dumbbell Interchange



Arrangement (A) is the **simple** form of intersection, using two bridges and a large rotary pavement. When traffic volumes increase, there is adequate space to permit the introduction of signals to the roundabout entries, and to further increase capacity by modest widening on the approaches.

At higher volumes still, arrangement (B) can be adopted. This layout, known as a **three-level roundabout**, takes the cross-traffic on a direct ramp, leaving the roundabout to handle only turning traffic. Such a layout can be introduced incrementally if the median of the cross route is constructed at the outset with a width sufficient to accommodate the future flyover.

Positive attributes	Negative attributes
• Easily understood and conventional layout. • Simple to sign. • Can be signalized to provide additional capacity or to manage queues on off-ramps.	• Requires two or more bridges. • Higher land-take than diamond or dumbbell layouts. • Unsignalized layouts can lock up if there is a lack of capacity downstream.

Figure 18.10 : Grade-separated Roundabout



18.3 Selection of Interchange type

18.3.1 General

The design procedures for selecting the form of interchange most suitable for a particular location are dealt with in the following paragraphs. The geometric design standards for the individual elements within the chosen interchange form are generally to be found in Chapters 3 to 6.

The designer should prepare a number of preliminary sketch designs, and these are to be compared and considered before the final selection of the interchange type and the production of a detailed design.

18.3.2 System Interchanges

System Interchanges are those which connect a freeway or expressway to another freeway or expressway. They should always be free-flow interchanges of the types illustrated in Figures 18.1 to 18.6.

18.3.3 Service Interchanges

Service Interchanges connect to roads of a lower class than freeway or expressway. If the road is an arterial, then the full range of interchange options can justifiably be considered. For roads of lower class, interchanges which incorporate some at-grade movements (such as shown in Figures 18.7 to 18.10) are the norm.

18.3.4 Route Strategy

In rural areas, the spacing of interchanges is likely to be so great that each can be considered entirely on its own merits. Topographical and traffic flow considerations predominate, and consistency of exit patterns and minimizing of weaving on the main line have a considerable influence on the choice.

If a new route is being designed it is good practice to consider it in its entirety. This requires that the interchanges are planned in to the location studies so that the final alignment is compatible (in three-dimensional terms) with the interchange sites.

In urban areas, interchanges are closer, and each interchange is likely to be influenced by the next one upstream and downstream. Consideration therefore needs to be given to issues of capacity, weaving and lane balance on the main line, which in turn may limit the choice of interchange type.

On a continuous urban route, all the interchanges should be considered together as a system, rather than being considered individually. Arrangements for the entire corridor can be sketched, and alternative interchange strategies can be developed, analyzed and compared. It is important not to forget the intersecting

minor roads, and confirm that they are suitable for the additional traffic which the presence of an interchange will channel on to them.

In general, cloverleaf interchanges are less well suited to urban areas because of the amount of land which they occupy.

18.3.5 Traffic Flows and Design Year

Interchanges are designed using the Design Hour Volumes (DHV) as described in Chapter 2. Of particular importance for interchange design is the volume of traffic predicted to undertake each turning maneuver, and all proposed design flows are therefore to be agreed with Dubai Municipality Roads Department before design begins.

It should be noted that the practical capacity of a single-lane loop lies in the range 800pcu/h to 1200pcu/h. Loops rarely operate as two-lane pavements, regardless of their width, and in general they should not be designed to do so because of the difficulties in designing proper ramp terminals and for driver discomfort reasons. In general, therefore, when a DHV of around 1000pcu/h applies to the one-way turning movement in one quadrant of an interchange, serious consideration should be given to the adoption of a form of connection other than a loop.

18.3.6 Interchange Spacing within the Network

In selecting the form of grade-separated facility to provide, the designer should consider the location of that interchange within the overall road network. The aim should be to produce a consistent interchange strategy across the network that maximizes safety. Guidance on the interchange strategy for a particular location should be sought from Dubai Municipality Roads Department.

The indicative minimum spacing of intersections set out in Chapter 13 (Table 13.1) is aimed at providing adequate lengths of uninterrupted flow appropriate to the road class. These spacings allow effective signing to be provided for each interchange, but the minimum values should not be adopted without first considering the length required to accommodate any weaving which may occur on the intervening section of road between the last on-ramp terminal of one interchange and the first off-ramp terminal of the subsequent one. Guidance on the design of weaving sections is given later in this Chapter.

18.3.7 Initial Information Requirements and Decisions

The following information should be assembled and used as the basis for the selection of interchange type:

- the class, cross-section and Design Speed of all the intersecting roads
- the Design Hour Volumes
- the location and nature of any constraints to the scheme - land ownership,



existing and proposed utilities, planning constraints, topography, dry wadi courses, flood plains and ground conditions.

- environmental constraints - proximity to dwellings, severance of communities, plants of particular importance, animal habitats and regularly used animal tracks and migration routes.

Having collated the above information the designer must take the following action before he can finalize the form of interchange to be used:

- He should discuss the overall interchange strategy with Dubai Municipality Roads Department.
- He should agree the DHV (including turning volumes) with Dubai Municipality Roads Department.
- He should decide which turning movements are to be accommodated.
- He should decide which movements within the interchange are to be given priority with grade-separated links and which movements (if any) are to be accommodated through at-grade intersections.
- He should confirm the vertical and lateral clearances for structures.

18.3.8 Type of Interchange for Preliminary Design

The type of interchange needs to be selected, on the basis of the relative advantages and disadvantages set out above, before preliminary design can begin. For a given location two or more solutions may be worked up into outline designs (usually in sketch form) for preliminary evaluation.

The choice of “over or under” frequently arises, and no firm guidance can be given. In general, however, one of the roads is likely to have a higher design speed than the other, and so requires longer vertical curves to achieve the necessary level difference. Keeping it at or near its open road level therefore usually proves economic. Note also that any scheme which involves pavement levels below the existing ground level requires careful design, especially where water table levels are high, for example near creeks or the coast.

18.3.9 Preliminary Designs

Preliminary designs (considering both horizontal and vertical geometry) are prepared for alternative interchange arrangements in sufficient detail to determine the land take required. Items to be defined in the preliminary design include:

- Safety implications for road users.
- Number of lanes required for each movement.
- Design speed for individual elements within the interchange.
- Horizontal radii (especially important for loops).
- Vertical clearances for structures.
- Maximum pavement grades.

- Length of ramps and ramp terminals.
- Length of weaving sections (between interchanges and within each one).
- Provision for crossing traffic (not wishing to join the main line).
- Provision for pedestrians.
- Estimate of construction costs.

The designer must also consider:

- Method of construction.
- Method of maintenance and the need, if any, for a maintenance layby.
- Environmental effects including landscaping.
- Lighting and signing principles.
- Provision of fences and barriers.

Preliminary designs will need to be discussed with Dubai Municipality Roads Department and their approval received before the designer progresses further. Certain elements of the preliminary designs may need to be worked up in greater detail if requested by the Municipality.

18.4 Lane provision

Initial estimates of lane provision are undertaken on the basis that the Design Hour Volumes should be accommodated, Service Volume being taken as 1800 pcu per hour per lane. The designer may wish to increase the lane provision above the minimum number required to accommodate the predicted future flow, for operational or lane balance reasons.

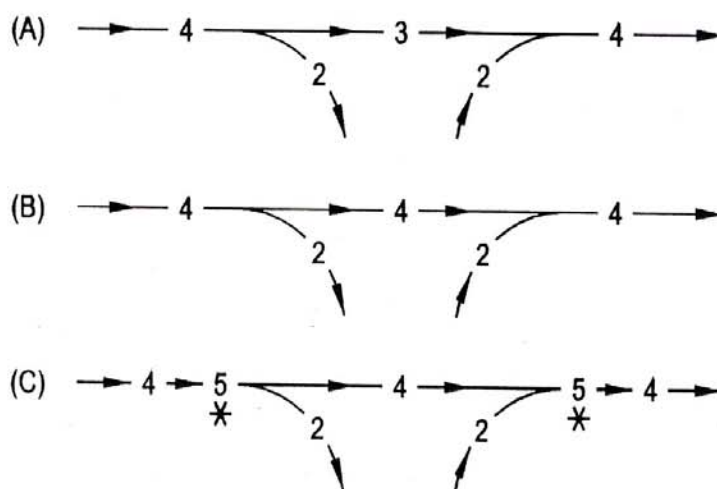
Lane balance considerations are important. Three basic principles apply:

1. Entries
The number of lanes downstream should not be less than the sum of all the joining lanes, less one.
2. Exits
The number of lanes upstream of the exit must be the sum of the downstream lanes on the main line and the exit roadway(s), less one. (There is one exception to this - the short length of auxiliary lane which exists on a cloverleaf interchange between the on-loop entrance and the off-loop exit. In this case, the number of upstream lanes may be the same as the sum of the downstream lanes.)
3. Lane drops
The traveled way of a road should not be reduced by more than one lane at any location.



It is not normal for there to be a lane-drop on the main line passing through an interchange. Should this be considered appropriate, the specific approval of Dubai Municipality should be obtained.

Figure 18.11 shows a typical situation.



- (A) Lane requirements from basic capacity considerations would lead to lane drop through interchange. Although in accordance with principles, continuity may require 4 lanes to be continued.
- (B) Increase in through lanes violates principles 1 and 2, and is unacceptable.
- (C) Provision of auxiliary lanes at * produces satisfactory design.

Figure 18.11 : Correlation of lane balance with continuity requirements

18.5 Design Speed

As the design speeds of the two main alignments are already determined, the factor which remains to be considered is the design speed of the elements which connect them. Three different conditions are relevant:

- free-flow links, which connect the two alignments directly, turning through generally small angles;
- ramps, which connect from a ramp terminal on one alignment to an at-grade intersection on the other, and vice versa;
- loops, which are also free-flow between the two alignments, but which generally turn through an angle of around 270 degrees; and

It is normal practice to provide a lower design speed on these connecting elements than on the main alignments, and whereas the stepping-up of design speed on leaving a connecting road causes no difficulty, the stepping-down from the initial higher design speed of the main alignment needs to be carefully handled. In the tabulation of design speeds in Table 18.2 below, the main line design speed is the design speed which applied prior to entering the connecting roadway, except for on-ramps, where it is the design speed of the alignment which is reached by following the ramp.

Table 18.2 : Design speeds for connecting roadways

Main line design speed (km/h)	Design speed for connecting roadway (km/h)		
	Free-flow links	Ramps	Loops
50	n/a	50	30
60	n/a	50	40
70	n/a	50	40
80	70	60	50
90	70	60	50
100	80	70	50*
120	100	80	50*
140	120	90	**

* Higher Design Speeds may be appropriate in rural areas.

** Loops on a 140km/h design speed road should always be accessed via a C-D road with a lower design speed.

These design speeds apply to the connecting roadway itself. The ramp terminals require to be designed in accordance with the design speed of the main line.



18.6 Off-Ramp Terminal Design

18.6.1 Selection of Layout Type

There are two types of exit arrangement available to the designer, namely **taper type** and **parallel type**. The parallel type provides a greater length over which exiting maneuvers can take place.

Both layouts can be used with or without a lane-drop on the through main line, and both can be used with a single-lane or two-lane off-ramp.

The decision as to which layout to use requires the designer to exercise his judgment, but the following guidance may be helpful.

- The taper type is the normal design, suitable for light to moderate volumes of exiting traffic.
- The parallel type is generally used where the volume of traffic leaving the main line is relatively high, or where lane balance considerations dictate its use (see Section 18.4 above).
- As a guide, if the flow on the off-ramp is predicted to exceed 1250 pcu/h/lane in the Design Year, an auxiliary lane generally appropriate.

18.6.2 Geometric Parameters for Off-ramp Terminals

Off-ramps diverge from the main line at an angle between 2° and 5° . The parameters are set out in Figures 18.12 to 18.15 on the following pages.

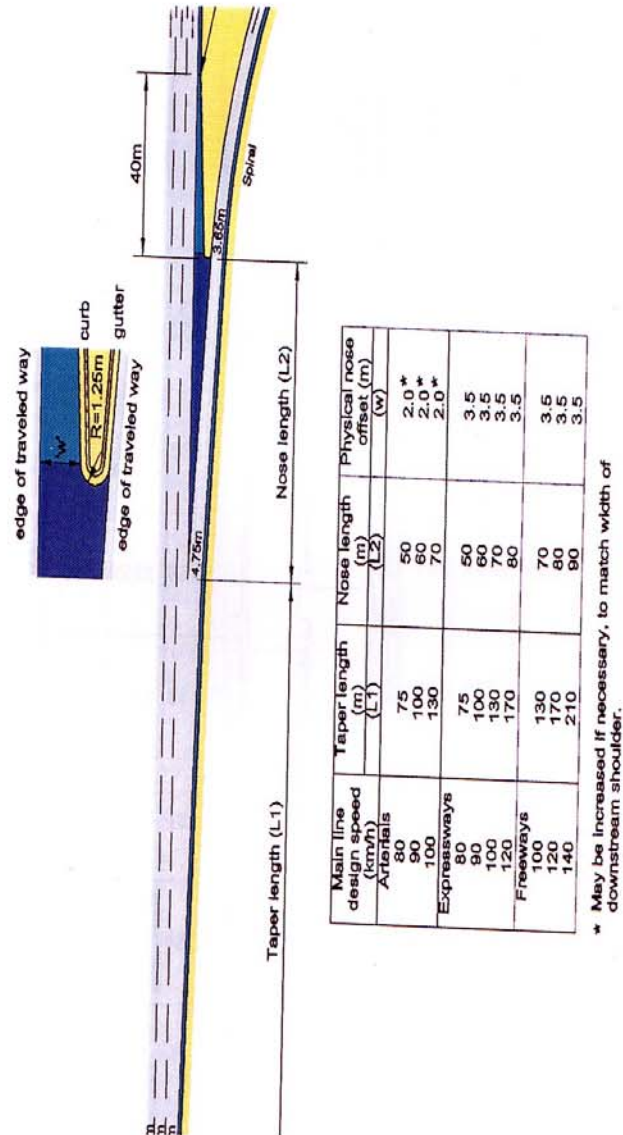


Figure 18.12 : Taper Type Off-Ramp (1-lane)

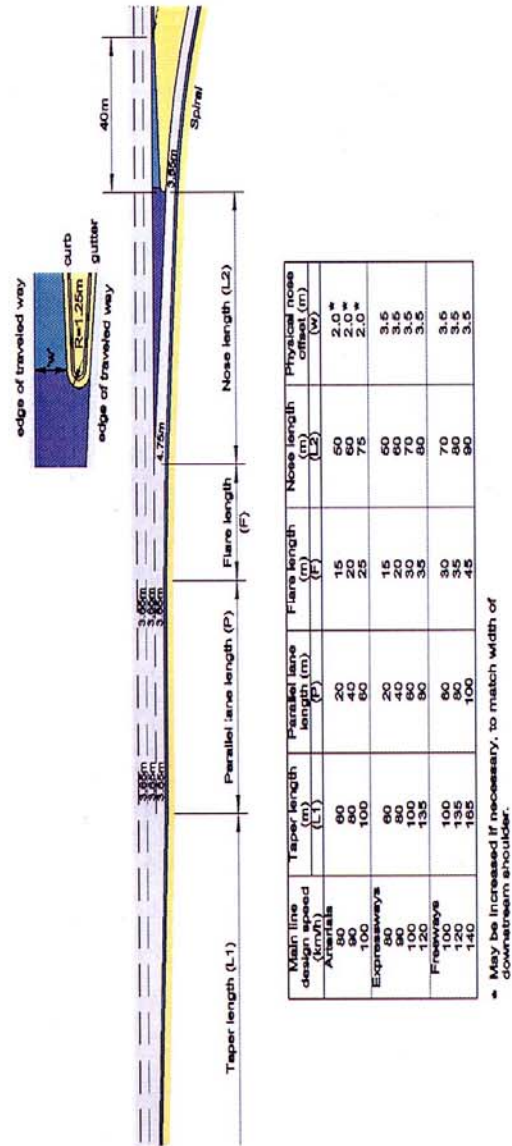


Figure 18.13 : Parallel Type Off-Ramp (1-lane)

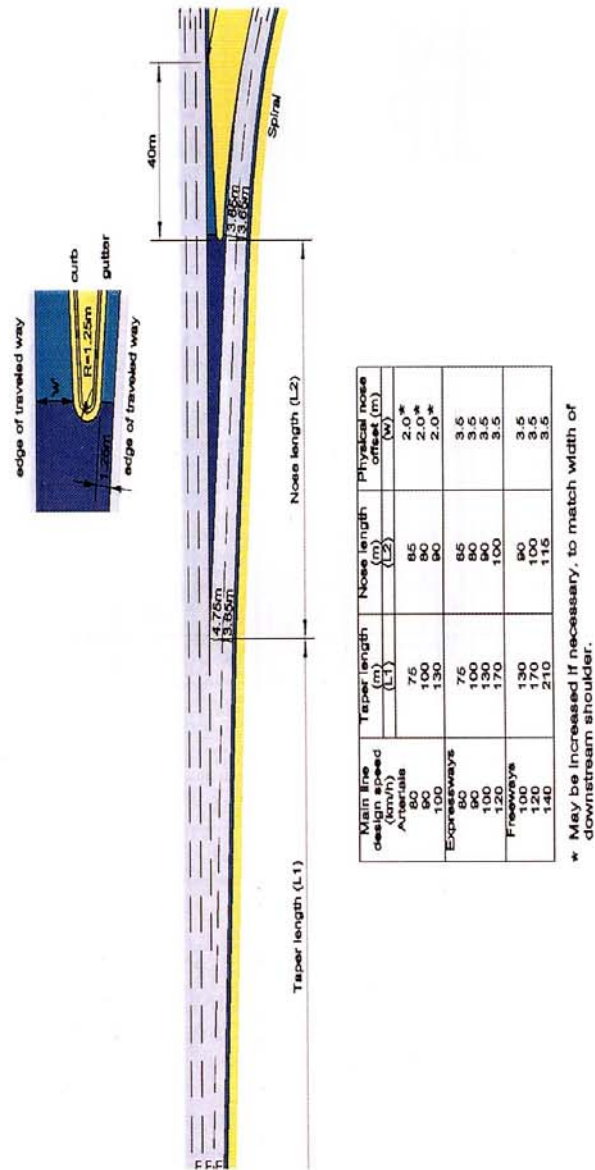
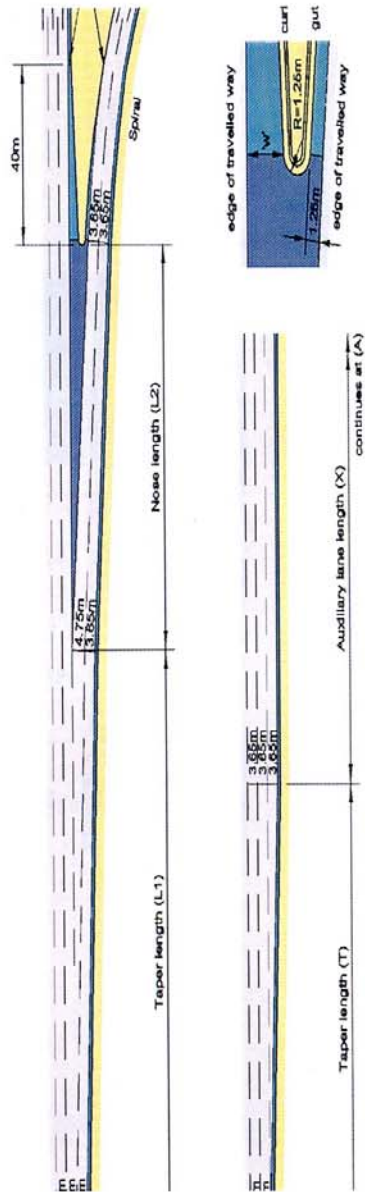


Figure 18.14 :Taper Type Off-Ramp (2-lane with lane drop)



Main line design speed (km/h)	Taper length (T) (m)	Auxiliary lane length (X) (m)	Taper length (L1) (m)	Nose length (L2) (m)	Physical noise offset (w) (m)
Arterials					
60	60	100	75	85	1.5
80	80	150	100	80	1.5
100	100	200	130	90	2.0
Expressways					
60	60	100	75	85	3.6
80	80	150	100	80	3.6
100	100	200	130	90	3.6
120	136	400	170	100	3.6
Freeways					
100	100	200	130	90	3.6
120	136	400	170	100	3.6
140	165	>500	210	115	3.6

Figure 18.15: Parallel Type Off-Ramp (2-lane without lane drop)

18.6.3 Deceleration distances

Vehicles leaving the main line need enough distance to enable them to decelerate, clear of the main line, to the design speed which pertains on the connecting roadway. This distance is measured from the painted nose.

The length necessary for deceleration depends on initial speed and the relevant design speed of the off-ramp, and should be provided in accordance with Table 18.3.

Table 18.3 : Distance to effect deceleration at change of design speed - level road

Design speed of main line (km/h)	Deceleration distance (m) - See note								
	Design speed of connecting roadway (km/h)								
	30	40	50	60	70	80	90	100	120
50	60	45	-						
60	80	65	50	-					
70	n/a	85	70	55	-				
80	n/a	n/a	90	75	55	-			
90	n/a	n/a	110	95	75	60	-		
100	n/a	n/a	125	115	100	80	65	-	
120	n/a	n/a	165	150	140	125	110	85	-
140	n/a	n/a	n/a	n/a	n/a	n/a	150	140	95

Note

- The values in Table 18.3 should be increased by 20% for down grades of 3% and 4%, or by 35% for down grades of 5% or more.
- Up grades theoretically reduce the length required, but this may generally be ignored. Where spatial constraints dictate, allowance for this shortening may be made, and the designer is referred to Table X-5 of AASHTO⁽¹⁾.

Design features to the lower design speed standard must not be introduced before the relevant distance beyond the tip of the painted nose has been reached.



18.6.4 Forward visibility

When checking forward visibility (which extends over a length of road, and thus may span sections of different design speed), the following criteria should be used for the three sections as set out below:

- Over the taper length - apply visibility standards appropriate to the main line design speed.
- Thereafter for the distance defined in Table 18.3 - apply visibility standards appropriate to the average of main line and connecting roadway design speeds (rounded down, if necessary, to give an exact design speed value).
- Thereafter - apply visibility standards appropriate to the connecting roadway design speed.

18.6.5 Superelevation

It is normal to continue the main line superelevation across the width of the ramp terminal, but where the main line is on a left-hand curve, it may sometimes be necessary to introduce a reversal of the main line superelevation on the approach to a right-hand curved off-ramp. If this is the case, then the magnitude of the differential between the two falls should not exceed 3%.

Beyond the painted nose, the vertical profile of the main line and the off-ramp may diverge, and this effect may be made more pronounced if superelevation is being developed on the off-ramp. Care must be taken to ensure that the fall across the paved gore is not too great, and a value of 4% should be taken as a working maximum.

The superelevation across the recovery area (beyond the paved gore) should be the same as that of the main line, and the design of the transition from the crossfall prevailing in the gore area requires careful consideration.

18.6.6 Left Off-ramps

Ramps leaving from the left (inner) side of the pavement are not recommended. Should one be warranted, it should be preferably be treated as a major fork, and adequate overhead signing and full Decision Sight Distance must be provided in all cases.

18.6.7 Major Fork

Where a freeway or expressway diverges into two routes of similar importance, and neither branch is considered to be the main through route, a major fork layout should be adopted. This is shown in Figure 18.16.

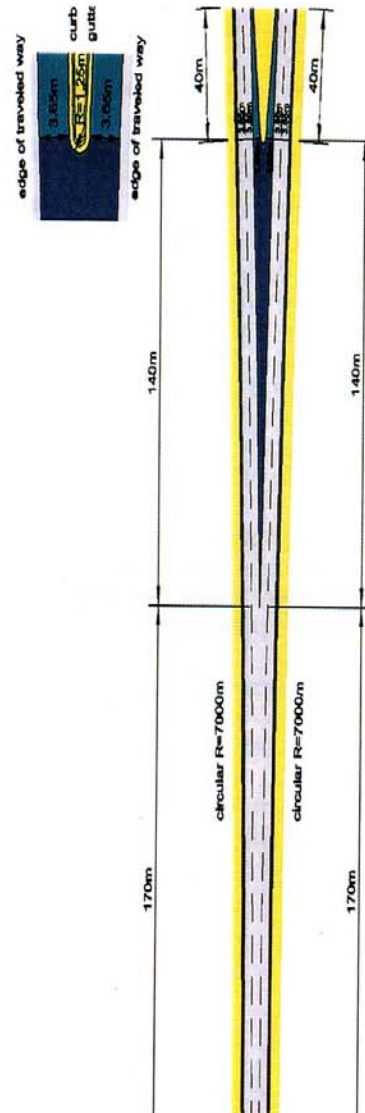


Figure 18.16: Major Fork



18.7 On-Ramp Terminal Design

18.7.1 Selection of Layout Type

As for exits, there are two types of entry arrangement available to the designer, namely the **taper type** and **parallel type**. The parallel type provides greater length for merging the entering flow in to the traffic on the main line.

Both can be used with or without a lane-gain on the through main line, and both can be used with a single-lane or two-lane on-ramp.

The designer needs to exercise his judgment when selecting the most appropriate entry arrangement, and he may find the following guidance helpful.

- The taper type is the normal design, suitable for light to moderate volumes of entering traffic.
- The parallel type is generally used where the volume of traffic joining the main line is relatively high, or where lane balance considerations dictate its use (see Section 18.4).
- As a guide, if the entering flow is predicted to be more than 1000 pcu/h/lane in the Design Year, a parallel type arrangement should be considered. (It may be justified with lower flows, depending on how heavily-loaded the outer through lane is anticipated to be.)

18.7.2 Geometric Parameters for On-ramp Terminals

Typical layouts, showing geometric parameters, are given in Figures 18.17 to 18.20. Note that, where lane gain is indicated, the auxiliary lane may be merged with the nearside lane after a further distance of 400m, using a taper rate of 1:50 for design speeds of 100 km/h and below, or 1:70 for higher speed roads.

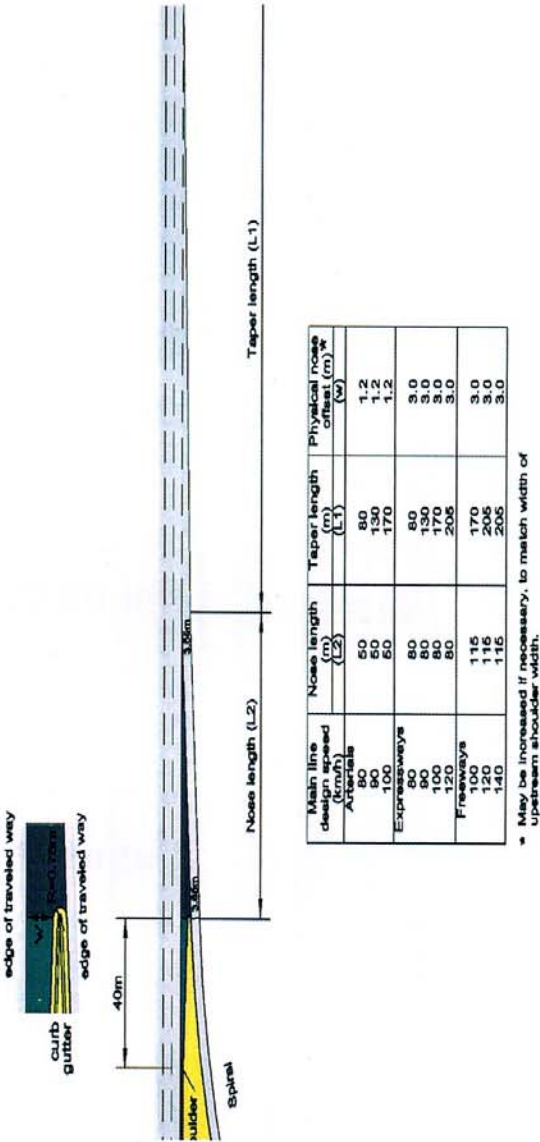


Figure 18.17: Taper Type On-Ramp (1-lane)

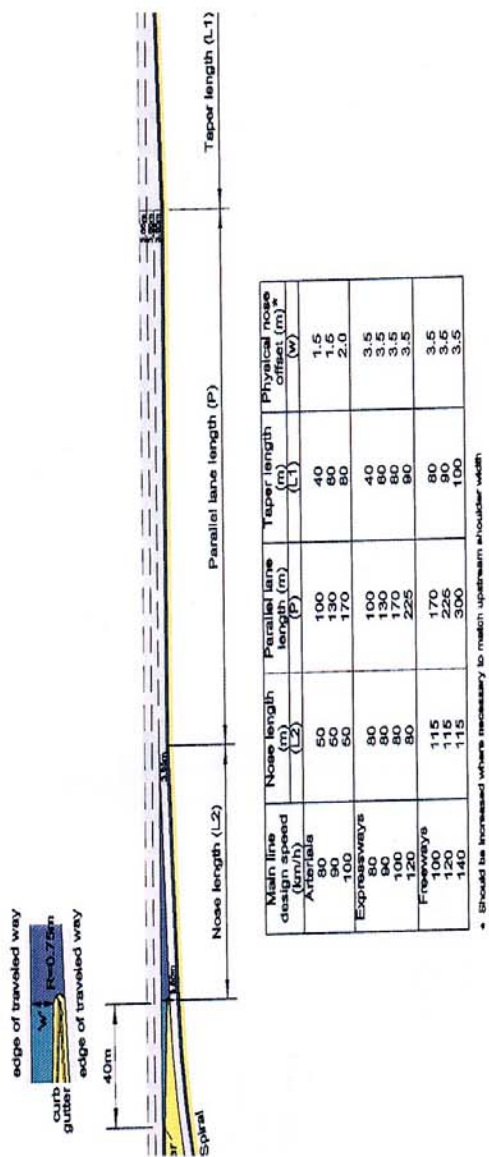


Figure 18.18: Parallel Type On-Ramp (1-lane)

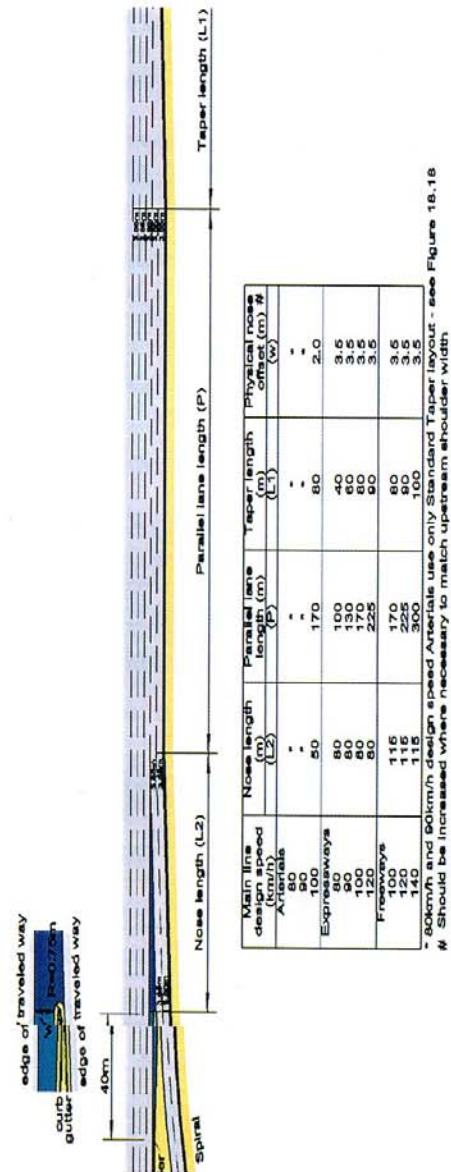


Figure 18.19: Tapper Type On-Ramp (2-lane with lane gain)

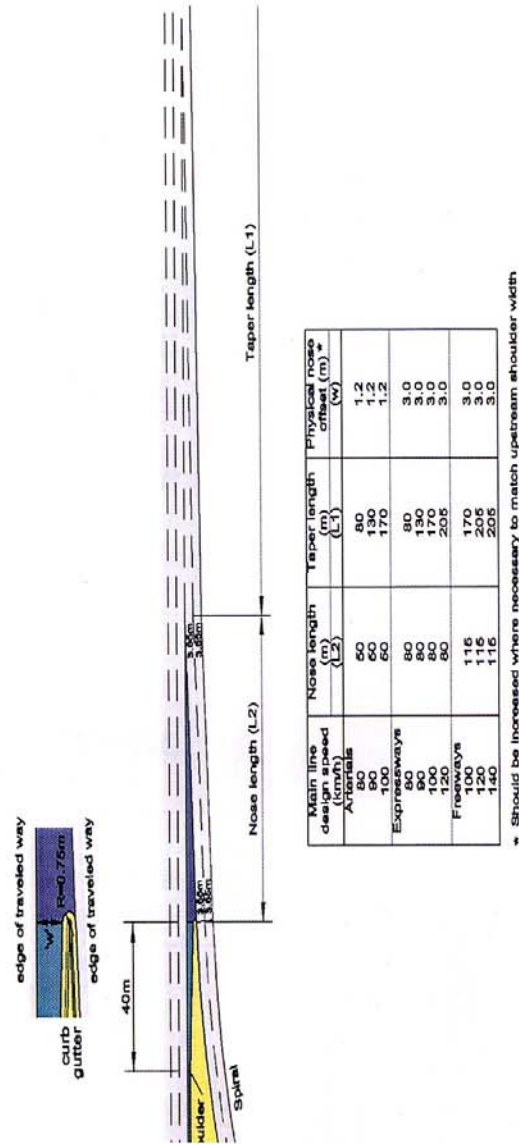


Figure 18.20: Parallel Type On-Ramp (2-lane with lane gain)

18.7.3 Acceleration Distances

Vehicles joining the main line need enough distance to enable them to gain enough speed to be able to merge smoothly into the flow on the main line, and this acceleration should take place clear of the main line.

Acceleration distance is measured from the end of the curve or other speed-limiting feature on the ramp, to the point at which the traveled way of the ramp falls below 3.65m.

The length necessary for acceleration depends on initial speed on the ramp and the relevant design speed of the main line, and should be provided in accordance with Table 18.4. The standard geometry of Figures 18.17 to 18.20 should be maintained, any additional length required for acceleration being provided between the end of the curve (or other speed-limiting feature) and the physical nose.

Table 18.4 : Distance to effect acceleration at change of design speed - level road

Design speed of main line (km/h)	Acceleration distance (m)									
	Stop	Design speed of connecting roadway (km/h)								
		30	40	50	60	70	80	90	100	120
50	60	50	#	-						
60	100	70	50	#	-					
70	145	n/a	85	50	#	-				
80	195	n/a	n/a	100	50	#	-			
90	275	n/a	n/a	175	130	50	60	-		
100	370	n/a	n/a	265	220	145	50	65	-	
120	520	n/a	n/a	445	400	335	245	170	70	-
140	690	n/a	n/a	n/a	n/a	n/a	n/a	450	200	90

Acceleration is not a relevant consideration, as the design speed differential is only 10km/h

Grades of 3% and above affect significantly the length required for acceleration, especially at higher operating speeds. Tables 18.4a to 18.4d set out the corresponding values for different grades.



Table 18.4a : Distance to effect acceleration at change of design speed - 3% and 4% up-grade

Design speed of main line (km/h)	Acceleration distance (m)									
	Stop	Design speed of connecting roadway (km/h)								
		30	40	50	60	70	80	90	100	120
50	70	65	#	-						
60	120	90	65	#	-					
70	175	n/a	110	70	#	-				
80	235	n/a	n/a	150	75	#	-			
90	330	n/a	n/a	265	195	75	60	-		
100	445	n/a	n/a	425	375	250	90	65	-	
120	625	n/a	n/a	715	680	570	440	310	125	-
140	830	n/a	n/a	n/a	n/a	n/a	n/a	810	360	165

Acceleration is not a relevant consideration, as the design speed differential is only 10km/h

Table 18.4b : Distance to effect acceleration at change of design speed - 5% and 6% up-grade

Design speed of main line (km/h)	Acceleration distance (m)									
	Stop	Design speed of connecting roadway (km/h)								
		30	40	50	60	70	80	90	100	120
50	80	70	#	-						
60	130	100	75	#	-					
70	190	n/a	130	80	#	-				
80	255	n/a	n/a	170	95	#	-			
90	360	n/a	n/a	315	260	105	60	-		
100	480	n/a	n/a	505	485	350	125	65	-	
120	675	n/a	n/a	1200	1200	1100	860	650	290	-
140	900	n/a	n/a	n/a	n/a	n/a	n/a	2000	1700	500

Acceleration is not a relevant consideration, as the design speed differential is only 10km/h

Table 18.4c : Distance to effect acceleration at change of design speed -

3% and 4% down-grade

Design speed of main line (km/h)	Acceleration distance (m)									
	Stop	Design speed of connecting roadway (km/h)								
		30	40	50	60	70	80	90	100	120
50	45	35	#	-						
60	60	50	35	#	-					
70	95	n/a	55	35	#	-				
80	130	n/a	n/a	65	35	#	-			
90	165	n/a	n/a	105	80	30	60	-		
100	225	n/a	n/a	160	135	90	30	65	-	
120	315	n/a	n/a	270	240	200	150	105	45	-
140	415	n/a	n/a	n/a	n/a	n/a	n/a	270	120	55

Acceleration is not a relevant consideration, as the design speed differential is only 10km/h

Table 18.4d : Distance to effect acceleration at change of design speed - 5% and 6% down-grade

Design speed of main line (km/h)	Acceleration distance (m)									
	Stop	Design speed of connecting roadway (km/h)								
		30	40	50	60	70	80	90	100	120
50	40	35	#	-						
60	60	45	30	#	-					
70	90	n/a	50	30	#	-				
80	110	n/a	n/a	55	30	#	-			
90	155	n/a	n/a	95	75	30	60	-		
100	185	n/a	n/a	135	110	75	25	65	-	
120	260	n/a	n/a	225	200	170	125	85	35	-
140	345	n/a	n/a	n/a	n/a	n/a	n/a	225	100	45

Acceleration is not a relevant consideration, as the design speed differential is only 10km/h



18.7.4 Forward Visibility

The forward visibility appropriate to the ramp design speed should be provided until the vehicle reaches the physical nose. Thereafter, the visibility should be in accordance with the design speed of the main line.

18.7.5 Superelevation

The considerations applying to on-ramp terminals apply equally to exits.

18.8 Connecting Roadways

18.8.1 Width

A lane width of 3.65m should be adopted on all connecting roadways, with widening only being provided where the horizontal curvature requires it.

Due allowance must be made for the consequence of a stalled vehicle on the connecting roadway. Two-lane facilities provide for passing, but on a single-lane facility, adequate shoulder width should be provided to allow passing of the largest design vehicles. As the geometric considerations are the same as apply to right-turning roadways in at-grade intersections, details can be found in Section 14.10.4 (Condition C applies).

18.8.2 Shoulders and Lateral Clearances

AASHTO⁽¹⁾ provided the following advice on shoulders and lateral clearances on ramps, and this should be adopted in Dubai:

- When shoulders are provided on ramps, they should have a uniform width for the full length of ramp.
- Ramps with a design speed of more than 60 km/h should have a right shoulder of 2.4 to 3.0m and 3.0 to 1.8m left shoulder. For the other ramps, the sum of the right and left shoulder widths should not exceed 3.6m, with a shoulder width of 0.6 to 1.2m on the left and the remainder as the right shoulder.
- The single-lane ramp traveled-way widths from Table 14.8 for Case 2 should be modified when shoulders are provided on the ramp. The ramp traveled-way width should be reduced by the total width of both right and left shoulder. However, the ramp-traveled-way width should never be less than required for Case 1. (For example, with condition C and 125m radius, the Case 2 ramp traveled-way width without shoulders is 6.6m. If a 0.6m left shoulder and a 2.4m right shoulder are provided, the minimum ramp traveled-way width would be 4.8m).

- The two-lane ramp traveled-way widths from Table 14.9 should be reduced by 0.6 where shoulder of 1.2 or more is provided,
- For freeway ramp terminals where the ramp shoulder is narrower than that on the freeway, the shoulder width of the through lane should be carried into the exit terminal, and should begin within the entrance terminal, with the transition to the narrower ramp shoulder effected gracefully on the ramp end of the terminal. Abrupt change should be avoided.
- Ramps should have a lateral clearance on the right outside of the edge of the traveled way of at least 1.8m, and preferably 2.4 to 3.0m, and on the left a lateral clearance of at least 1.2m beyond the edge of the ramp traveled-way.
- Where ramps pass under structures, the total roadway width should be carried through without change. Desirably, structural supports should be located beyond the clear zone. As a minimum of 1.2m beyond the edge of paved shoulder. (Chapter 7 of the this manual gives guidance on clear zone and the use of barriers).
- Ramps on overpasses should have the full approach roadway width carried over the structure.

18.8.3 Grade

Grades of up to 2% more than the relevant main line may be adopted, giving the following maxima shown in Table 18.5.

Table 18.5 : Maximum grades on connecting roadways

Main line class	Maximum grade on connecting roadway
Freeways / Expressways	6%
Arterials / Collectors	8%

Where a roadway connects a freeway or expressway to an arterial or connector, the maximum grade for the freeway / expressway (that is, 6%) should prevail.

On loops, the grade should be uniform throughout the length of the curve, and is generally be determined by the radius of the loop and the vertical separation of the roadways.

18.8.4 Superelevation

The maximum superelevation for connecting roadways is normally 4%, but values of up to 6% may be considered in urban areas.

For loops, however, the maximum value is 8%.



18.8.5 Vertical Alinement - Effect on Horizontal Geometry

The design of interchanges needs to be considered in three dimensions, and some key issues for the designer to consider are set out below:

- ***What is the likely construction thickness of overbridge decks?***
This depends on factors such as the span, the skew, the form of construction chosen, and whether the bridge has open or closed abutments
- ***What vertical clearance is required between the two road profiles?***
This is the construction thickness plus a clearance of at least 5.50m. As both roadways are likely to be superelevated, and possibly on vertical curves, it is necessary to check all four corners of the structure over the road pavement to ensure that minimum headroom is maintained at all points.
- ***What vertical alinement should be adopted in order to achieve the necessary vertical clearance between profiles?***
The chosen alinement generally dictates the horizontal location of the nose relative to the bridge structure.
- ***What slope should be used for the earthworks between the roads?***
This figure, which depends on the nature of the material concerned, should be agreed with the Roads Department of Dubai Municipality before design begins. It has a direct effect on how close the connecting roadway can be to the main line, and so the horizontal geometry should be checked at all points for compliance with this maximum slope value. Where physical constraints would require the adoption of steeper slopes, consideration should be given to the use of retaining walls or elevated viaduct structures, as these enable the two horizontal alinements to be kept close together.

18.9 Spacing of Ramp Terminals

18.9.1 Possible arrangements

There are four possibilities when considering two adjacent ramp terminals:

- Both are exits
- Both are entries
- The first is an exit, the second an entry
- The first is an entry, the second an exit

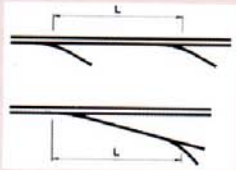
These are dealt with in turn below.

18.9.2 Exit / Exit

It is important that drivers are presented with simple choices, and for this reason the distance between the noses of successive exits from the main line need to be spaced at an appropriate distance. Similarly, having left the main line, the driver should not immediately be given a further choice as the ramp splits - this decision needs to be some distance beyond the main line exit nose.

In Table 18.6 below, these minimum distances, measured from one painted nose to the next, are set out.

Table 18.6 : Minimum spacing between successive exits

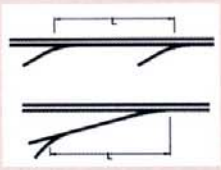
		Minimum distance from preceding exit nose (m)	
		Freeways / Expressways	Arterials / Collectors / C-D roads
Along the main line		300	250
On a ramp or connecting roadway	In a free-flow interchange	250	
	In other interchanges	180	

18.9.3 Entry / Entry

When two traffic streams join, this generally produces an area of “turbulence” for a distance downstream. A subsequent entry therefore needs to be located far enough downstream to avoid this unstable area, and Table 18.7 sets out the recommended spacings.



Table 18.7 : Minimum spacing between successive entries

		Minimum distance from preceding entry nose (m)	
		Freeways / Expressways	Arterials / Collectors / C-D roads
Along the main line		300	250
On a ramp or connecting roadway	In a free-flow interchange	250	
	In other interchanges	180	

18.9.4 Exit / Entry

This is the safest of the four layouts, and this is reflected in the shorter distances set out in Table 18.8.

Table 18.8 : Minimum spacing between an exit and the following entry

Minimum distance from preceding exit nose (m)	
Freeways / Expressways	Arterials / Collectors / C-D roads
150	120

18.9.5 Entry / Exit

This is the most complex of the four layouts, as weaving of traffic streams generally occurs. Only if the terminals are sufficiently far apart do they operate as a merging movement first, followed by a length of "open road" conditions, followed by a divergence.

Three considerations apply:

1. There is a minimum distance between noses to ensure safe operation even under very light flow conditions - this is the **minimum spacing**.
2. There is a minimum distance between noses to permit the traffic streams in the design year to cross each other safely - this is the **weaving length**.
3. There is a spacing beyond which weaving is considered not to be a relevant factor - this is the **upper bound** for weaving.

Considerations 1 and 3 are purely geometric, and are dealt with here; relevant values are given in Table 18.9. Consideration 2 is determined by the volumes of weaving traffic, and is dealt with in Section 18.10.

Table 18.9 : Spacing criteria for entry / exit arrangements

	Distance from preceding entry nose (m)			
	Minimum spacing			Upper bound
	Freeways / Expressways	Arterials / Collectors / C-D roads	For clover-leaf loops	All types
Leading to, or leading from, a free-flow interchange	600	480	The minimum is dependent on the geometric design of the clover-leaf loops	3000
Between two other interchanges	480	300		2000

Notes: 1. Longer lengths may be required for weaving - see below.
2. Where the length is less than 450m, an additional lane should be provided

18.10 Weaving

Where two streams of traffic, traveling in the same direction along the same section of road, require to cross, weaving occurs. If all vehicles are to cross each other safely, then there needs to be both sufficient width on the road, and sufficient length between the relevant entry and subsequent exit points. Both of these elements depend directly on the volume of traffic in each stream, and require to be calculated by the traffic engineer.

These calculations are outside the scope of this manual, and the designer is referred to the Highway Capacity Manual⁽²⁾. In essence, the length of the weaving section depends on the weaving traffic volumes (ignoring the non-weaving flows) and the operating speed. The width depends on the total flow on the weaving section, with weaving streams being given an appropriate additional weighting factor over non-weaving streams.

Where weaving volumes are high, and non-weaving volumes relatively low, the designer should consider carefully whether the amount of weaving could be



reduced, for example by reversing the ramp arrangements.

Weaving at clover-leaf interchanges is generally best handled on collector-distributor roads. Without these, the turbulence generally interferes with the smooth flow of traffic on the main line, and safety can be jeopardized. Weaving calculations must always be undertaken, as the outcome may well influence the design of the loops, or indeed dictate that another form of interchange be used. In all situations, a recovery area should be provided at the exit nose at the end of the weaving section.

18.11 Collector-Distributor Roads

Collector-Distributor (C-D) Roads are provided as a means of eliminating weaving on the main line. They are normally found within an interchange, but may be considered for use between interchanges if weaving difficulties are anticipated. C-D roads are at least two lanes in width, and generally adopt design speed 10km/h to 20km/h less than that of the main line. Decision Sight Distance to the downstream exit point should normally be provided for drivers on a C-D weaving length.

C-D roads should be considered for all cloverleaf interchanges, which inherently generate significant weaving movements. When design weaving volumes exceed 1000pcu/h, C-D roads should always be provided.

Although the provision of C-D roads increases the landtake through an interchange, its lower design speed may enable smaller loop radii to be adopted, thus offsetting this disadvantage.

Where a continuous length of C-D road is provided, transfer roads are provided to link it to the main line at suitable intervals. Both ends of the transfer road are designed as ramp terminals of the appropriate standard.

18.12 Other Design Considerations

18.12.1 Abnormal Load Requirements

The Designer should seek guidance from Dubai Municipality Roads Department to ascertain whether any additional clearance or headroom is required at specific structures in order to accommodate the movement of abnormal loads.

18.12.2 Superelevation

Superelevation and crossfall should be designed in accordance with the relevant advice in this manual. The Designer must ensure that the entire pavement drains

effectively and that there is no risk of long vehicles grounding at changes of superelevation.

18.12.3 Safety Barriers

Special consideration should be given to the safety barrier treatment at the physical nose of off-ramps. High speed vehicles which stray into the gore area are at particular risk, and the ends of safety barriers at these locations should be given special treatment to reduce the dangers of head-on impact. Consideration should also be given to the provision of energy absorbing terminations for these locations, particularly if bridge piers or other massive elements are located in the gore area..

Direction and warning signs for interchanges may be large and possibly gantry-mounted. The need for protection of isolated signs supports and gantry legs should be carefully assessed.

In addition to safety barriers designed to mitigate accidents, consideration should be given to provision of fences to prevent unauthorized movements within an interchange. Unauthorized movements such as those across verges between ramps and main line are highly dangerous and must be strongly discouraged.

18.12.4 Signing

Effective and clear signing is essential for the safe operation of any intersection. This is particularly true for interchanges, where vehicle speed and traffic volumes are high. Signs are large and frequently gantry-mounted, and adequate space must be allowed for the large foundations and clearances required.

Detailed guidance on signing is provided in the Dubai Traffic Control Devices Manual⁽³⁾. The Designer must consider the signing requirements at the preliminary design stage, because often these may be found to be more onerous, in spacing terms, than the geometric criteria set out in this manual. At this early stage the Designer can also identify suitable locations for signs, and check that visibility is not likely to be obscured, for example by a preceding overbridge.

18.12.5 Lighting

Suitable lighting can greatly reduce the potential for accidents throughout the road network. The Designer should consider lighting requirements at the preliminary design stage, and should bear in mind that tall lighting supports can have large bases which may need special attention.

18.12.6 Utilities

Information must be obtained from the Utility Authorities at an early stage of the design. Diversion or modification to existing or proposed equipment can have a



major impact on the detailed design and cost of an interchange. Utility Authorities may require service reservations to be provided through the interchange to accommodate future equipment as yet unspecified.

18.12.7 Emergency Vehicles

At the preliminary design stage the Designer should consider how emergency vehicles would reach the scene of an incident, particularly if the road is blocked by other vehicles held up by that incident. Provision of additional clearance width beneath structures could be considered, along with emergency median crossovers with demountable safety barriers. The potential advantage of an interchange which permits U-turns by emergency vehicles should also be borne in mind.

18.12.8 Maintenance Provisions

Maintenance of the pavement and the structures will be required during the life of the scheme, and the Designer should consider the implications of maintenance strategies and traffic management on the layout of his proposed interchange. He must ensure that the interchange can be safely maintained and that traffic movements can be reasonably accommodated while maintenance is taking place. The provision of one or more layby for the use of maintenance vehicles should be considered.

18.12.9 Environmental Issues

Environmental issues also need to be considered from the outset. All reasonable efforts should be made to design out unacceptable environmental impacts. Those impacts which remain should be mitigated as far as is practical.

A main impact of interchanges is the visual intrusion due to their sheer size. Careful landscaping can reduce the impact of large structures above ground level, and a combination of hard and soft landscaping often achieves the best results. The Designer should use materials in keeping with the surroundings and carefully consider colors, textures and styles. In proposing soft landscaping the Designer must consider how it can be safely maintained throughout the year, and define an appropriate watering regime.

Landscaping cannot be allowed to interfere with the operational requirements of the interchange, and in particular, landscaping features must not interfere with proper sight distances, obstruct visibility of signs, or reduce the effectiveness of road lighting.

18.12.10 Ramp Metering

When main line flows are near to capacity, vehicles entering a freeway or expressway find difficulty in merging safely with the through traffic. This can result in erratic driver behaviour and unexpected sudden braking, and can precipitate a reduction in Level of Service to LoS F.

The provision of a traffic signal on the on-ramp can enable the entering flow to be metered, and vehicles to be released into "gaps" in the through traffic flow.

Ramp metering signals are usually added to existing ramps, and operate only at peak periods when flow sensors indicate that flow levels have exceeded a pre-set threshold. It is very rare for the geometric design of an on-ramp to be undertaken with future ramp metering in mind.

Factors relevant to ramp metering include the following:

- The signals should be located far enough in advance of the merge point that released vehicles can accelerate from stop to the anticipated downstream operating speed.
- There should be adequate reservoir space, so that waiting vehicles do not interfere with the safe operation of the intersection or roadway at the head of the ramp.
- As the ramp will operate unmetered for most of the day, it should be designed to the normal geometric standards set out in this chapter.

References for Chapter 18

- (1) A Policy on Geometric Design of Highways and Streets 1994, American Association of State Highway and Transportation Officials, 1995.
- (2) Highway Capacity Manual (Special Report 209), Transportation Research Board, National Research Council, Washington DC, 1997.
- (3) Dubai Traffic Control Devices Manual (*draft*), 1995.