

avenue, but this can be unsatisfactory without focal points. It may be better to concentrate available land on one side of the road and plant a single row of trees, or to utilise any irregularities in the fence line for planting in groups. A spacious appearance can be given to the road by planting between the footway and the boundary, or beyond the boundary if the land is in the ownership of the local authority. Planting should normally be informal, but formal treatment may be required in certain places, as, for example, near a civic centre.

Trees should be chosen and sited so that they will not outgrow their positions, damage surfacing or underground services, overshadow adjoining buildings or require frequent pruning. Varieties which are liable to shed branches should not be selected. Trees which shed large leaves should not be planted close to the carriageway.

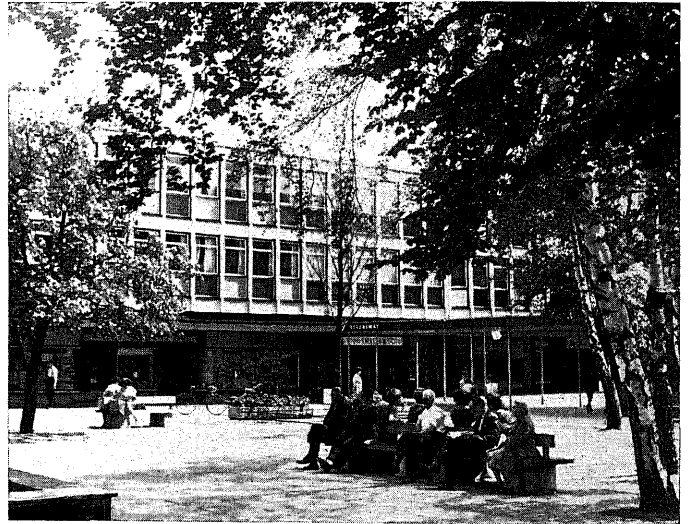
Trees and shrubs should never be planted where they might interfere with visibility; they should be set back a sufficient distance from the edge of the carriageway to allow for growth without prejudicing minimum clearances. If the road is likely to be widened in the future they should if possible be located where they will not be disturbed.

A dense plantation of trees and shrubs between the road and adjoining development may be useful as both a visual screen and a baffle against noise and dust.

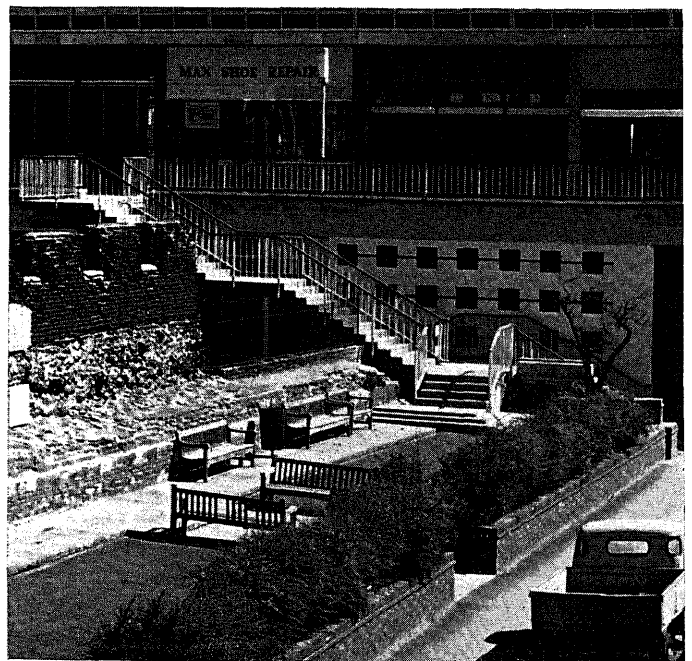
Useful information on the choice, siting and maintenance of trees is given in the Ministry of Housing and Local Government publication *Trees in Town and City*.¹³

5.8 Roadside advertisements

Full guidance on the safety aspects of the control of roadside advertisements is given in Circular No. 11/62 issued by the Ministry of Housing and Local Government.¹⁴ On motorways, only authorised traffic signs are permitted, but some advertisements may be allowed within service areas. It is obviously desirable that no advertisements likely to constitute a danger to traffic or to be detrimental to amenity should be erected on land adjacent to urban motorways and other distributor roads.



Trees add much to the attractiveness of this shopping centre



Roadside garden with steps leading to elevated footway system at London Wall

6 Structures

In the preliminary stages of establishing the line of a road in plan and profile, consideration should be given to the structures which will be required and to the economic, structural and aesthetic aspects of their design and construction. Bridges and tunnels should fit into the general road alignment, but their siting—especially in the case of major structures—may have an important bearing on the choice of route. A booklet on the appearance of bridges has recently been prepared by the Ministry of Transport with the assistance of the Royal Fine Art Commission.¹⁵

Bridges with curves or excessive skews, or founded on poor ground, are likely to prove difficult and costly to construct. Careful choice of route and some realignment of existing roads can often avoid these problems.

6.1 Bridge loadings

Bridges should be designed to carry the loadings specified in Ministry of Transport Memorandum No. 771: *Standard Highway Loadings*.¹⁶ Details of the standard loadings are given in Appendix A of British Standard 153, Part 3, Section A, 1954.¹⁷

6.2 Bridges over the road

Minimum clearances between the carriageway and the faces of abutments or piers are specified in Table 4-2. Minimum head-room of 16 ft. 6 in. must be provided and maintained over the carriageways and normally over paved verges (if any).

Bridge piers should be sufficiently robust to withstand possible vehicle impacts. When economically justifiable there should be no piers on the central reserve.

Where the road is in cutting and the bridge is of typical three- or four-span construction the slopes of the cutting should continue unchanged under the bridge. Slopes under bridges should be suitably paved with material in keeping with the appearance of the bridge.

6.3 Bridges carrying the road

Small-span bridges should be unobtrusive; where they are of the buried-culvert type the embankment should be carried through at full formation width.

Consideration should be given to possible advantages of designing bridges carrying dual carriageways with a separate structure for each carriageway. The two decks need not be widely separated, as the main economy can be achieved by breaking the transverse continuity. Open gaps between the structures can be achieved by covering with slats or open grids designed to withstand Type HA loading, as described in B.S. 153, Part 3, Section A, 1954.¹⁷ Where light wells are provided they should be protected by safety fences together with parapets matching those on the nearside.

The crossfall or superelevation of carriageways on bridges should conform to the normal standards for the road. Similarly, the footways, hard shouldered and central reserve should be constructed to the standard crossfalls. The whole of the deck

area including the verges and central reserve should be paved to prevent the ingress of water, and no earth should be allowed to encroach on the structure.

Consideration should be given to the possible need for electrical road heating on bridges and viaducts which may be particularly vulnerable to icing.

Bridges carrying the road over a railway should be designed to minimise possessions of the line during construction. The slowing-down of trains can often be avoided by providing greater



Hammersmith Flyover



Temporary flyover at a congested junction in Birmingham

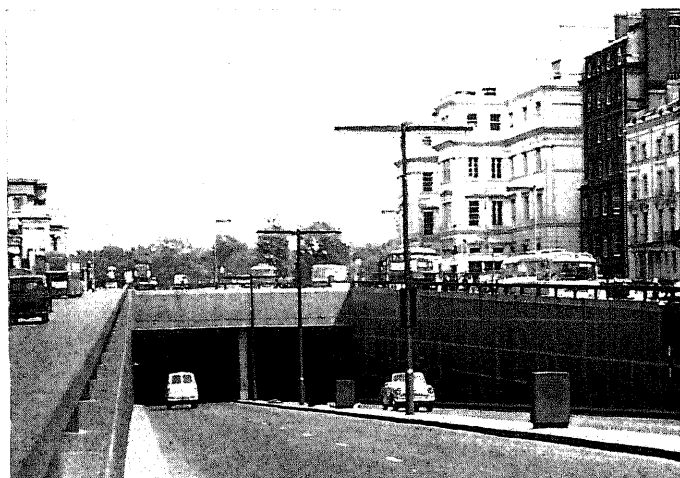
lateral clearances than the minimum demanded, and this may prove cheaper than using the minimum standards. The parapets must normally be of solid construction 4 ft. high, or 5 ft. high on bridges over railways electrified on the overhead system.

6.4 Tunnels

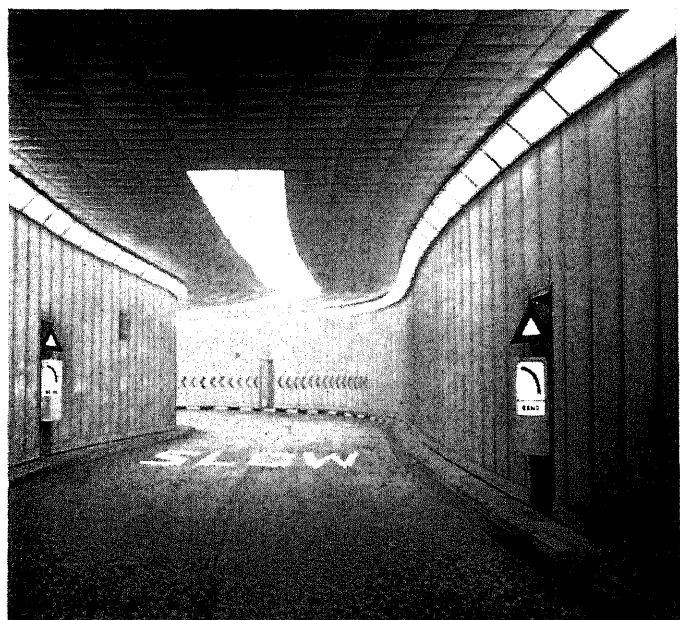
Tunnels are expensive to construct, drain and maintain, but it may sometimes be possible to meet at least part of their extra cost by permitting development to take place above them. The lighting of tunnel entrances and exits requires particular attention to ensure safe transitions between daylight and artificial lighting. The ventilation systems needed in long tunnels are costly to install and maintain. Ventilation must be adequate to cope with conditions arising from traffic congestion.

Roads in tunnel should usually conform to the normal design standards, but lower standards may be warranted in special cases. For example, at some junctions it may be advantageous to construct special tunnels with steeper gradients and lower headroom than normal solely for cars and other light motor vehicles, thereby affording sufficient relief to certain traffic streams to obviate the need for more costly and elaborate improvements.

The high cost of tunnel construction may make it impracticable to provide paved verges on urban motorways passing through long tunnels; in such cases lay-bys should be provided instead for emergency use.



Hyde Park Corner Underpass



Tramway tunnel converted for the use of cars and other light vehicles proceeding from Waterloo Bridge to Kingsway, London

7 Sewers and public utility services

7.1 Surface water drainage

Recommended procedures for the application of the 'rational' (Lloyd Davies) formula and the Road Research Laboratory hydrograph method to the design of surface water sewerage systems are given in Road Note No. 35: *A guide for engineers to the design of storm sewer systems*.¹⁸ The Note includes results of the work of the Hydraulics Research Station on the flow characteristics of sewers.

Crossfalls of carriageways, footways, etc., should be sufficient to ensure the rapid drainage of surface water without causing discomfort or danger to road users. Recommended crossfalls are given in Chapter 4. Surface water should normally be collected by means of gullies and discharged through a piped drainage system. Gullies should preferably be placed behind the kerb and should have side-entrance gratings. Gully gratings in the channels may be necessary, however, if the space behind the kerb is occupied by other underground services or if the steepness of the gradient precludes effective drainage by recessed or weir-type gullies. Suitable arrangements should be made for collecting surface water at changes of crossfall such as those arising from the introduction of superelevation.

Where the road is in cutting, French drains may be needed to intercept soil water and lower the water table under the road. French drains may also be required along grass-covered central reserves with a dished cross-section. Where French drains discharge into sewers, care should be taken to avoid their being flooded if the sewers become surcharged.

Special attention should be given to the drainage of underpasses, subways, cuttings, valley curves and other points where flooding might cause serious difficulties. The possible need for storm water storage and pumping should be considered. Drainage design for such situations should be sufficiently generous to cope with heavy storms.

7.2 Location of sewers

Surface water and foul sewers will usually be laid under the carriageway; there is little risk of interference to traffic as sewers rarely need to be uncovered for repairs. Where, however, there is a wide central reserve or the footways and verges are wide enough to accommodate sewers as well as other services, consideration should be given to siting the sewers clear of the carriageway. Main sewers should preferably be routed along streets of little traffic importance and through open spaces.

As sewers are normally laid in straight lines between manholes, their distance from the side of the road will depend upon road curvature. Clearances should always be sufficient for the accommodation of other services at the side of the road. Sewers should be deep enough to ensure that branch connections can be made without interference to other services. Where roads are wide and many branches are needed the duplication of sewers may be justified to shorten the connections and reduce the risk of having to open the road for repairs.

7.3 Public utility services

Public utility services are essential to the life of the community, but their proliferation has made the problem of accommodating

them within the highway extremely difficult. Furthermore, repair and maintenance operations often hinder traffic and accelerate the deterioration of the road structure.

Although any attempt to rationalise the positions of services in existing streets would be impracticable because of the high cost and interruption to traffic it is important that the positions of underground mains should be accurately recorded to facilitate repair work and minimise obstruction and traffic delays.

The construction of new roads or the improvement of existing ones will afford opportunities for the orderly accommodation of services under the footways and verges instead of under the carriageways. The laying of distribution mains in duplicate, one on each side of the road, will obviate the need for lengthy service connections under the carriageway; this will be advantageous to traffic and often more economical to the undertakers. Where, however, it is necessary for service connections to cross the road they should be laid before the carriageway is constructed.

As recommended in a report published by the Institution of Civil Engineers,¹⁹ mains should normally be located in the following order between the highway boundary and the kerb: electricity, gas, water, telecommunications. To ensure reasonable working space for each utility and to accommodate junction

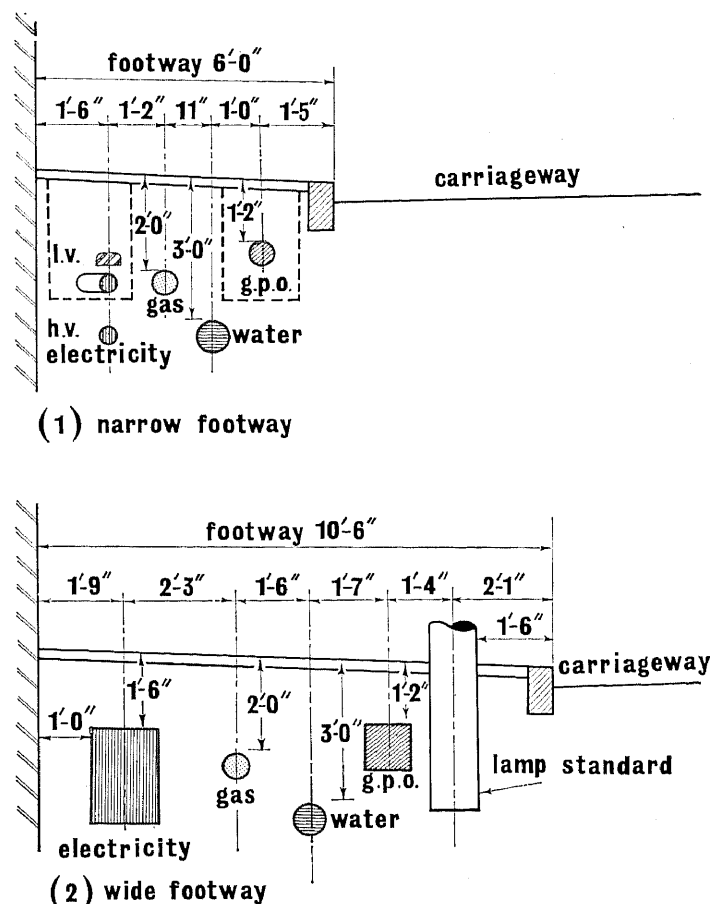


Fig. 7-1 Services under footways

boxes, hydrants, etc. a footway width of 10 ft. 6 in. is suggested, though where there are few pedestrians a lesser width may be accepted provided the mains are moderate in size. Fig. 7-1 shows the suggested disposition of mains in both narrow and wide footways. Electricity and telecommunications mains will require additional cover when placed beneath the carriageway. To accommodate services in narrow footways it may be necessary to site lighting columns at the back of the footway or to fix the lanterns to adjoining buildings.

Where land alongside the road has been acquired for future widening, the undertakers should be allowed to lay their mains on the land in advance of the roadworks, care being taken to ensure that the mains are laid on alignments and at depths in accordance with the final layout. At junctions and other points where services need to cross the road, pipes and ducts for both existing and proposed services should be laid before the roadworks start. Where it is known that additions to services will be needed in the near future it may be advantageous to lay the necessary pipes or ducts along the road in advance of the roadworks. Crossings of existing roads should be made by thrust borings where practicable to avoid disturbing the road surface and the flow of traffic.

In view of the high cost and other disadvantages of subways for the accommodation of services they are unlikely to be constructed along roads, but short subways may be useful where services cross under busy roads or important junctions. Services should usually be carried across road bridges in pipe bays under the footways.

Transmission and trunk mains should preferably be routed along streets of little traffic importance or across open ground. Where, however, they have to be laid along major roads they should be accommodated under the footways, verges or central reserve wherever possible.

To avoid obstruction of the highway any undertakers' equipment located above ground should desirably be sited outside the highway boundary or, if this is impracticable, behind the footway. Although the Postmaster General has special powers to site telegraph poles and other above-ground equipment within the highway it is his normal practice to meet the reasonable wishes of the highway authority on the siting of equipment. Telegraph poles are only erected in urban areas where distribution by underground cable is quite uneconomic.

7.4 Services along or across urban motorways

With the exception of the Postmaster General, statutory undertakers are not entitled to lay apparatus on, under or over land *along* the route of a motorway. Having regard to the paramount need not to restrict or endanger the flow of traffic and in view of the limited space available it will be virtually impossible to accommodate services along motorways additional to those needed for their operation.

Although apparatus may be laid down or erected on lines *crossing* motorways, subject to the consent of the Special Road Authority, including any necessary conditions, the number of such crossings should be as few as possible. Roads crossing over or under motorways will usually serve as convenient crossing points for pipes and cables. On bridges over motorways, pipe bays or cable ducts adequate for future needs should be provided under the footways. Where it is necessary for pipes and cables to cross the motorway at points other than bridges they should be placed at heights or depths suitable for their protection and the safety of the motorway and the traffic thereon; they should normally be placed in sleeves so that they can be withdrawn and replaced from outside the motorway. Manholes, inspection chambers, switch gear, pylons, etc. should be sited

outside the boundaries of the motorway so that maintenance and repair work can be carried out without interference to the road or the flow of traffic. Cases where existing apparatus falls within the boundaries of a new motorway should be considered on their merits.

As it may be necessary to provide facilities for telecommunications equipment both along and across motorways the G.P.O. should be consulted at an early stage so that their requirements can be ascertained before bridge and road designs are prepared.

8 Bus and coach services

8.1 Co-ordination of highway and public transport planning

Efficient public transport services must form an integral part of the overall plan for the development of every town and city. The future demand for public transport must be estimated at the forecasting stage of every comprehensive land use/transport study. In all towns public transport should be planned to be as attractive an alternative as possible to the use of the private car, particularly in town centres where some limitation of car usage may be unavoidable (see Planning Bulletin No. 7: *Parking in Town Centres*²⁰).

When improving existing roads or planning new ones it is important that there should be full consultation with the Traffic Commissioners and the operators to ensure that suitable facilities are provided for bus and coach services. Consultation should take place in the initial stages of the preparation of road schemes and should cover the provision to be made for bus and coach services to serve existing and proposed development as well as the siting of bus stops, terminals, bus stations and interchange points with other forms of transport.

8.2 Bus routes

Bus routes should be planned to give rapid and convenient access to as many parts of the town as practicable. Roads which are or may be used as bus routes should be suitable in width, alignment and construction and should include bus bays and passenger shelters where necessary. Junctions where buses turn should have easy corner radii and appropriate facilities for turning traffic.

In planning future development early consideration should be given to the likely demand for bus services, so that roads and junctions can be designed accordingly. Failure to foresee such demands may involve the use of unsuitable routes or even the restriction of services.

Buses will normally share roads with other traffic and will be subject to the same controls on movement, but special arrangements may be necessary to ensure that services can be effectively maintained and to avoid delays due to traffic congestion. These may include the application of waiting, loading and unloading restrictions to other vehicles, especially during peak hours, and allowing buses to carry out movements forbidden to other traffic. In some cases the reservation of lanes for use exclusively by buses or the exclusion of traffic other than buses from particular streets may need to be considered.

Buses will mainly be routed along *primary* and *district distributors*, but some routeing along *local distributors* will be needed to give easy access to environmental areas and central pedestrian precincts. Where local services penetrate into environmental areas street and junction layouts must be adequate; streets in environmental areas should not be used for non-stop through services. Buses may be routed along urban motorways but will not be allowed to stop on the through carriageways to pick up or set down passengers. As shown in Fig. 8-1, stops may be located on slip roads at interchanges or on special bus slip roads between interchanges.

8.3 Bus stops

Bus stops should not be sited where their use might unreasonably interfere with the flow of traffic or restrict visibility on bends or at junctions. When considering a site in the vicinity of an intersection its possible effect on traffic movement and the capacity of the approaches and exits should be taken into account.

A bus stop on the approach to an intersection should be far enough away to ensure that:

- (i) a waiting bus does not obstruct visibility leftwards from the main road to the side road, or to the right from the side road to the main road;
- (ii) traffic wishing to turn left is not obstructed by the bus (if buses turn left at the junction it may be possible to incorporate a bus bay at the beginning of an additional lane for left-turning traffic);
- (iii) a bus requiring to turn right after leaving the stop has ample room to cross safely to the lane for right-turning traffic;
- (iv) waiting buses do not interfere with the efficient working of traffic signals or the movement of traffic at a roundabout.

To avoid the above difficulties it will often be preferable (provided the road layout and other factors permit) to site bus stops on the exit side of an intersection, especially where bus routes diverge at the intersection.

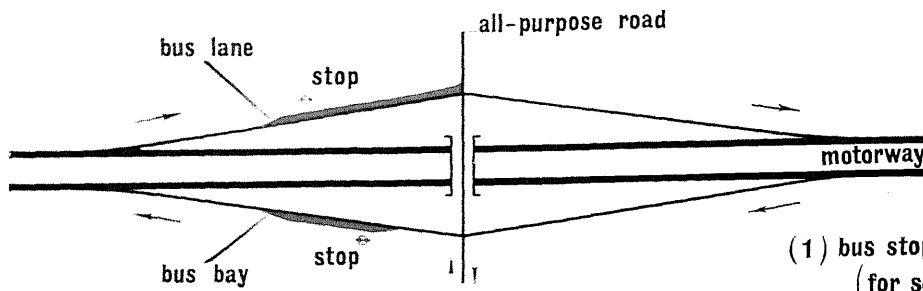
Stops located midway between junctions have the advantage of avoiding interference with turning traffic, but may sometimes be less convenient for passengers and may tempt them to cross the road at unsuitable points. Where possible, bus stops should be located in conjunction with pedestrian subways and bridges.

Where the width available is insufficient for the construction of a waiting bay and buses have to stop at the normal kerb line, there should be room for at least one line of traffic in the same direction of travel in addition to the space occupied by the bus. To ensure that buses can stop at the kerbside without obstructing the through lanes, other vehicles should not be allowed to park near bus stops.

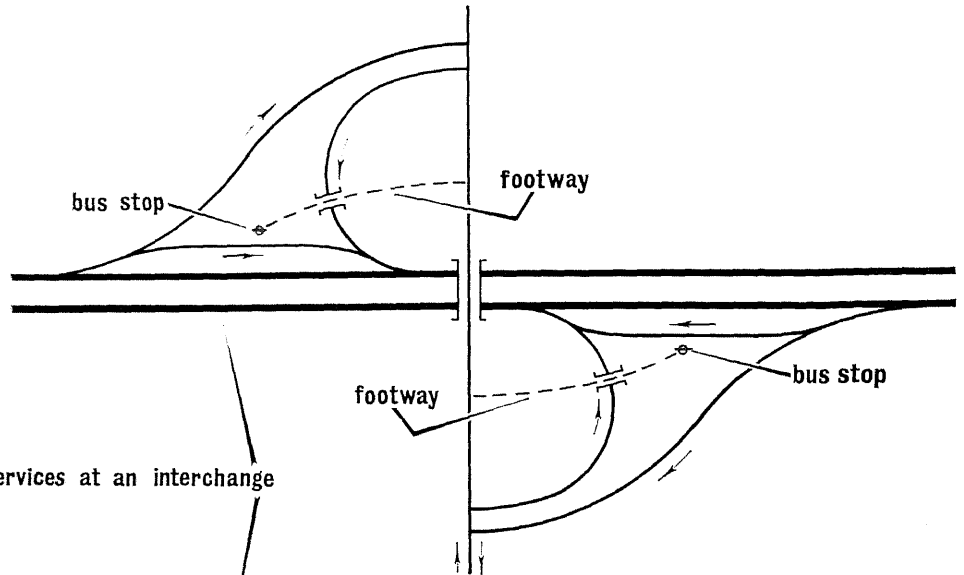
Bus stops on opposite sides of single two-way carriageways should be staggered, preferably so that buses stop tail-to-tail and move off away from each other. The staggered stops should be 200 to 300 ft. apart.

To maintain reasonable operating speeds and minimise interference to other traffic, bus stops should preferably be spaced at intervals of not less than 1,200 ft. along all-purpose distributor roads. On important roads with a high degree of access restriction a spacing of 1,800 ft. or more may suffice. A lower spacing than normal may be warranted where the demand is heavy, especially where pedestrians might otherwise have to cross a heavily-trafficked junction to reach a bus stop.

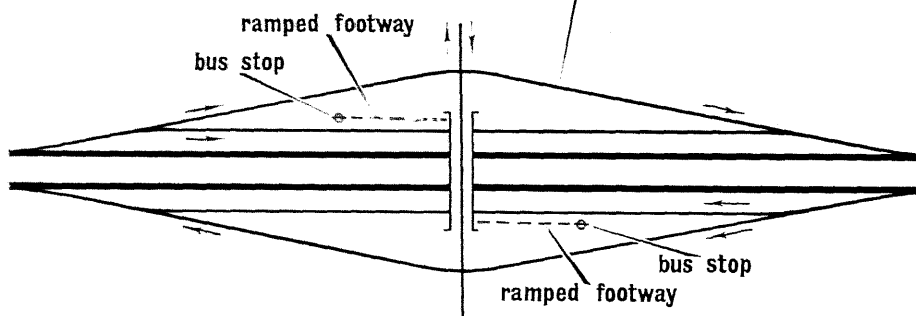
Although buses will not be allowed to stop on the through carriageways of urban motorways, stops may be located at bus bays on interchange slip roads and on special bus slip roads at intermediate points with easy pedestrian access to the all-purpose road system. Some typical arrangements are shown in Fig. 8-1.



(1) bus stops on interchange slip roads
(for services entering or leaving
an urban motorway)



(2) bus stops for through services at an interchange



(3) bus slip roads and stops at points between interchanges

Fig. 8-1 Typical arrangements for bus stops on motorway slip roads

8.4 Bus bays

Where space permits, bus bays should be provided at bus stops. Their length will depend upon the number of buses they may have to accommodate at any one time. As shown in Fig. 4-5 bus bays should preferably be 10 ft. 9 in. wide, but where space is restricted or costs are likely to be high narrower bays will still be useful; the minimum width should normally be 9 ft. At each end, bus bays should be tapered gradually towards the carriageway so that buses can leave or rejoin the traffic stream smoothly and safely. Where bus bays and ordinary lay-bys have to be combined the spaces for buses should be clearly marked so as to permit easy ingress and egress.

To lessen the risk of a bus queue being splashed in wet weather, it is preferable that the crossfall of a bus bay should be outwards from the kerb towards the carriageway. With this arrangement surface-water drainage will require special attention; the provision of slotted drainage blocks across the mouth of the bay may be helpful.

8.5 Passenger shelters

Queue shelters should be erected at busy stops not only to give shelter but to encourage orderly queueing; they should be provided with splash guards to protect the queue from splashing by vehicles. Queue shelters must of necessity be erected adjoining the kerb (with the appropriate clearances as indicated in Table 4-2), and footways may have to be widened to accommodate them. Care should be taken to ensure they do not interfere with sight lines.

Shelters equipped with seats may be desirable where travellers may have to wait for long periods. These should usually be erected at the back of the footway or behind the highway boundary.

8.6 Bus stations and terminals

Where many services radiate from the town centre, bus and coach stations may be required to serve both local and long-distance traffic. There should be full consultation with the operators and with the Traffic Commissioners when such arrangements are being considered. Ideally the stations should be combined or near to one another. If the railway station is close to the town centre it will be convenient if the combined bus and coach station is located nearby.

Bus stations will normally be located within or close to the central area and should have easy access to the distributor road system. Buses should be able to enter and leave the station without delaying or endangering other traffic—preferably without having to cross or turn right against opposing traffic streams. Unless bus stations and their accesses are carefully sited the concentration of bus traffic may overload nearby streets and junctions.

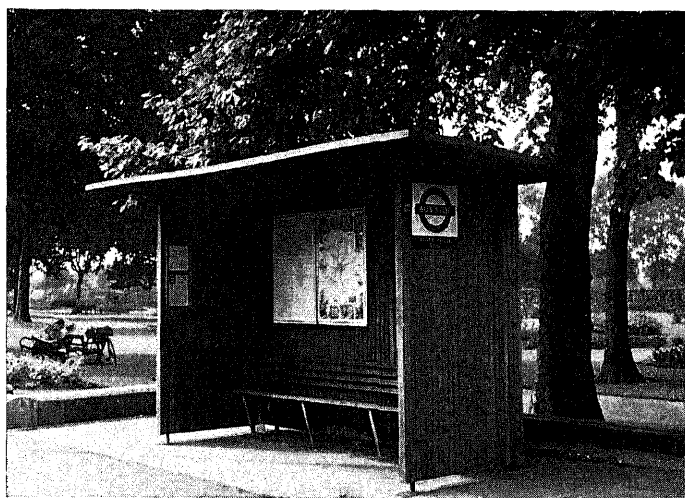
Special attention should be given to the design of pedestrian routes to and from bus, coach and railway stations. Pedestrian crossings, subways and bridges should be provided where necessary. Ideally the stations should be linked to a comprehensive system of pedestrian ways.

Accommodation should be provided off the highway for buses waiting at terminal points during quiet periods; terminals should be designed to avoid any need for reversing, having regard to turning circle requirements. Large factories and offices with special bus services should have space for loading and unloading within their boundaries, with safe access to the highway. Consideration should also be given to the possible need for car parking facilities when picking up passengers at stations or terminals.

The introduction of 'park and ride' facilities from bus stops or terminals on the outskirts of the town or central area should be considered if the use of cars in the central area is to be discouraged. Provision of all-day car parks adjoining suitable bus stops or terminals and the issue of combined parking and bus tickets will offer the commuter an attractive alternative to the use of the private car for travelling into the town centre.

8.7 Cab ranks

Cab ranks are likely to be required near railway and bus stations. Where possible they should be sited within the curtilage of the stations. Cab ranks at other points should be sited away from main thoroughfares but should be easily accessible. Cabmen's shelters should be located where they do not restrict visibility or obstruct the footway or carriageway; they should preferably be sited off the highway.



Passenger shelter located behind highway boundary



This bus station is conveniently located directly beneath Birmingham's Bull Ring Shopping Centre

9 Junction design—general considerations

9.1 Accidents at junctions

The need for good junction design is exemplified by the fact that well over half the fatal and serious road accidents in built-up areas occur at junctions.

The value of restricting the number of junctions along major roads has been demonstrated by an analysis of accidents at three-leg priority junctions. This showed that the number of accidents in a given period is approximately proportional to the square root of the product of the flows on the major and minor roads.²¹ If two side roads are linked before reaching the major road the number of accidents will be about 30% less than if they join it separately. If several side roads can be combined before reaching the main road the gain will be even greater.

9.2 Junction capacity

The capacity of an urban road is often governed by that of its junctions. If the volume of crossing or turning traffic is small and the major road is lightly trafficked, simple junction designs will suffice, but on busier roads the achievement of the required route capacity and the avoidance of excessive delays will call for the adoption of more complex designs with channelisation, gyratory systems, traffic signals, grade separation, or a combination of these features.

Junctions should normally be designed with sufficient capacity to accommodate the planned future peak flows that are practicable on the network. In planning the network, junction capacity should be kept in balance with that required on the road system between junctions. The impracticability of widening certain roads in the foreseeable future may affect the distribution of traffic and influence junction design. Where road widths are restricted, maximum flows may be estimated by adding 15% to the practical carriageway capacities given in Tables 1-4 and 1-5 and should usually assume prohibition of waiting on the carriageway.

9.3 Design considerations

Junction designs should have regard to the flows, speeds, composition, distribution and future growth of traffic. Where an existing junction is to be improved an examination of the accident record will frequently indicate defects which should be remedied in the new layout. Designs should be tailor-made for each site, with due regard to physical conditions at the site, the amount and cost of the land required, the cost of construction and the effect of the proposals on the neighbourhood. Due allowance should be made for the space needed to accommodate traffic signs, lighting columns, underground services, subways, etc.

The preparation of alternative designs and a comparison of their costs and benefits will often be desirable, especially for the more complex and costly proposals. Where grade separation is envisaged ultimately, any earlier improvements should be planned as far as practicable to conform to the future layout.

9.4 Control of development, access and street parking

Where the improvement of a junction is being carried out in stages over a period of years it is important that development proposals in the vicinity should conform to the ultimate layout. As the efficiency of a junction may be prejudiced by the presence of vehicular and pedestrian accesses, it is essential that all development nearby should be carefully controlled. Places of public resort and other development attracting large numbers of people and vehicles should not be located near a junction unless satisfactory arrangements can be made to avoid interference with the flow of traffic and to ensure the safety of pedestrians.

Where necessary the capacity and safety of junctions should be preserved by prohibiting parking on the approaches and exits and by adopting appropriate measures to safeguard pedestrians.

9.5 Pedestrians at junctions

The difficulty of reconciling the interests of pedestrians with those of other road users is greatest at junctions, since at these points the movements of vehicular traffic are usually complex and demand the close attention of drivers, sometimes to the detriment of pedestrian safety.

When designing junctions the possible need for (and the siting of) guard rails, refuges and pedestrian crossings should be considered. At the busiest junctions pedestrian subways or bridges may be required. At junctions where the construction of special bridges or subways is impracticable or cannot be justified, other methods should be considered; these might include the simplification of traffic movements by channelisation or prohibiting certain turns or, at signal-controlled junctions, the introduction of pedestrian phases.

In planning the future road system provision should be made for the segregation of pedestrian and vehicular traffic at points where there will be heavy concentrations of both and dangerous conflicts will otherwise be likely to occur.

9.6 Visibility at junctions

To ensure safety and maximum capacity it is important that junctions should have at least the standards of visibility recommended in Section 10.2. Where a junction has to be located on a bend, in a cutting, at or near a summit, or near a bridge, the achievement of the required visibility may be difficult, but special care should be taken to comply with the standards. Telephone kiosks, signs, shrubs, etc. should not be placed where they would restrict visibility.

It will assist traffic flow and safety if single-level intersections have reasonably level approaches. The easing of gradients on the approaches may improve visibility and will facilitate stopping and starting, particularly in frosty weather.

9.7 Lighting and signposting

The adequate lighting of junctions in urban areas is essential and should include the illumination of channelising islands and

refuges in a manner sufficient to render them visible even in misty weather. The safety of a junction will also depend on the adequacy of the carriageway markings and traffic signs; these should be provided in accordance with the latest standards and should be maintained in good condition at all times.

9.8 Junction spacing

The spacing between junctions should always have regard to design and traffic requirements such as the lengths needed for right-turn or speed-change lanes or for weaving manoeuvres and should be calculated accordingly. As a rough guide, suggested minimum spacings along various types of road are given below:

<i>Primary distributor</i> (urban motorway)	1,800 ft.
<i>Primary distributor</i> (all-purpose)	900 ft.
<i>District distributor</i>	700 ft.
<i>Local distributor</i> or <i>access road</i>	300 ft.

Greater distances should be provided where necessary, as for example between junctions with linked traffic signals, where a spacing of 1,300 ft. would be appropriate between junctions on all-purpose *primary distributors* with a 40 mph speed limit, and one of 900 ft. between junctions on *district distributors* with a 30 mph speed limit.

The location of and spacing between all major points of access, including accesses to bus stations, vehicle parks, etc. as well as junctions, should be carefully considered to ensure safety and freedom from congestion.

10 Priority junctions

At a priority junction, traffic from the minor road is expected to give way to that on the major road and is controlled by a GIVE WAY sign or, at certain minor junctions, by carriageway markings only (where visibility is severely restricted, control may be effected by STOP signs, but these would not be appropriate for new or improved junctions). Priority junctions include three-leg intersections (T, Y or fork) and four-leg intersections (direct or staggered). At these junctions the presence of the major road should always be clearly evident from the layout, signposting and road markings. Where both roads are of about the same traffic importance (e.g. the junction of two *access roads*) priority should be given to one (normally the more heavily trafficked) and the junction designed accordingly.

Many of the design features described in this part will also be applicable to other types of junction.

10.1 Capacity

The curves in Fig. 10-1 are applicable to both T junctions and crossroads. Staggered crossroads should be regarded as two T junctions. For direct crossroads the curves indicate the traffic that can enter from the more heavily trafficked side road.

With good visibility from the side road the capacity of the junction will be as indicated by Curves 1 and 2. When traffic gaps on the major road are long enough, vehicles may be able to emerge from the side road in groups, without necessarily having to stop at the major road.

Curves 3 and 4 show the maximum volume of traffic that can enter or cross the major road from a side road with a single-lane approach when visibility is restricted on the approach but adequate at the stopped position.

These curves afford only a general guide to junction capacity in urban conditions. Gaps in the major road flow caused by traffic signals or pedestrian crossings nearby may increase capacity. On the other hand, capacity may be reduced by unequal directional distribution of traffic on the major road, substandard visibility at the junction, an up-grade on the side road approach, or a high proportion of heavy traffic from the side road.

Improved capacity can be obtained where the major road has a central reserve wide enough to shelter traffic and permit movements to or from the side road to be made in two parts. A reserve width of at least 15 ft. is desirable for this purpose.

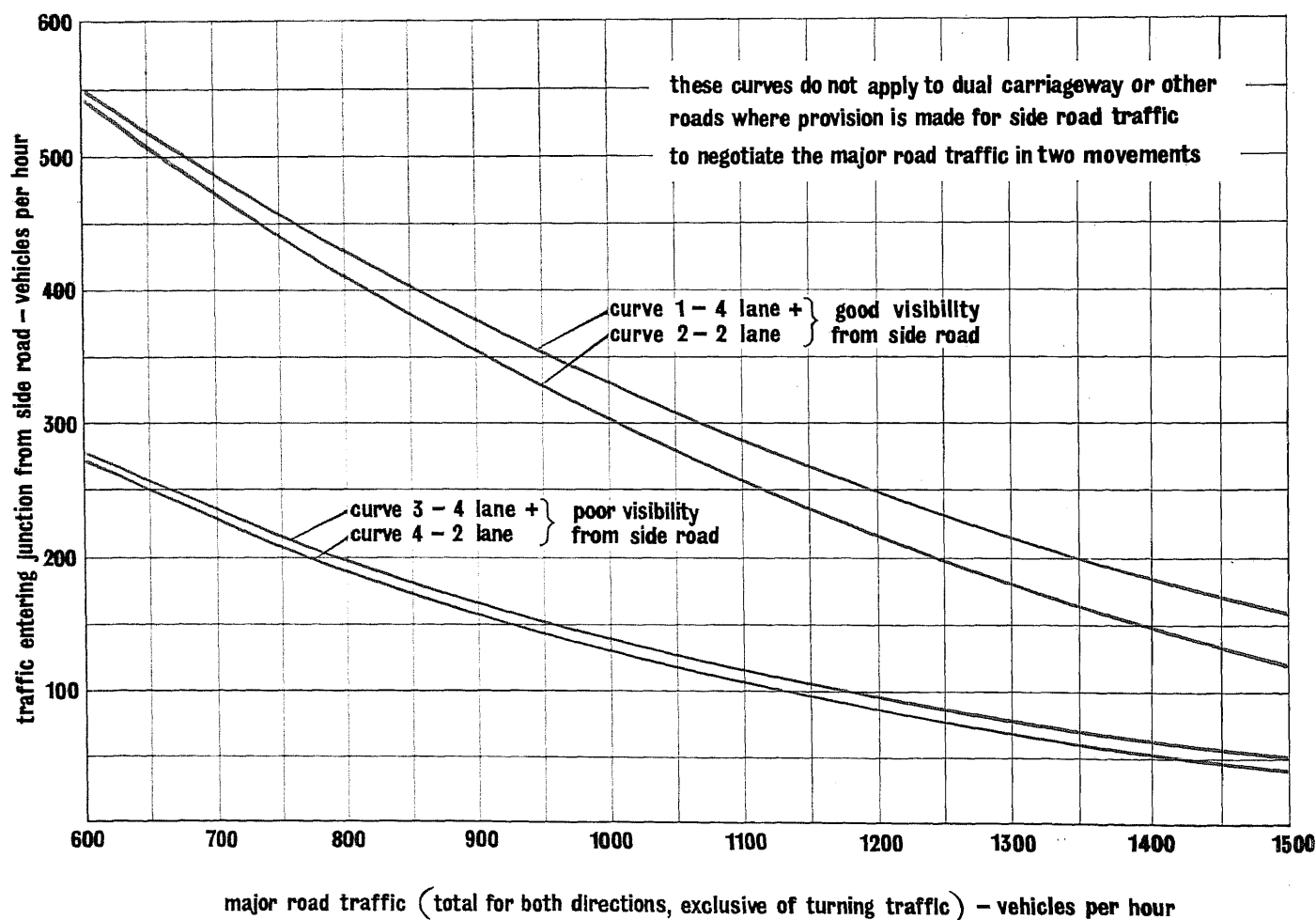


Fig. 10-1 Capacity of priority junctions

10.2 Visibility

At priority junctions full visibility will be needed to the right and left between points 3 ft. 6 in. above road level over areas defined by:

- (i) a line x ft. long measured along the centre line of the side road from the continuation of the nearer edge of the major road carriageway (for values of x see Table 10-1);
- (ii) a line y ft. long measured along the nearer edge of the major road carriageway from its intersection with the centre line of the side road (for values of y see Table 10-1);
- (iii) a straight line joining the ends of the above lines.

Table 10-1 Visibility distances at priority junctions

Type of major road	Speed limit mph	Minimum visibility distance y ft.
All-purpose <i>primary distributor</i>	50	500
	40	400
<i>District or local distributor</i>	30	300
<i>Access road</i>	30	200

The x distance should normally be 30 ft. Some reduction may be reasonable if the side road is lightly trafficked, as may be so for some culs-de-sac and other *access roads*. On such roads the x distance may be reduced to 15 ft. in urban areas, but the y distance should remain the same.

These standards will apply to new junctions and, where possible, to improved junctions. It is recognised, however, that site difficulties may sometimes make it impossible to improve existing junctions to the standards recommended above. In such cases the best possible sight lines should be provided, but full visibility y should always be obtainable from a point on the centre line of the side road either in line with the continuation of highway boundary of the major road or 7 ft. back from the edge of the major road, whichever gives the greater x distance.

If the major road is one-way a single splay line in the direction of approaching traffic will suffice. Similarly, if the major road has dual carriageways with no gap in the central reserve only a single splay line to the right will be needed. If the side road serves as a one-way exit from the major road, no splay will be required provided forward visibility for turning vehicles is adequate (Table 13-3 gives appropriate stopping distances for various radii).

Where the major road has dual carriageways with a central reserve wide enough to shelter turning vehicles (15 ft. or more) the normal visibility splay to the left of the side road will not be needed, but the central reserve should be clear of obstructions to driver visibility for at least y ft.

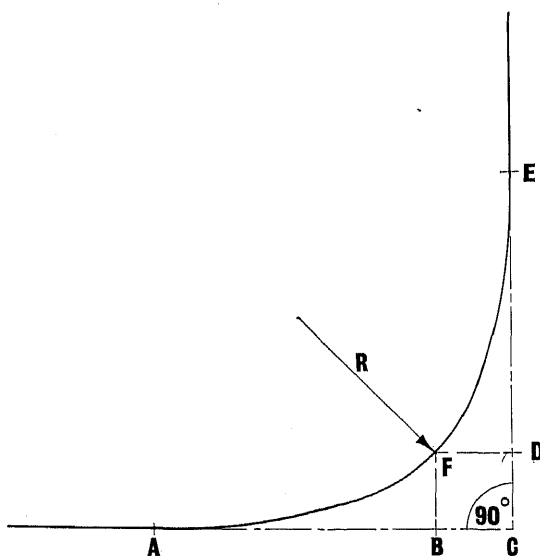
Dangerous conditions may arise if, despite the provision of visibility splays, vehicles are allowed to park within the splay lines, thereby obstructing visibility. Where necessary, parking and access should be controlled to minimize this risk.

10.3 Corner radii

Junctions should be designed so that vehicles do not have to go over to full lock when turning. In view of the relatively small proportion of vehicles with turning circles in excess of 70 ft. diameter, a kerb radius of 35 ft. will suffice for junctions used by commercial vehicles. In residential streets a kerb radius of 20 ft. should normally be regarded as the minimum.

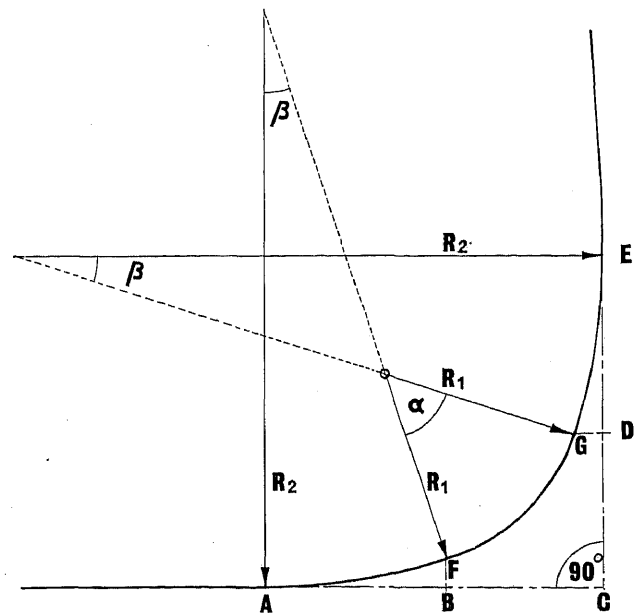
Turning can be made easier and safer by providing transition or compound curves on the corners instead of circular arcs. This will reduce risks due to vehicles swinging out of lane to avoid the rear wheels hitting the kerb. The transition or compound curves should have a minimum radius appropriate to the type of traffic using the junction. Compound curves will normally be three-centred, but two-centred designs will sometimes be useful. The major radius or radii should be two or three times the minor radius; the arc lengths of each segment should be about the same.

The use of spirals and compound curves in junction design is illustrated in Fig. 10-2.



min. radius R	AC, CE	AB, DE	BF, DF
35'	65.4'	51.6'	13.8'
30'	56.0'	44.2'	11.8'
20'	37.4'	29.5'	7.9'

(1) spiral



R_1	R_2	β	α	AC, CE	AB, DE	BF, DG
35'	105'	18°	54°	60.5'	32.9'	5.1'
30'	90'	18°	54°	51.8'	28.2'	4.4'
20'	60'	18°	54°	34.5'	18.8'	2.9'

(2) compound curve

Fig. 10-2 Corner design

10.4 Channelising islands

Channelising islands should be provided where necessary at priority and other types of junctions:

- (i) to separate conflicting traffic streams;
- (ii) to assist traffic streams to intersect or merge at suitable angles;
- (iii) to control vehicle speeds;
- (iv) to provide shelter for vehicles waiting to carry out certain manoeuvres such as turning right;
- (v) to encourage drivers to take the correct path and deter them from taking incorrect ones;
- (vi) to assist pedestrians to cross;
- (vii) to reduce excessive carriageway areas.

Fully channelised designs may require too much space for universal adoption, but it will often be useful both to safeguard and to facilitate major turning movements by partial channelisation. Separation of the less important turning movements may not be necessary or may be impracticable without making the channelising islands too small.

To enable islands to be seen clearly they should usually be bordered by raised kerbs and should have an area of at least 50 sq. ft.; smaller areas may be defined by carriageway markings alone. Risk of overriding the islands can be reduced by slightly offsetting the approach nose from the edge of the carriageway, as shown in Diagrams (1) and (2) of Fig. 10-3; an offset distance of 1 or 2 ft. will usually be suitable in urban areas. Where necessary, additional guidance to traffic should be given by carriageway markings in advance of the nose [Diagram (3)]. The markings should be reinforced by diagonal white stripes or chevrons where it is particularly important that the nose should be conspicuous [Diagrams (4), (5) and (6)].

It is important that channelised junctions should be well lighted at night. Without adequate lighting they may be confusing to motorists.

10.5 Refuge islands

A traffic refuge can serve as both a channelising island and a haven for pedestrians. A refuge on the minor road at a T junction should preferably be sited so that the end nearer the intersection is at least 10 ft. behind the continuation of the kerb line of the major road. There should be sufficient room on both sides of the refuge to enable large vehicles to turn comfortably into and out of the side road. Where the major road has four or more lanes the clearance for traffic turning into the side road should preferably be 18 ft. and not less than 15 ft.; that for traffic emerging from the side road should be at least 12 ft. These clearances should be measured to the continuation of the main kerb lines of the side road, not to the radius kerbing on the corner (see Diagram (2) of Fig. 10-6). If the major road has only two lanes even greater clearances will be needed where large vehicles turn, and it may be impracticable to site a refuge on the minor road sufficiently near the junction to be useful to pedestrians.

Refuges should only be provided on the major road at a junction if it is at least four lanes wide. Where possible, the normal lane width of the major road should be maintained past the refuges, but if some reduction is unavoidable the clearances should not be less than 18 ft. The refuges should be sited as near to the junction as possible but should allow ample room for large vehicles to turn into and out of the side road. Refuges may be located in the manner suggested in Section 10.7 for positioning gaps in a central reserve; it will often be useful to site them temporarily in the first place in order that the position best suited for local conditions can be determined by observation.

The carriageway widths of both major and minor roads should be increased as necessary to accommodate traffic refuges. The additional width should be obtained by the gradual widening of the approaches, preferably on flares not sharper than 1 in 25.

Typical junction designs incorporating refuges are shown in Figs. 10-6 and 10-7. Recommendations on the construction and illumination of refuges are given in Sub-Section 4.1.8.

10.6 Carriageways in junctions

Where any length of a single-lane or two-lane carriageway in a channelised or grade-separated junction is on a sharp bend it should be made wide enough to ensure adequate clearances, with due allowance for vehicle widths, frontal overhang and off-tracking of the rear wheels. Suggested carriageway widths for turnings used by large commercial vehicles are given in Table 10-2 (for lane widening on larger curves see Sub-Section 4.1.2). The widths in the second column are appropriate for short turnings at channelised junctions and single-lane carriageways of one-way slip roads (see Section 13.3); those in the third column are suitable for longer connections and also indicate desirable carriageway plus nearside verge widths for single-lane one-way slip roads; those in the last column apply to either two-way or one-way carriageways requiring two traffic lanes. Compound curves or curves with transitional approaches should be used where possible on sharp bends.

Table 10-2 Carriageways in junctions

Inner radius ft.	Single-lane width ft.	Single-lane width with space to pass stationary vehicle ft.	Two-lane width for one-way or two-way traffic ft.
35	18	34	38
50	17	31	35
75	16	28	32
100	15	26	30
125	14	25	29
150	14	24	28
200	14	23	27

10.7 Gaps in the central reserve

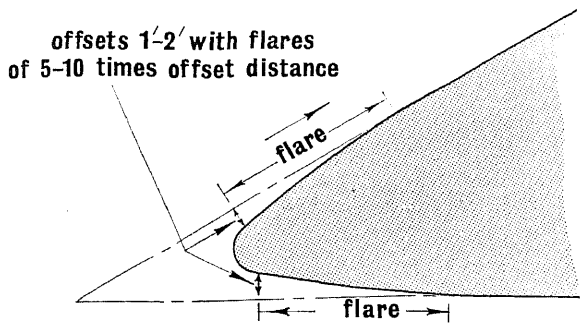
To ensure that large vehicles can turn right without difficulty to or from the major road, the gap in the central reserve at a junction should normally extend at least 10 ft. beyond the continuation of both kerb lines of the minor road to the edge of the major road (see Fig. 10-4) and should also be determined by 40 to 50 ft. radius control circles tangential both to the centre line of the minor road (or to the sides of any refuge or island) and the side of the central reserve away from the minor road. To facilitate turning the ends of the central reserve should be bullet-nosed.

10.8 Speed-change lanes

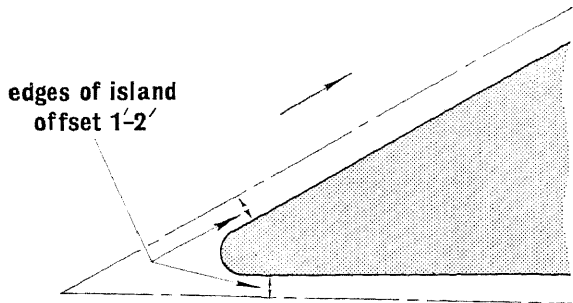
Provision of full-length acceleration and deceleration lanes will rarely be warranted at priority junctions in urban areas, but the provision of shorter lanes to assist merging and diverging manoeuvres may be useful in conjunction with channelised designs. Lane lengths will depend on site conditions but should desirably be at least half those quoted in Table 13-2.

10.9 Right-turn lanes

Storage lanes for right-turning traffic constructed within the width of the central reserve are useful both on new schemes and

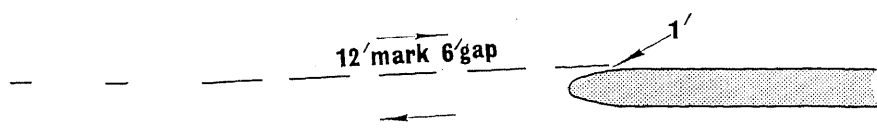


(1)

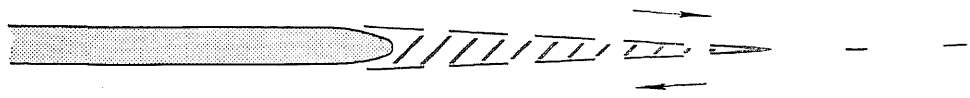


(2)

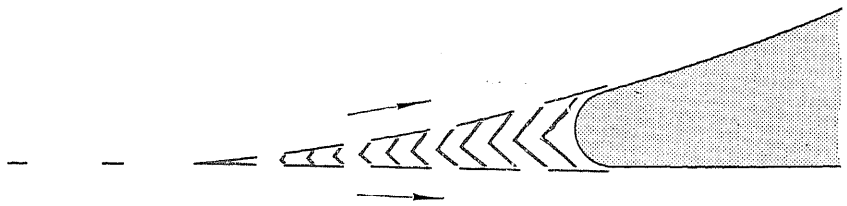
methods of offsetting approach nose of channelising island



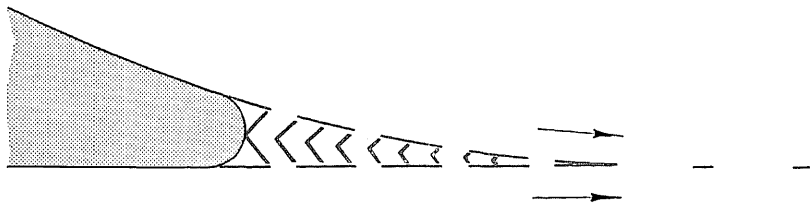
(3) warning markings in advance of median island



(4) use of diagonal markings in advance of median island



(5) use of chevron markings where a traffic stream divides



(6) use of chevron markings where two traffic streams merge

(note: arrows indicate direction of traffic, not carriageway markings)

Fig. 10-3 Channelising islands

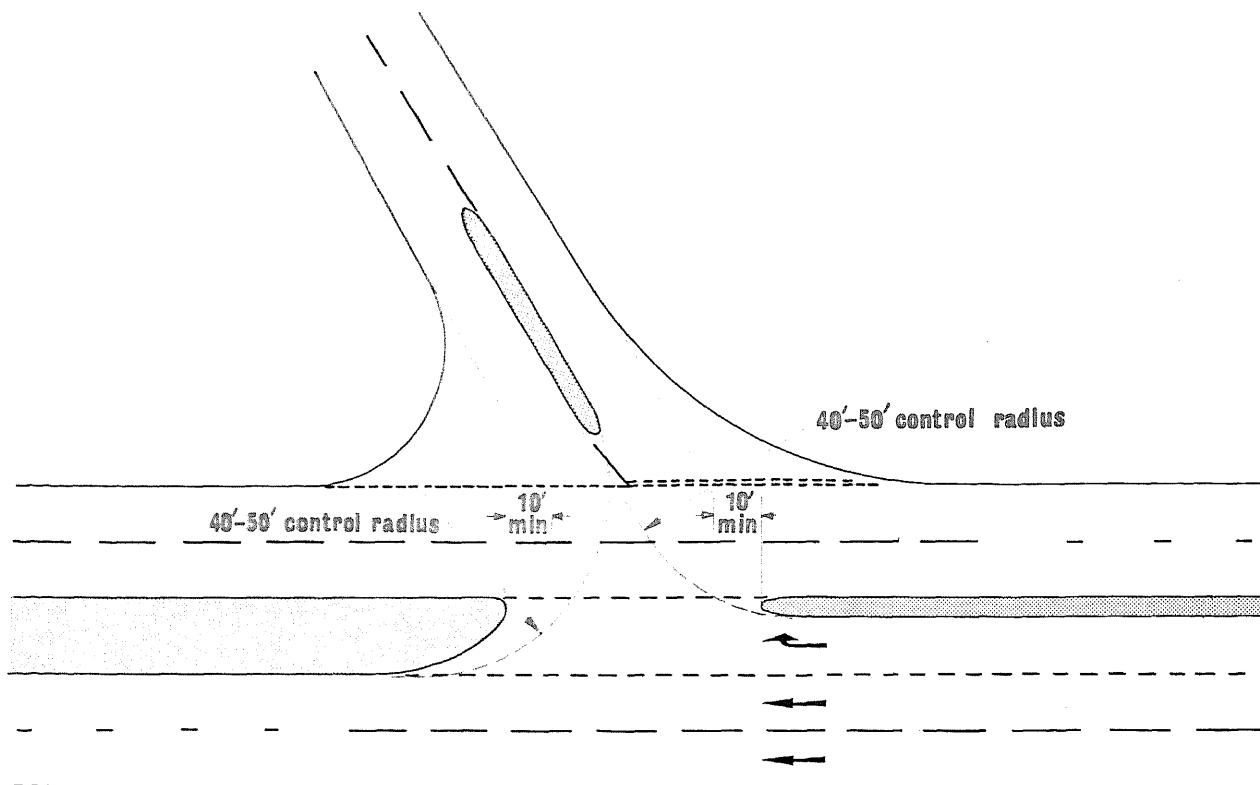


Fig. 10-4 Gap in central reserve at junction

as modifications of existing layouts. These lanes should normally be designed as full-width deceleration lanes with an end taper of 100 ft. Suggested lengths for right-turn lanes (including the end taper) are shown in Table 10-3. The overall length should be increased as necessary if more than one or two vehicles are likely to be waiting to make the turn at any one time. Where space is restricted shorter lanes will still be useful; in these circumstances the length of the end taper should be reduced before that of the full-width lane.

Table 10-3 Length of right-turn lanes

Design speed of major road (mph)	50	40	30
Length of right-turn lane, including 100 ft. end taper (ft.)	400	330	260

10.10 Reducing the number of conflict points

Methods of improving safety by separating traffic streams and points of conflict have been outlined in Section 10.4. Methods of improving safety by reducing the number of points of conflict arising from right-turning movements are equally important and can make a material contribution to the capacity of an intersection.

Examples of traffic cuts at the junction of roads with two traffic lanes are shown in Fig. 10-5. As shown in Diagram (1) there are normally three traffic cuts at a T junction. Prohibition of the right turn from one leg (2) or the introduction of two-phase signal control (3) will reduce the number of cuts to one. If the head of the T is one-way there will either be no cuts or one cut, depending on the direction of the one-way stream (4). If the tail is one-way there will be one cut (5), but this can be eliminated by prohibiting the right turn (6).

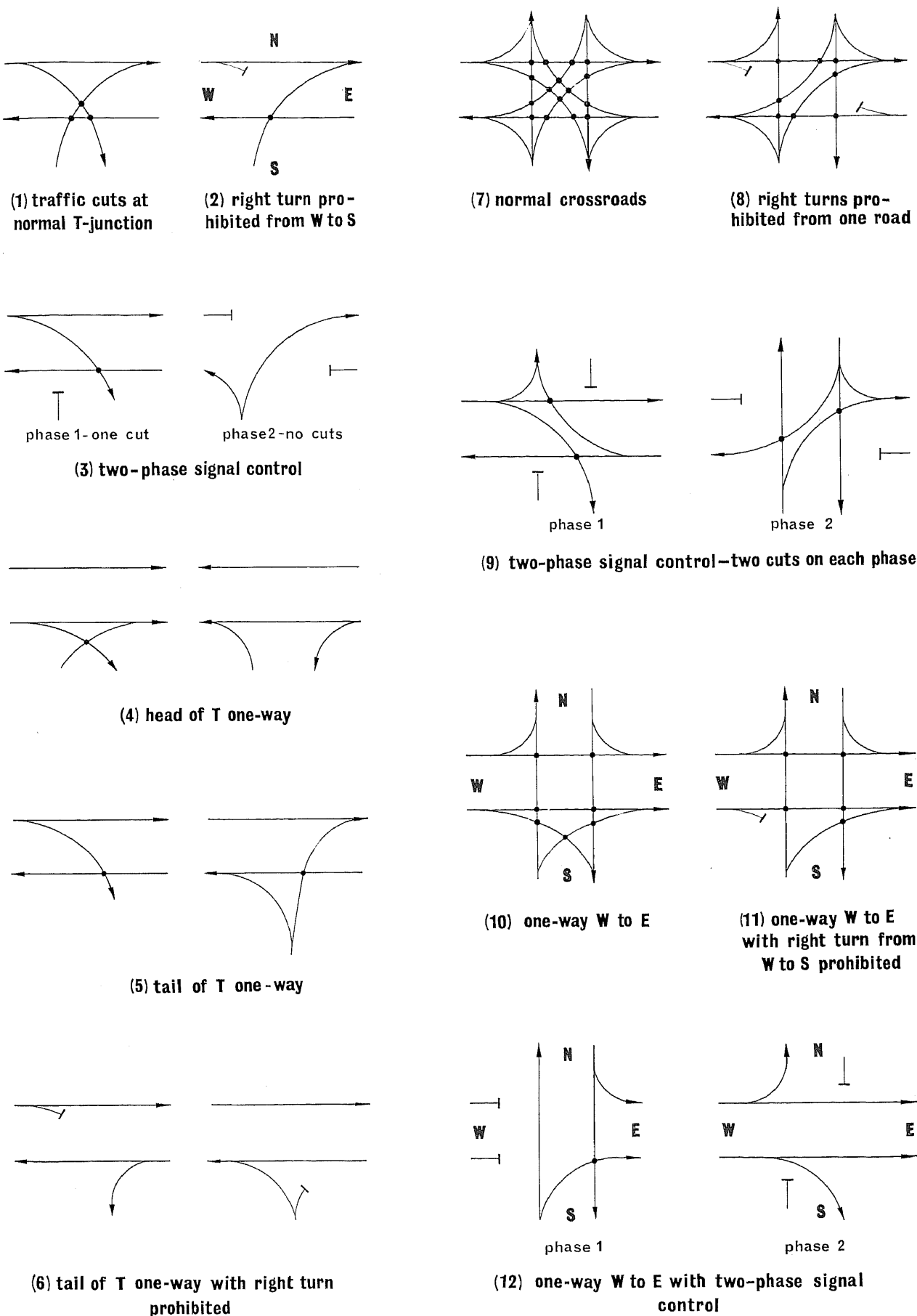


Fig. 10-5 Traffic cuts at T junctions and crossroads

At a crossroads there are normally sixteen traffic cuts (7); the number can be reduced to eight by prohibiting right turns from one road (8) or to four by the introduction of two-phase signal control (9). If one of the roads is one-way the number of conflict points is reduced to seven (10), or to five if right turns are banned from one road (11), or one if two-phase signal control is introduced (12).

10.11 Typical designs for three-leg junctions

Some typical designs for three-leg junctions are shown in Fig. 10-6 and are described below. These designs should be adapted as necessary to meet the physical and traffic requirements of any particular site. Similarly the carriageway markings should be chosen with regard to site conditions; those shown in this and subsequent figures are given as examples only.

Diagram (1) shows a conventional layout with the head of the T at or nearly at right angles to the stem. The aim should be to provide corner radii of 35 ft. where the side road is used by a considerable volume of commercial traffic and radii of at least 20 ft. at junctions used mainly by private cars. As indicated in Section 10.3 the use of transition or compound curves on the corners will facilitate turning movements and lessen interference to other traffic. Visibility splays should be as recommended in Section 10.2.

The widening of the side road to accommodate a refuge or channelising island is illustrated in Diagram (2). The refuge should be sited far enough back from the carriageway of the major road to avoid any obstruction to turning traffic, but should not be so far back that it would not be used by pedestrians. A set-back of 10 ft. to the tip of the refuge will enable a car turning into the minor road to stop clear of the major carriageway when pedestrians are crossing the mouth of the junction. A right-turn lane is provided on the major road to the east of the junction (assuming north to be at the top of the page). The major road has been widened on the north side and allows east-west traffic a straight run without risk of encroaching on the right-turn lane. Lane and arrow markings will be required to indicate clearly the paths to be followed by through and turning traffic.

Where the major road has four lanes (possibly divided by a chain of refuges) but cannot be widened to include a right-turn lane, the layout in Diagram (3) may be suitable provided the proportion of traffic turning right from the major road is not high enough to obstruct through traffic. But, where space permits, layouts incorporating a separate right-turn lane are much to be preferred. Also shown in (3) is the provision of a second approach lane on the side road to increase the capacity of the junction.

Although the orthogonal layouts described above will be typical of most urban T junctions, right-hand splay layouts as shown in Diagram (4) are acceptable provided the major road has a single carriageway and the angle between the roads is not unduly acute—an angle of 60° should be regarded as the normal minimum. This layout eases major-to-minor right turns and minor-to-major left turns, but makes it more difficult for vehicles turning around the acute angle. Where the major road has dual carriageways the side road should be preferably realigned as in Diagram (5) to enable the crossing of the nearside carriageway of the major road to be made as nearly as possible at right angles. The central island in the side road should extend around the bend. Where possible the central reserve of the major road should be wide enough to accommodate a right-turn lane; a reserve width of at least 15 ft. is desirable for this purpose. Local widening of a narrow reserve to provide a right-turn lane is shown in Diagram (6), which also includes a fully channelised layout for the mouth of the junction.

see section 10-2 for visibility splays
see section 10-3 for corner radii

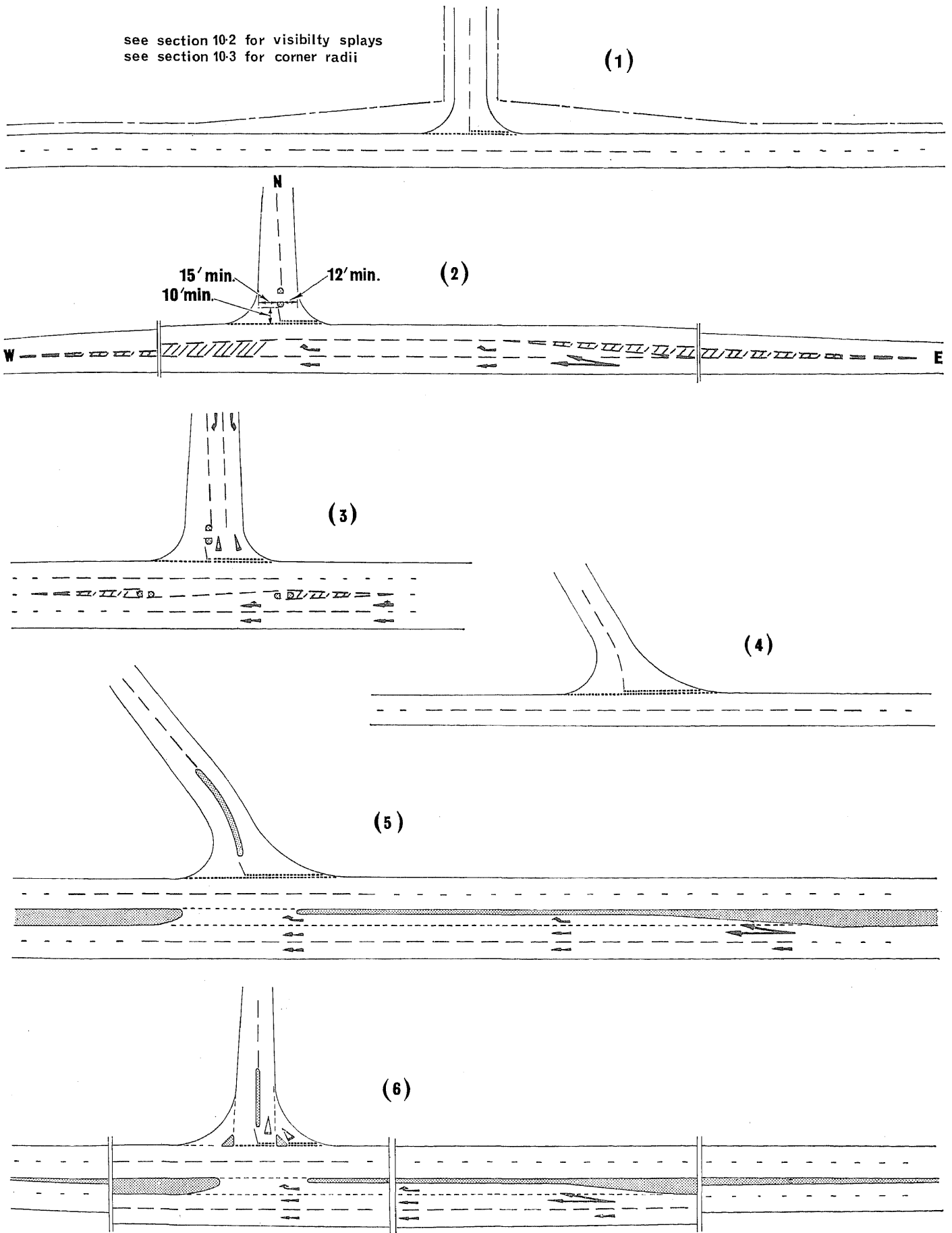


Fig. 10-6 Three-leg junctions

Where the side road has an appreciable left-hand splay as shown by dashed lines in Diagram (7), it is difficult to turn right to or from the major road. Designs with an appreciable splay are undesirable unless it is intended to prohibit right turns. The simplest method of improving a junction of this type is to ease the splay by introducing a gradual bend on the side road, as shown in the diagram. Where there is a heavy left turn into the side road it may be preferable to form a one-way connecting road by means of a single channelising island, as shown in Diagram (8). At more important junctions a greater measure of channelisation may be required as in Diagrams (5) and (6).

Where a side road on a left-hand splay is linked to another side road as in Diagram (9) the undesirable movements to and from the splay road can be suppressed by making it one-way as shown and prohibiting the right turn from the major road. If there is a heavy right-turn movement from west to south at the crossroads it will sometimes be useful to divert the right-turning stream via the splay road, thereby replacing the turn by a direct crossing from north to south as indicated in the diagram.

The right-hand and left-hand splay layouts described above can usually be adapted to suit Y junctions. Where, however, traffic volumes on both branches of the Y are approximately equal the channelised layout shown in Diagram (10) may be more appropriate. The layout does not allow turning movements from A to B, but provision can be made for these where necessary by means of a link road as shown in the diagram.

Diagrams (1) to (8) provide for all turning movements at the junctions. As indicated in Section 10.10 junctions can be made safer by reducing the number of right turns; this reduction will usually enable the design to be simplified. In Diagram (11) the side roads are one-way and all right turns are prohibited; there are no gaps in the central reserve opposite the junctions. If the side road is two-way and heavily trafficked it may be desirable to extend the channelising island into the major road as in Diagram (12); the through lanes and turning lanes should be clearly indicated by arrows on the major road approach.

10.12 Typical designs for four-leg junctions

Where two important roads cross, control by traffic signals, a roundabout or grade separation is desirable; a direct crossing will then be more appropriate than a staggered layout. Where, however, the minor road is lightly trafficked and there are enough gaps in the traffic streams on the major road the staggered layouts shown in Fig. 10-7 may be suitable for junction improvements. When designing new networks it should normally be possible to avoid the need for staggered layouts.

The design of a staggered crossroads will be similar to that of two T junctions. The priority of the major road should be clearly evident from the junction layout, carriageway markings and signposting. Standards of visibility should be as specified in Section 10.2.

In Fig. 10-7 alternative designs are shown for right-left staggers and left-right staggers; the former are preferable from the safety aspect and should be used where circumstances permit.

Diagrams (1) and (2) show simple layouts suitable for lightly-trafficked major and minor roads where the volume of cross or right-turning traffic is small enough not to create any difficulties.

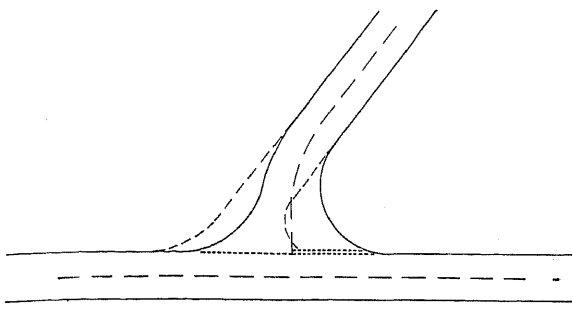
Diagrams (3) and (4) will be suitable for greater volumes of turning and cross-traffic. In both designs the major road has been widened to provide an additional lane for right-turning traffic. Layout (4) has the disadvantage that the length of the right-turn lanes is limited by the distance between the side roads.

Where the major road has a four-lane carriageway divided by a chain of refuges or a narrow central reserve the layouts (5) and (6) may be appropriate if the width available is limited and the volume of right-turning or crossing traffic is low. But layouts (7) and (8), which include right-turn lanes, are much to be preferred where space permits. The hambone-shaped dividing island provided in (8) will require an overall central reserve width of at least 20 ft. and does not provide storage lanes long enough for deceleration clear of the through traffic streams. Full channelisation of the junction mouths will only be required at the more important junctions.

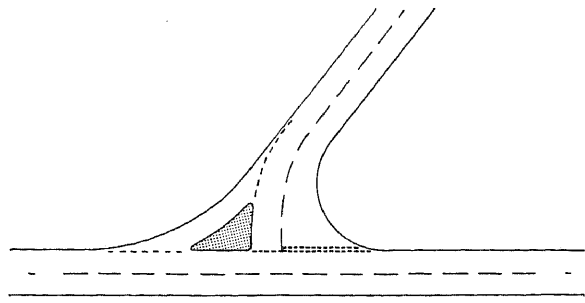
10.13 Multi-leg junctions

Multi-leg junctions (as shown in Diagram (1) of Fig. 10-8) are liable to be confusing and dangerous, and, where possible, side roads should be joined before reaching the junction so that a simplified layout can be achieved (2). Alternatively a roundabout layout may be suitable provided adequate weaving lengths can be obtained (3). A roundabout layout with grade separation for the major route is shown in (4).

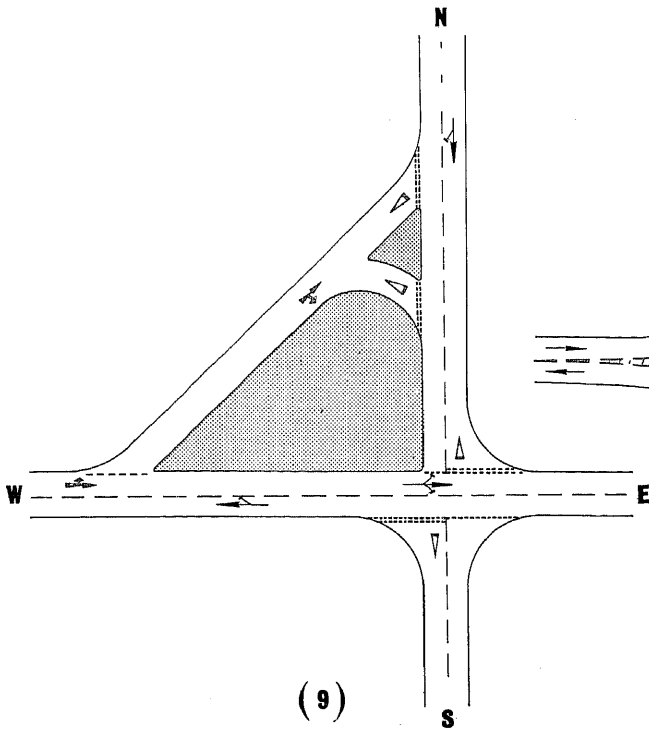
Traffic movements at complex junctions can frequently be simplified without altering the layout by the introduction of one-way working on one or more legs of the intersection.



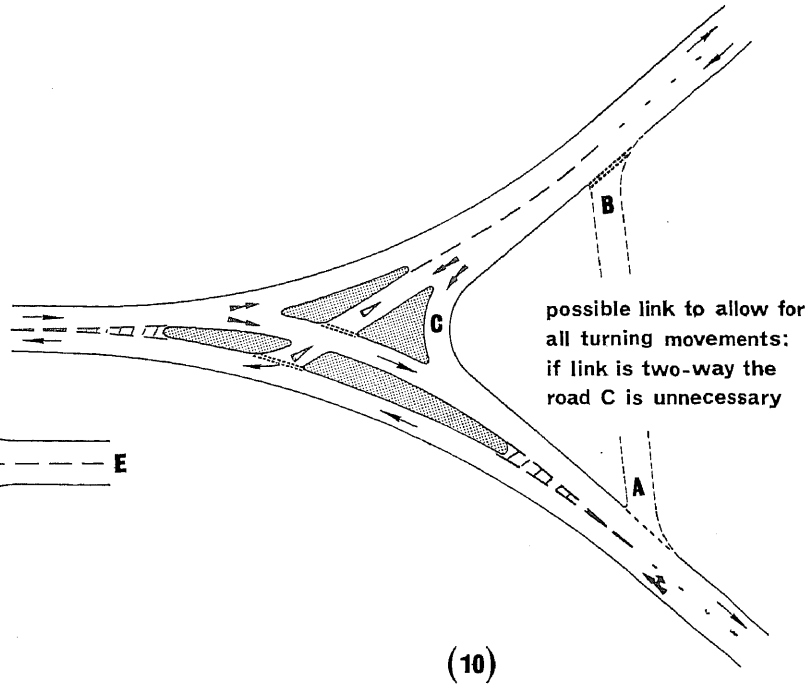
(7)



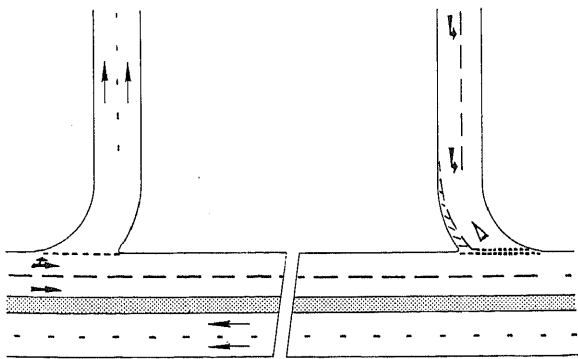
(8)



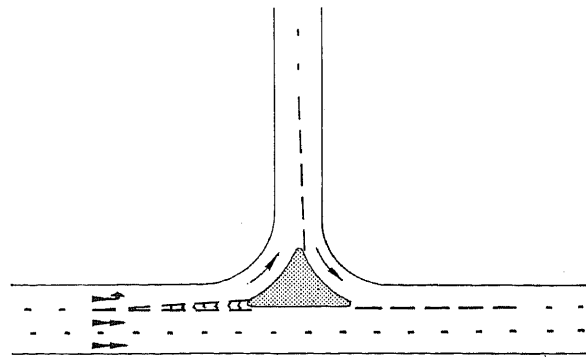
(9)



(10)



(11)



(12)

the following symbols indicate traffic movements but are not carriageway markings :-
 permitted movements thus →
 prohibited movements thus —|

Fig. 10-6 Three-leg junctions (continued)

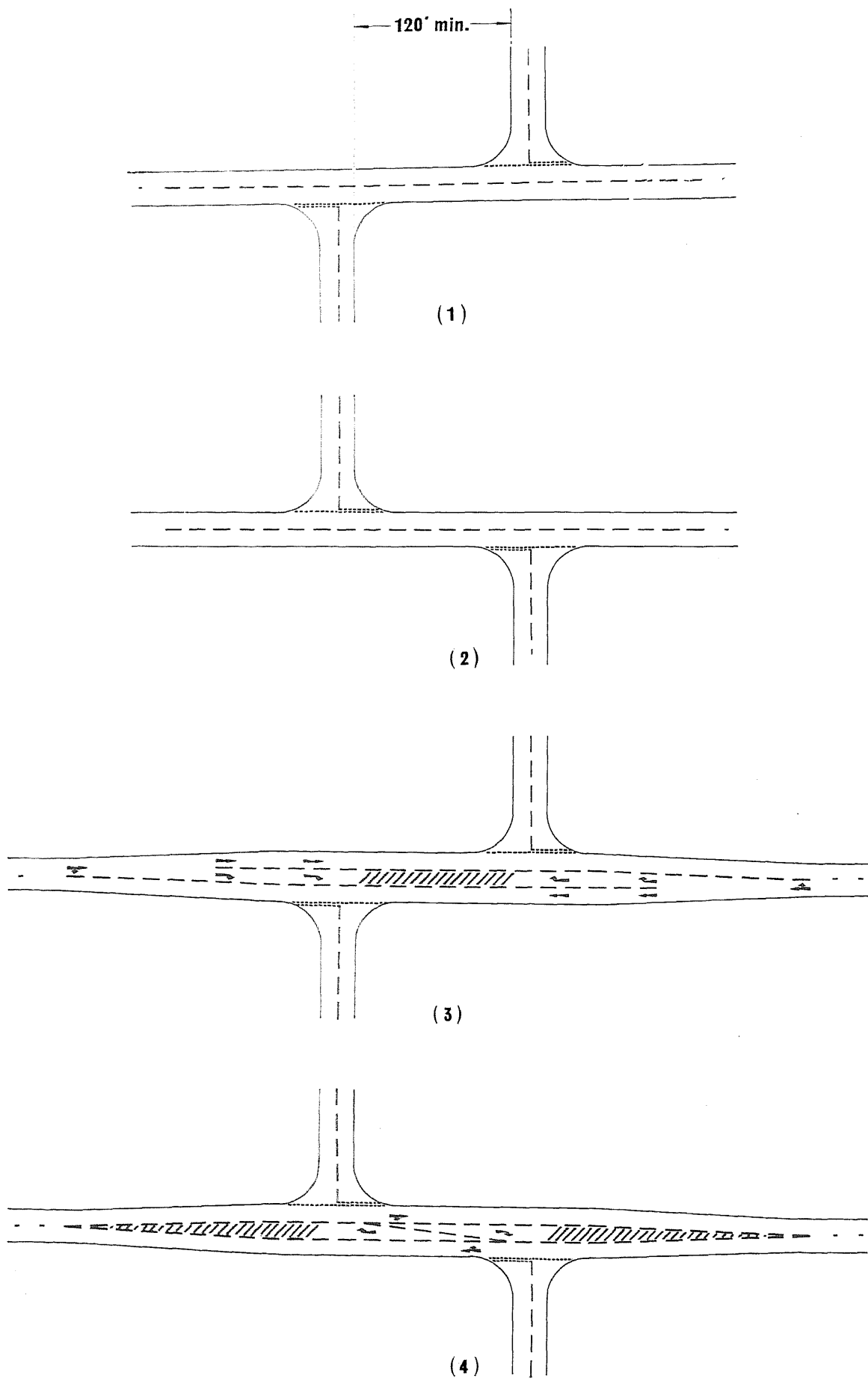


Fig. 10-7 Four-leg junctions

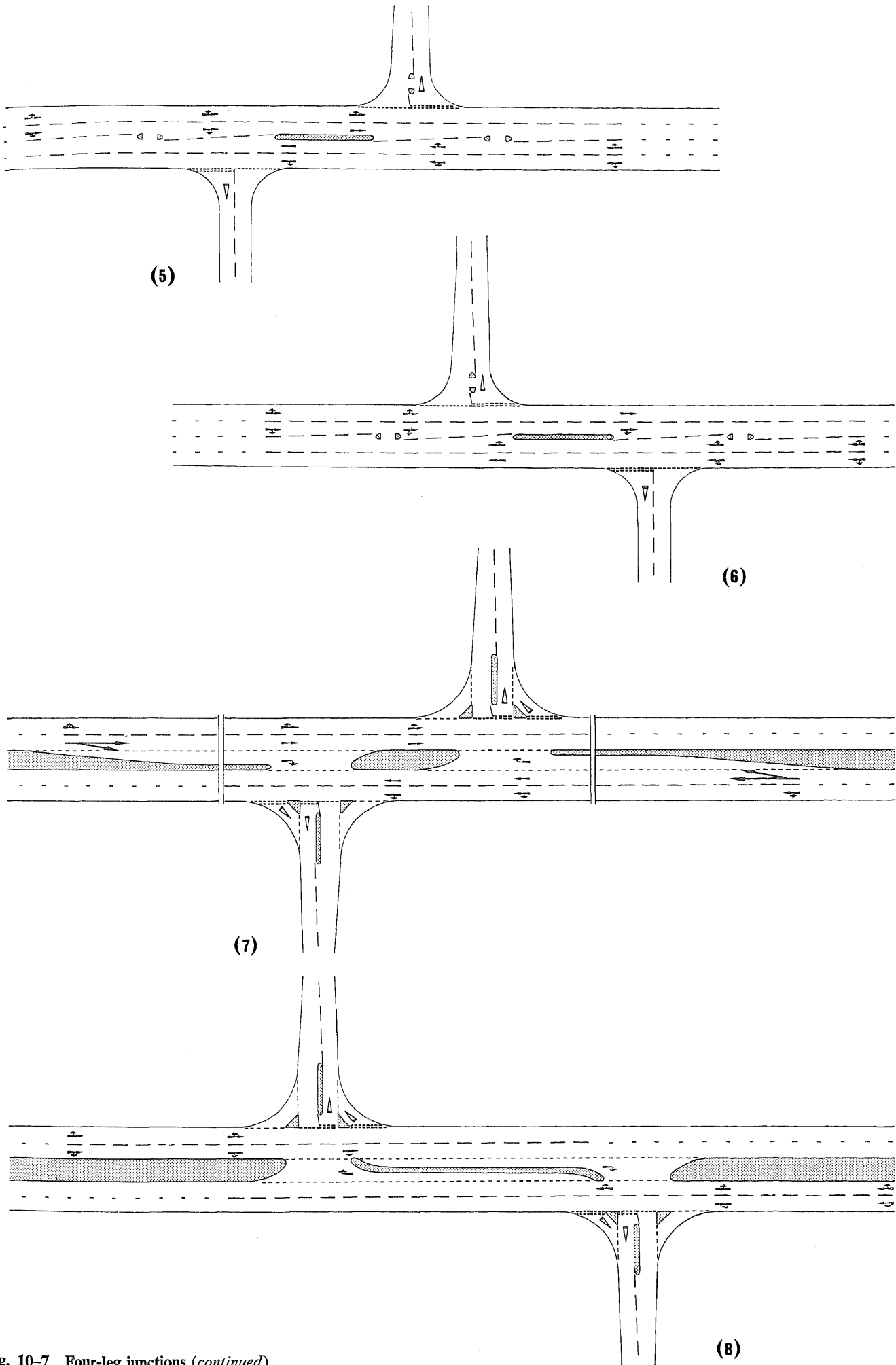
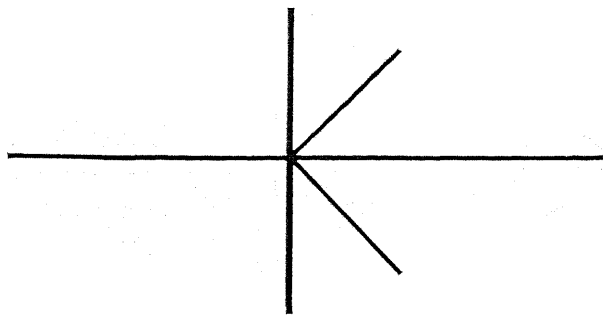
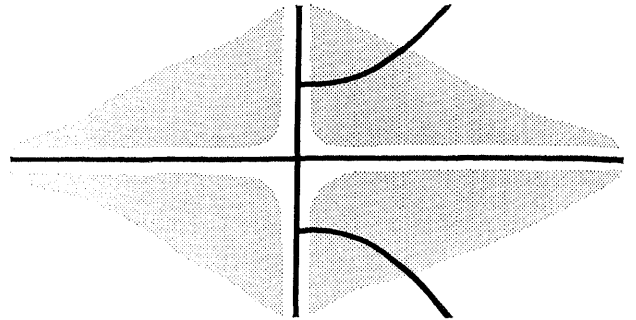


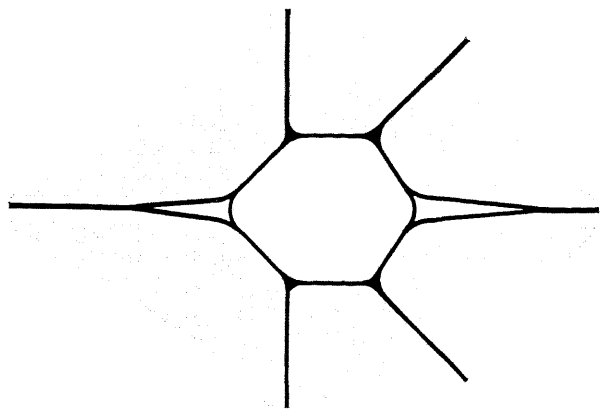
Fig. 10-7 Four-leg junctions (continued)



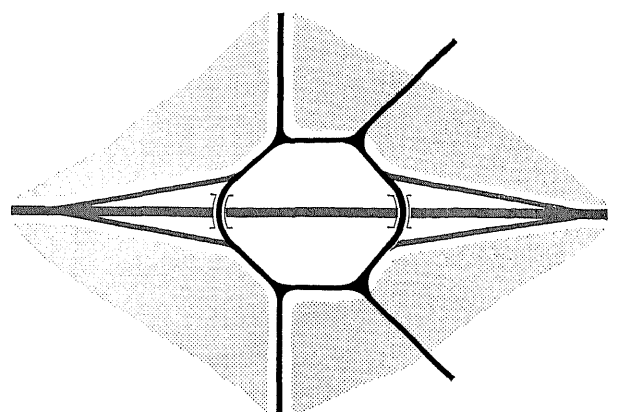
(1)



(2)



(3)



(4)

Fig. 10-8 Multi-leg junctions

11 Signal-controlled junctions

When priority junctions in urban areas become overloaded, congestion and accidents will result. Improved safety and often additional capacity can be obtained by the installation of traffic signals, though at times when flows are light delays may be greater than with priority control. Signals can often be installed without need for additional land or major changes of layout.

For further information on the design and capacity of signal-controlled junctions reference should be made to *Urban Traffic Engineering Techniques*,⁷ *Road Research Technical Paper No. 56*²² and *Road Note No. 34*.²³

11.1 Types of signals

In Great Britain most traffic signals are vehicle-actuated and the green periods are related to traffic demands. The standard sequence is: red—red/amber shown together—green—amber. The amber period is standardized at three seconds and the red/amber at two seconds; the two-second red/amber is provided only by the latest controllers, the older type giving a three-second red/amber.

The latest types of vehicle-actuated signals include the following facilities:

- (i) *Minimum green period.* This is the shortest period of right of way which is given to any phase and is long enough for vehicles waiting between the detector and the stop line to get into motion and clear the stop line. The period is variable and depends on the number of vehicles waiting at the start of the green period.
- (ii) *Vehicle-extension period.* The minimum green period may be extended by vehicles which cross the detector during the green period. Each vehicle, as it crosses the detector, extends the green period by an amount called the vehicle-extension period. The extension depends on the speed of each vehicle, as measured at the detector, and is automatically varied to enable the vehicle to reach 10 or 20 ft. beyond the stop line.
- (iii) *Maximum period.* To limit delay on the waiting phases when there is a continuous stream of traffic on the running phase a maximum period is timed off, after which the signals change right of way independently of any outstanding vehicle-extension period. The maximum period is timed from the beginning of the green period if vehicles are waiting on other approaches or from the moment the first vehicle passes over the detector on one of the other approaches. When required the maximum period can be made variable so that the normal maximum can be extended if at the expiration of the period the traffic flow is above a pre-set value.
- (iv) *Intergreen period.* The standard intergreen period is 4 seconds (3 seconds on old equipment), but when a longer clearance is necessary for safety, e.g. to protect clearing traffic, a variable clearance period can be provided. Additional clearance is then given whilst vehicles are clearing the junction, but is omitted if there is no traffic clearing (for special conditions a fixed extra clearance can be given).
- (v) *Early cut-off.* To facilitate a heavy right-turn movement from one approach the green time of the opposing stream

can be cut off a few seconds early. The duration of the early cut-off period can readily be adjusted by detectors operated by the turning traffic.

- (vi) *Late start.* An alternative way of facilitating a heavy right turn is to delay the movement of the opposing traffic stream for some seconds.

11.2 Co-ordinated control systems

Owing to the frequency of junctions in urban areas the linking of signals is often desirable to reduce delays to traffic. One object of co-ordination is to establish a definite relationship between the appearance of the green period at two or more intersections so that interference to the through traffic streams is reduced to a minimum. When two intersections are very close to each other some form of linking is often used to prevent the queue of vehicles at one intersection from extending back and interfering with the other. The interlocking arrangements can be made very flexible if vehicle-actuated signals are used.

Brief details of some methods of linking signal installations are given below:

- (i) *Simultaneous system.* All signals along the controlled section display the same aspect to the same traffic stream at the same time. This system has the disadvantage that it may encourage speeding, as drivers may try to get through as many intersections as possible before the signals change.
- (ii) *Alternate (or limited progressive) system.* With this system adjacent signals show opposite indications alternately along the route. The aim is that vehicles should travel one block in half the cycle time. If drivers exceed the design speed of the system they are stopped at each signal. The system is not very suitable for streets where the distance between junctions varies appreciably.
- (iii) *Flexible progressive system.* The cycle time for all intersections in the system is the same, but the green periods are displaced with respect to each other according to the desired road speed. This is intended to give a progression of green periods along the road—in both directions if the road is two-way. If desired this system can be adapted to give preference to certain directions, e.g. preference can be given during the morning peak to traffic flowing towards the town centre and during the evening peak to traffic flowing away from the centre. The cycle time for the system can be made to vary according to the traffic requirements.
- (iv) *Tailor-made systems.* Systems of linked signals are often tailor-made for particular routes. These systems do not generally have a master controller as this may lead to less efficient control at key intersections along the route. These key intersections are usually allowed to operate in a fully vehicle-actuated manner and to govern changes of right of way at neighbouring intersections.
- (v) *Area Traffic Control.* A new development is the use of digital computers to provide a system of area traffic control. The purpose of such control is to reduce delays by:
 - (a) more efficient linking of signals, having regard to the traffic situation at any given time;

- (b) diversion of traffic where spare capacity is available on alternative routes;
- (c) lane switching, or switching of peak period one-way systems, on tidal flow routes.

Evaluation of the benefits of area traffic control systems is at present in hand.

11.3 Pedestrian signals

Pedestrians at intersections controlled by signals are catered for in two ways in Great Britain. One method is to provide a crossing marked out in studs in front of the stop line (see Fig. 11-4) whereby pedestrians crossing the road fit in with the signal timings, i.e. no special phases are given for them. This type of crossing is normally used where there are not too many turning vehicles. The second method is to provide a special phase for the pedestrians and in this case the pedestrians' movements are signalled. This is a more positive method as all traffic which may pass over the crossing is halted before the pedestrian phase is given, but causes more delay to vehicles.

Existing pedestrian signals display the word WAIT in red and the word CROSS in white or green, all against a black background. As recommended in *Traffic Signs 1963*¹¹ future signals will show either a red standing man or a green walking man, both against a black background.

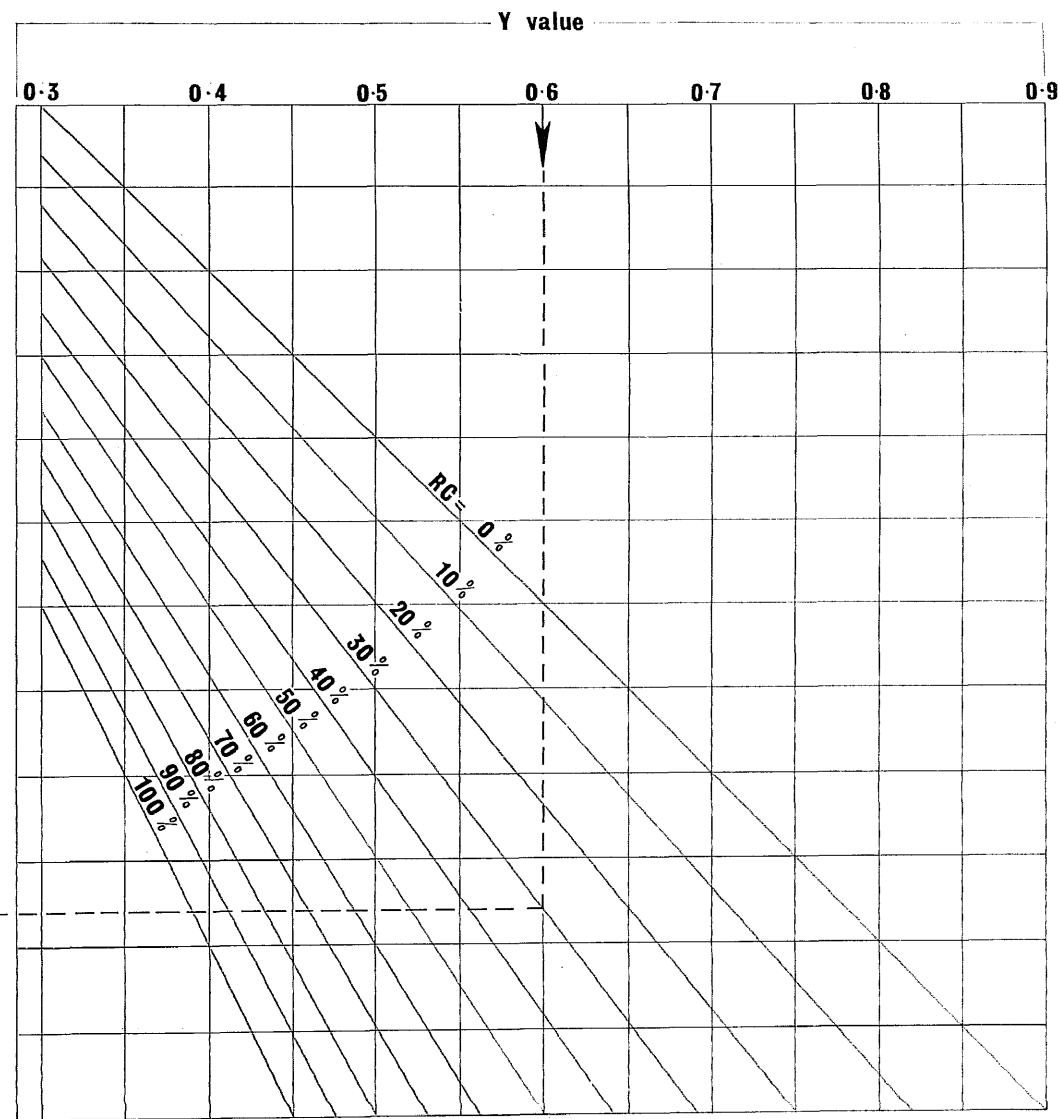
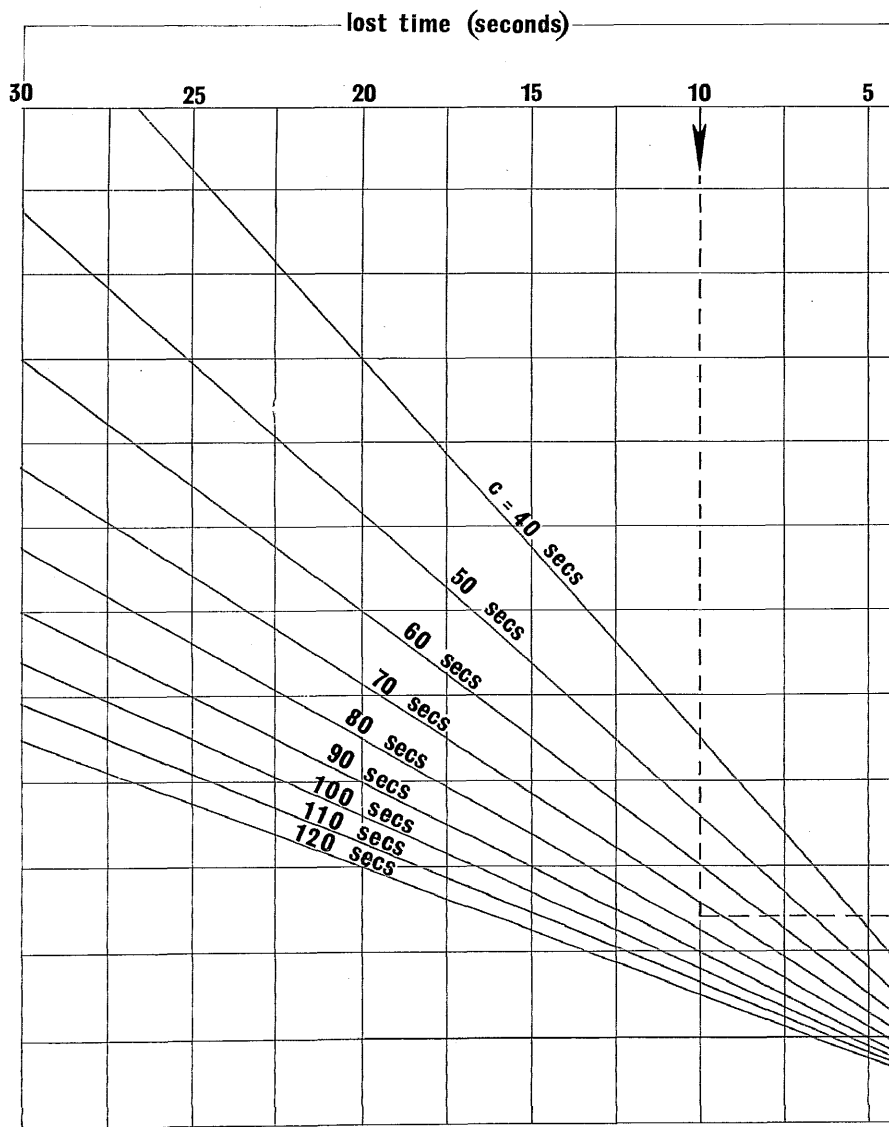
The pedestrian phase may be brought in either by operation of a push button (this is the normal arrangement and avoids unnecessary delay to vehicles) or automatically (this may be desirable on linked signal systems to avoid signals with pedestrian phases getting seriously out of step with adjacent signals). The green signal to pedestrians is displayed for a pre-set period of 6 to 10 seconds according to the pedestrian flow. It is usually preceded by an all-red period of about 2 seconds and followed by an all-red period of 2 to 8 seconds, depending on the width of the road.

Pedestrian crossings between junctions can be signalled in the same way. With one type of pedestrian-operated signal no vehicle detectors are installed and the right of way normally rests with the traffic. In the absence of demands from pedestrians it would remain so indefinitely, but when the push button is depressed the pedestrian receives right of way immediately (provided a pre-set minimum right-of-way period for vehicular traffic has expired since the pedestrian phase was last called). It is often possible to omit vehicle detectors without difficulties arising, but where vehicle approach speeds are high it is usually advantageous to provide them.

One difficulty with the pedestrian signals described above is that the pedestrian phase and clearance periods, being of fixed duration, have to be set to meet average conditions. This results in unnecessary delays to vehicles when only a few pedestrians wish to cross and to inadequate time for pedestrians at peak pedestrian times. Experiments are therefore in hand with a view to introducing a more flexible type of pedestrian crossing where the signal sequence to vehicles includes a flashing amber period following the red signal; during this period vehicles must give way to any pedestrians wishing to cross but may move over the crossing in the absence of pedestrians. Detectors would be required only where vehicle approach speeds were high.

11.4 Filter signals

Filter signals mounted alongside the main signals are sometimes used to permit movement of vehicles in the direction shown by the green arrow, even though the main signal is showing red. Filtering creates problems for pedestrians, particularly for those



To calculate reserve capacity, use the left-hand diagram to obtain a point corresponding to the lost time and the maximum cycle time suitable for the junction, extend a line horizontally from

this point to the right-hand diagram to meet a vertical line corresponding to the Y value—the reserve capacity (RC) may then be read at the point of intersection.

Example shown:

Lost time=10 seconds Cycle time=75 seconds
 Y value=0.6 Reserve capacity=30%.

67 Fig. 11-1 Traffic signal calculations: reserve capacity diagram

crossing the road from which the vehicle emerges. It also involves risk of collision with vehicles in any traffic stream with which the turning vehicle merges. For those reasons filter movements should be restricted to sites where a substantial advantage in handling traffic can be achieved and pedestrian needs can satisfactorily be met despite these movements. Special precautions may have to be taken depending on the site conditions, e.g. by erecting guard rails to prevent pedestrians crossing the approach with the filter movement or by siting the stop line 20 to 30 ft. from the pedestrian crossing to enable drivers and pedestrians to see each other.

A left-turn connecting road may sometimes be provided as an alternative to a left filter and will allow traffic to turn left before reaching the signals. An example of this layout is shown in Diagram (9) of Fig. 10-6.

A green arrow is sometimes shown with a full green to indicate to drivers that they can turn right safely as an early cut-off has been imposed on the opposing traffic stream.

11.5 Capacity

For additional information on the capacity of signal-controlled junctions, References 7, 22 and 23 should be consulted.

11.5.1 Phasing

To achieve high capacity and reduce delay, as much traffic as possible should be kept moving at the same time and main traffic streams which do not conflict should be arranged to run at the same time. The number of phases will depend on the number of roads entering the junction and the amount of right-turning traffic.

Two-phase control should be adopted where possible, but additional phases may be needed:

- (i) where troublesome conflicting movements cannot be eliminated;
- (ii) where right turns are too heavy to be dealt with by early cut-off or late start features or by extending the intergreen period;
- (iii) at complex junctions with five or more legs;
- (iv) at junctions where separate pedestrian phases are required.

Before adopting multi-phase control the alternative of altering traffic movements so as to permit two-phase control should always be considered.

Vehicle-actuated signals are usually arranged so that if no demand is received for a particular phase it can be omitted from the cycle, thereby reducing delays.

11.5.2 Reserve capacity

The reserve capacity (*RC*) of a junction at a given date is the difference between its practical capacity and the actual or estimated flow at that date, expressed as a percentage of the actual or estimated flow. To avoid excessive delays the flows used to determine the practical capacity of signal-controlled junctions are taken as 90% of the maximum possible flows.

Reserve capacity may be estimated from the nomogram in Fig. 11-1. The terms used in the nomogram are described below:

- (i) *Lost time (L)*. This is the total period during the cycle which is not effectively used for vehicle movement. It is made up of the time when all signals show red or red/amber plus an allowance of 2 seconds per change of phase to allow for tailing-off of flow during the amber period and starting delays at the beginning of the green period. At each change of phase the lost time amounts to 1 second less than the intergreen period.

Examples of signal aspects for two-phase control are illustrated in Fig. 11-2. Diagram (1) shows the normal 4-second intergreen period with 3 seconds lost time (made up of 1 second when all signals are either showing red or red/amber plus the 2-second allowance for tailing-off of flow and starting delays). As there are two changes of flow per cycle the total lost time per cycle (*L*) is 6 seconds.

Diagram (2) shows an intergreen period of 12 seconds, as may be needed to enable pedestrians to cross the road or vehicles to turn right or clear a wide intersection. This allows an all-red period of 7 seconds and has 11 seconds lost time. If the lost time at the second change of phase is 3 seconds the total lost time per cycle will be 14 seconds.

- (ii) *Cycle time (c)*. If right-turning traffic does not create difficulties the capacity of an intersection becomes greater as the cycle time increases because the ratio of lost time to useful time decreases. As, however, the gain in capacity with very long cycles is often insignificant it is usual to limit cycle times to 120 seconds. Cycle times should not be so long that queues of waiting vehicles extend beyond the available reservoir space or right-turning vehicles cause congestion by interlocking or by unduly interfering with through traffic movements. Linked signals generally require short cycles to ensure reasonable progression. Long cycles may be needed when lost time is high (as with multi-phase control) and on commuter and holiday routes (to ensure saturation of side road green periods).
- (iii) *Sum of flow ratios (Y)*. The ratio of the actual hourly flow to the saturation flow per hour of green time should be determined for each phase and totalled for all phases. The saturation flow is that which would be obtained with 100% green time and a continuous queue of vehicles on the approach; it is expressed in passenger car units, using the weightings given in the fifth column of Table 1-3.

As any phase may include flows from more than one approach the highest approach ratio should be chosen to represent the phase.

The saturation flow on each approach will depend mainly on its width and to a lesser extent on the amount of turning traffic, the composition of traffic, the gradient, the presence of parked vehicles and the nature of the site. With no turning traffic and no parked vehicles the peak period saturation flows for approach widths of between 10 and 17 ft. are as follows:

Table 11-1 Saturation flows

Approach width (ft.)	10	11	12	13	14	15	16	17
Saturation flow (pcu's per hour)	1850	1875	1900	1950	2075	2250	2475	2700

For greater approach widths (at least up to 60 ft.—the limit of present experimental observations) the saturation flow may be calculated from the expression

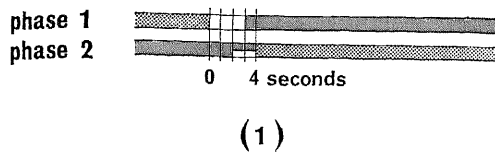
$$s = 160w$$

where *s* is the saturation flow in pcu's per hour and *w* the effective approach width in ft. (see References 22 and 23).

The above figures allow for the effect of left-turning vehicles on the saturation flow. Right-turning vehicles, except when they have an unopposed movement, should be allowed for as follows:

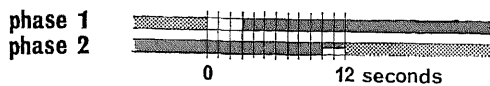
- (a) If they are so few that a separate right-turn lane is unnecessary the effect of each right-turning vehicle on its stream may be taken as equivalent to $1\frac{3}{4}$ straight-ahead vehicles.

intergreen period:- 4 seconds
lost time:- 3 seconds*

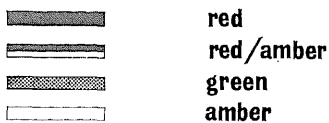


(1)

intergreen period:- 12 seconds
lost time:- 11 seconds*



(2)



* lost time at each change of right of way is assumed to be 2 seconds plus the time when either red or red/amber signals show to both phases

Fig. 11-2 Examples of signal aspects at 2-phase traffic signals

- (b) If no right-turn lane is provided and vehicles waiting to turn are sufficiently numerous to obstruct the straight-ahead flow, the saturation flow of the remaining vehicles may be estimated from the reduced approach width; a reduction of 7 ft. may suffice for a turning stream of cars and light vans but one of 9 ft. may be needed where there is a high proportion of heavy vehicles (say over 20%).
- (c) Where a right-turn lane is provided the saturation flow will relate to the remaining approach width and the flow of straight-through and left-turning traffic.

The above results apply to an average intersection. If conditions are exceptionally good (e.g. on dual carriageways with good visibility and alignment, adequate turning radii and exit widths, and no interference from pedestrians) the saturation flow should be increased by 20%. If conditions are poor (e.g. with poor visibility and alignment, and with considerable interference from pedestrians) the saturation flow should be reduced by 15%.

To allow for gradients on the approaches the saturation flow should be reduced by 3% for every 1% of uphill gradient and increased by 3% for every 1% of downhill gradient. This applies to gradients of between 10% uphill and 5% downhill.

Parked vehicles in the vicinity of an intersection may seriously affect its capacity and efficient operation. The effect of a parked vehicle on an approach may be expressed as follows:

$$\text{Effective loss of carriageway width (ft.)} = 5.5 - \frac{0.9(z - 25)}{g}$$

where z is the clear distance in ft. of the nearest standing vehicle from the stop line and g is the green time for the approach in seconds. If z is less than 25 ft. it should be taken as 25 ft. If the expression is negative the effective loss in all cases will be zero. The effective loss should be increased by 50% for a bus, lorry or wide van.

11.6 Design

Signal installations should be designed to meet peak conditions with appropriate reserve capacity. Information will be required on traffic volumes and turning movements for each peak period and on the estimated rate of growth. Traffic diagrams should then be examined in conjunction with a large-scale plan of the junction to enable the most suitable signal phasing and site layout to be determined. For high capacity and minimum delay, main traffic streams which do not conflict should be phased to run at the same time. Layouts should be compact so that clearance times between phases are kept as short as possible. Layout and phasing proposals may have to be adjusted to ensure adequate reserve capacity.

The sections in Chapter 10 dealing with kerb radii, channelising islands, refuges, gaps in the central reserve at junctions, right-turn lanes and methods of reducing traffic cuts are also applicable to the design of signal-controlled junctions.

The designs for three-leg junctions illustrated in Fig. 10-6 are all suitable for signal control. The arrangement shown in Diagram (9) of the figure for converting a right turn at a crossroads into direct crossing will often be useful and will enable heavy right turns to be dealt with by simple two-phase control. The channelised Y junction illustrated in Diagram (10) will only require two-phase signal control at the central intersection.

For signal-controlled four-leg junctions the staggered layouts shown in Fig. 10-7 will not normally be appropriate. Unless there are special site difficulties, layouts with direct crossings will be more efficient.

Signal control can often be applied to multi-leg junctions without need for major alterations to the layout, but may require three

or more phases. To develop maximum capacity two-phase operation is desirable, and may sometimes warrant modification of the junction layout, possibly with the prohibition of less-important traffic movements. If multi-phase operation is unavoidable it may be necessary to widen the approaches substantially to obtain the required capacity.

11.6.1 Visibility

Standards of visibility at signal-controlled junctions need not be so high as at priority junctions, but provision of reasonable inter-visibility between the various legs of a junction will give drivers confidence and promote safety and smooth traffic flow. Visibility should be good enough to enable drivers approaching the stop line to see as far as the stop lines on the other approaches and preferably 20 ft. or so beyond.

It will usually suffice to set back boundary fences or buildings on each corner behind a splay line joining points on the kerbs 40 to 50 ft. back from the intersection of the kerb lines at the corner. The precise set-back of the splay line will depend on the kerb radius and the footway width required around the corner.

11.6.2 Selecting approach widths

Because signal control permits traffic movement from any approach for only a proportion of the time it is sometimes necessary for the intersection approaches (where queueing takes place) to be wider than the roads which feed these approaches, in order to pass the required flows.

A preliminary assessment of the minimum approach widths needed for new or improved four-leg junctions with two-phase control may be made by means of the formula:

$$\frac{w_1}{w_2} = \frac{g_1}{g_2} = \sqrt{\frac{q_1}{q_2}}$$

where q_1 and q_2 are the larger approach flows in pcu's during Phases 1 and 2 respectively;
 g_1 and g_2 are the green times;
 w_1 and w_2 are the corresponding approach widths.

Thus a major approach carrying four times as much traffic as a minor approach should be twice as wide and have twice as much green time. The lengths of the widened parts of the approach should theoretically bear the same ratio. In some cases this rule may give approach widths for the major road which are less than those of the feeder roads. For obvious reasons these approaches should not be narrowed but should retain a constant width. Thus, in these cases more width is provided than is strictly necessary according to the above rule. In consequence, the green time can be shortened and any spare green given to the minor road, which can then be made narrower than the above rule would suggest.

For three-leg junctions with two-phase control the widths and green times should be:

$$\frac{w_1}{w_2} = \sqrt{\frac{q_1}{2q_2}} \quad \text{and} \quad \frac{g_1}{g_2} = \sqrt{\frac{2q_1}{q_2}}$$

where the suffix 2 refers to the stem of the T junction. Thus, a major road through a T junction carrying four times as much traffic as the stem should have a width 1.4 times that of the stem, a length of widening 2.8 times and a green period 2.8 times as long as that of the stem.

Calculations should cover morning, evening and other peaks to determine the predominant flows at different times of the day. The width required for any approach not considered may be determined from the green time allotted to its phase. In deciding the values of q_1 and q_2 for substitution in the above formula, right-turning vehicles if few in number should be taken as equivalent to $1\frac{1}{3}$ straight-ahead vehicles. If they are so

numerous as to require special right-turn lanes they should be subtracted from the flow q_1 or q_2 before determining the ratios of the remaining approach widths.

This method minimizes the total width of the approaches for a given capacity. It has the following advantages:

- (i) greater convenience for pedestrians crossing the road;
- (ii) reduced clearance distances and all-red times;
- (iii) reduced encroachment on frontage development and footways.

Where uniform widening of an approach is prevented by the presence of existing buildings it may only be possible to flare the approach. On dual-carriageway roads extra width may sometimes be obtained by reducing the width of the central reserve, but it should not be less than 4 ft. Although the final layout may be influenced to some extent by property acquisition difficulties or costs, it should always have regard to the integral number of lanes needed for through and turning traffic.

11.6.3 Traffic lanes

Approach widths may be estimated initially as recommended in Sub-Section 11.6.2 but may need to be adjusted to provide an appropriate integral number of lanes for straight-through and turning traffic, having regard to the overall width available. Where the approach width is less than 17 ft. no lane markings should be provided; for widths between 17 and 25 ft. the approach should be marked as two lanes; for widths between 25 ft. 6 in. and 27 ft. the approach should be marked as either two or three lanes, depending on the traffic movements required; for widths over 27 ft. the approach should be marked as three lanes. Lane widths need not all be the same and should be chosen with regard to the volume and type of traffic using each lane.

Lane widths of 10 ft. will often be suitable for new or improved junctions, but 11 or 12 ft. lanes may be warranted where traffic includes a high proportion of commercial vehicles. At restricted sites 8 ft. 6 in. lanes may have to be accepted. Nearside lanes up to 14 ft. wide may be useful where there are many bicycles.

The number of lanes on any exit from an intersection should normally be the same as the number of lanes for straight-through traffic on the approach, i.e. excluding any lanes provided solely for turning traffic. If it is necessary or desirable to reduce the width of the exit by one lane the reduction should be made by means of a taper at least 300 ft. long.

Special lanes should be provided where necessary for right- or left-turning traffic. Turning lanes should be so aligned and marked that they do not entrap through traffic. Obstruction of nearside lanes by parked vehicles or bus stops should not be permitted.

11.6.4 Carriageway markings

The provision of lane lines and arrow markings on the approaches to traffic signals will enable drivers to select the required route and will promote the orderly flow of traffic. Carriageway markings and direction signs should be located sufficiently far in advance of the junction to enable drivers to select the required lane before joining the queue of waiting vehicles.

Proposals to reserve particular traffic lanes exclusively for turning traffic require careful consideration. Unless the volumes per lane of straight-through and left-turning traffic are approximately equal the capacity of a junction would be reduced by reserving a lane for the left turn. Provision of an additional lane for right-turning traffic is desirable, but if space does not permit this the off-side approach lane should only be reserved for the turn if turning vehicles are sufficiently numerous to constitute a major obstruction to straight-through traffic.

11.6.5 Division of carriageways

In many cases, such as at Y junctions where traffic divides fairly evenly to forking roads, the centre line of the approach road may advantageously be offset so as to allow more lanes into the junction, as shown in Diagram (1) of Fig. 11-3.

In Diagram (2) the layout has been adjusted to take advantage of the three-lane width of the left fork so as to minimise the proportion of cycle time required for Phase 2.

Similarly, on the stem of a T junction the approach can advantageously be made one lane wider than the exit into the stem, as shown in Diagram (3).

Side roads often require a high proportion of the cycle time, and it may prove beneficial to widen them so that they require only a short phase to clear their traffic. This arrangement may increase the capacity of the major road by as much as 50% and is particularly useful where it is impracticable to widen it because of property acquisition or other difficulties. The rule given in Sub-Section 11.6.2 for a cross-road junction allows more width to the side road in relation to its flow than to the main road; for T junctions the rule favours the side road even more.

11.6.6 Siting of traffic signals

As signal control involves the timed separation of traffic conflicts it is essential that traffic signals should be clearly visible. The standard layout shown in Diagram (1) of Fig. 11-4 should form the general basis for designing new installations and modifying existing ones.

A primary signal is sited on the nearside of each approach close to the junction, and the carriageway is marked with a stop line about 3 ft. before the signal. A secondary signal giving the same indication is normally sited on the offside of the road beyond the junction. On roads with refuges or a central reserve the primary signal should be supplemented by a second primary signal on the refuge or reserve, and the secondary signal should be sited on the further refuge or reserve instead of on the offside of the road if it will then be more conspicuous to traffic. The secondary signal should be sited within an angle bounded by the centre line of the carriageway extended through the junction and a line 30° to the right of it, drawn from the intersection of the stop line and the centre line.

A typical signal layout for a junction with an early cut-off feature is shown in Diagram (2). The cut-off occurs on approach A so as to allow a heavy right turn from approach B, which has been widened to accommodate a turning lane by slightly off-setting the refuge.

As in Diagram (1) the secondary signal for approach B may still be sited on the opposite approach refuge, even though this will be somewhat to the left of the refuge on approach B. But the secondary signal for approach A is best sited on the far end of the adjoining refuge; this is to ensure that drivers waiting to turn right from A and pedestrians wishing to cross approach A are not misled into thinking the phase has ended by seeing a red signal in the normal secondary position.

The provision of a right-turn green arrow on the secondary signal for approach B (illuminated during the early cut-off period) will minimise delay and make the turn safer.

It will be noted that a channelising island has been provided in the wide mouth of approach C. This enables the traffic signals and the stop line to be brought close to the junction, thereby reducing the time required to clear the junction. Similarly the kerb on approach A has been realigned to improve the positioning of the stop line, but still ensures an easy turn from A to C.

11.6.7 Crossroad layouts for right-turning traffic

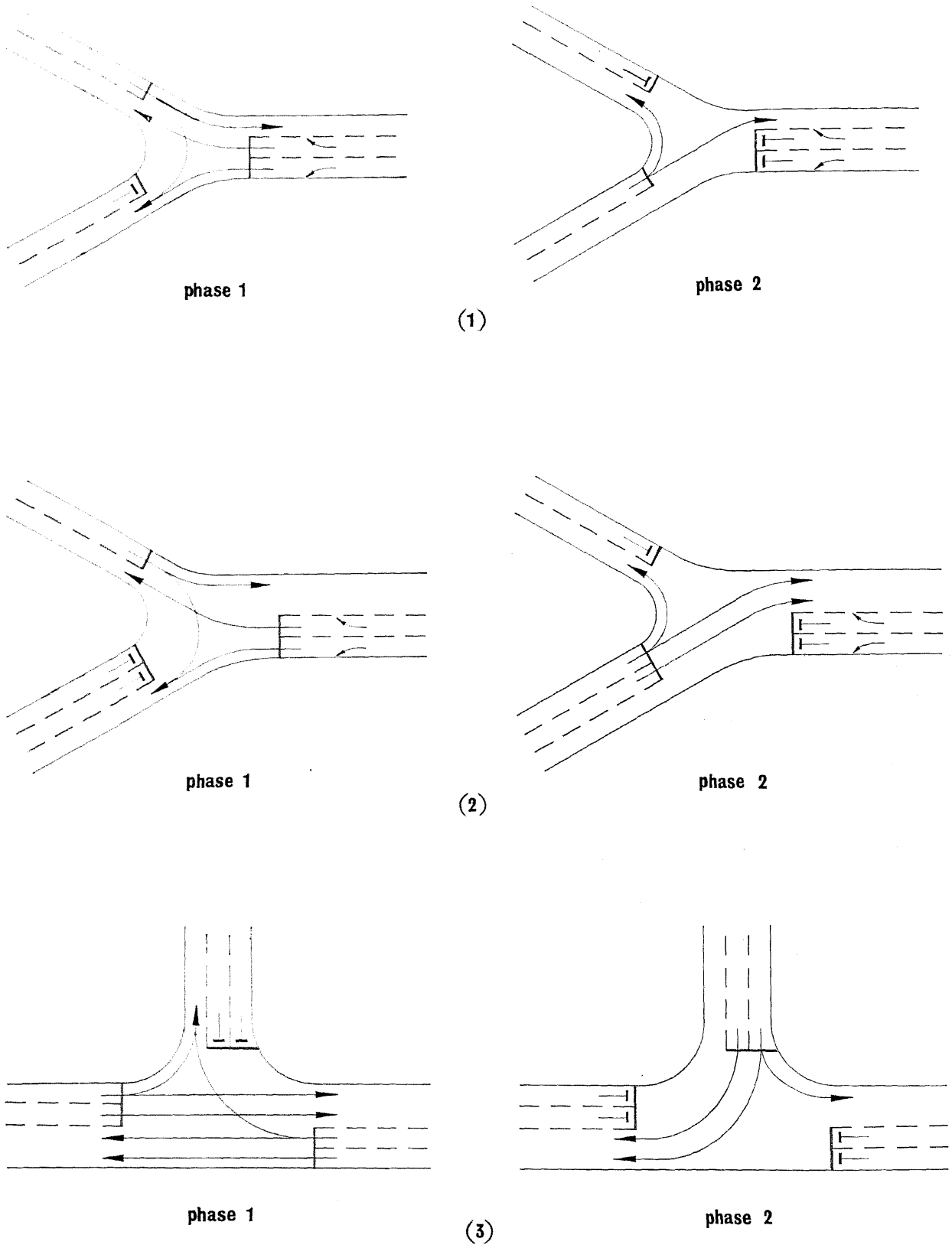
Opposing right-turning vehicles can turn either on the offside of each other or on the nearside. In the former case they have good visibility and can see an approaching gap in the opposing stream in which to complete their turn. But if there are too many turning vehicles from the two directions for the storage space within the intersection the two streams will interlock, with consequent congestion and delay. With the nearside method locking cannot occur, but visibility is often restricted and drivers may have to wait until the end of the green period before turning in order to be sure that there is no opposing straight-through traffic.

To overcome the visibility problem and preserve the advantage of nearside turning the layouts shown in Fig. 11-5 may be used. In Diagram (1) the central reserve is offset to provide additional lanes for turning traffic and better visibility from the stopped position. A further improvement in visibility and better placing of turning vehicles may be obtained as shown in Diagram (2) by widening the major road sufficiently for the turning lanes to be separated from the through traffic lanes by additional channelising islands.

If there is a preponderance of right-turners from one approach, early cut-off or late-start features should be provided, but if there are many right-turners from both approaches a separate phase may be needed in conjunction with the nearside method of turning.

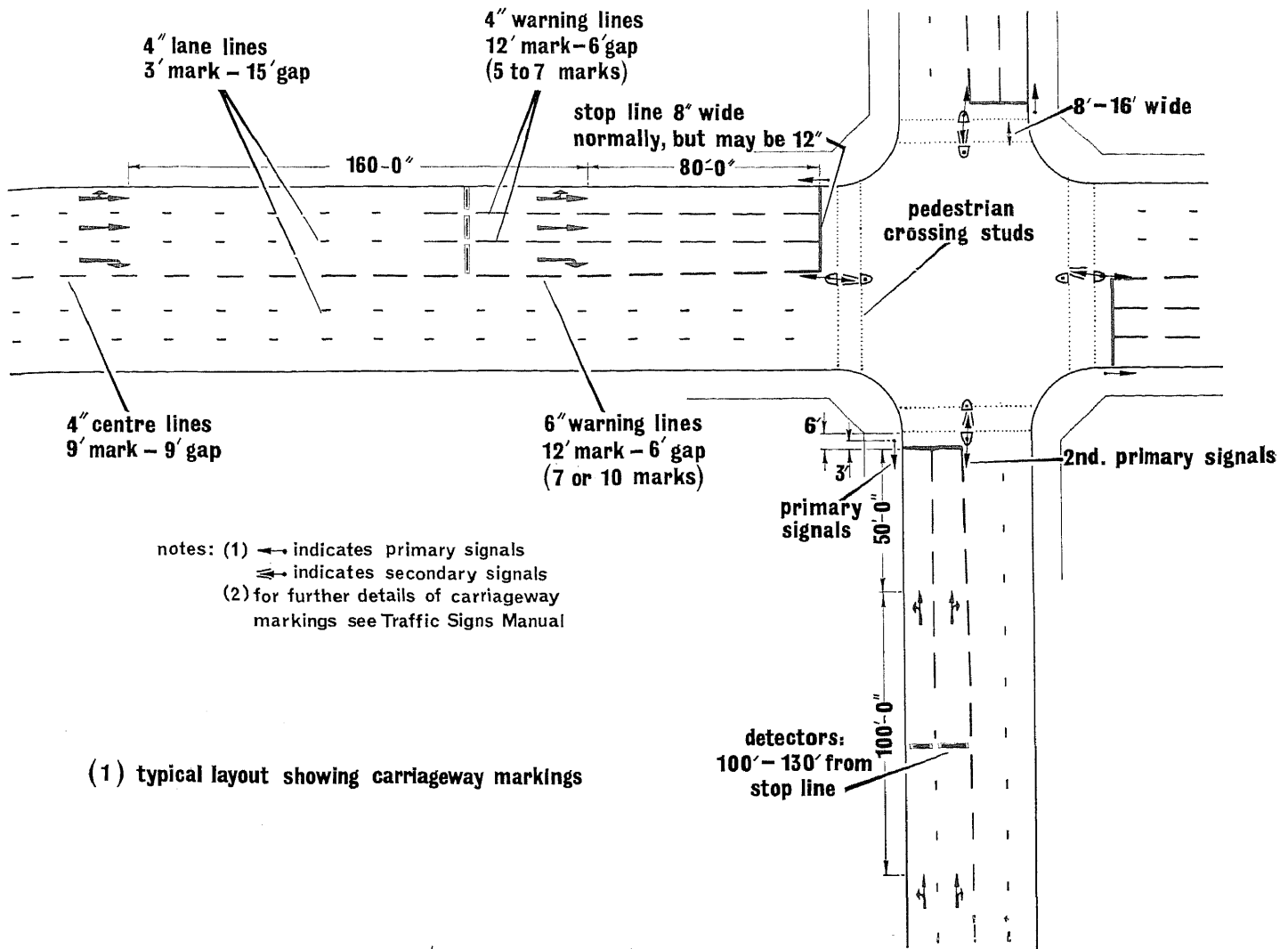
If the volume of right-turning traffic is large enough to require double turning lanes the turning traffic should always be signalled separately and should move only on its own phase.

Lane and arrow markings should be provided as shown for the guidance of drivers.

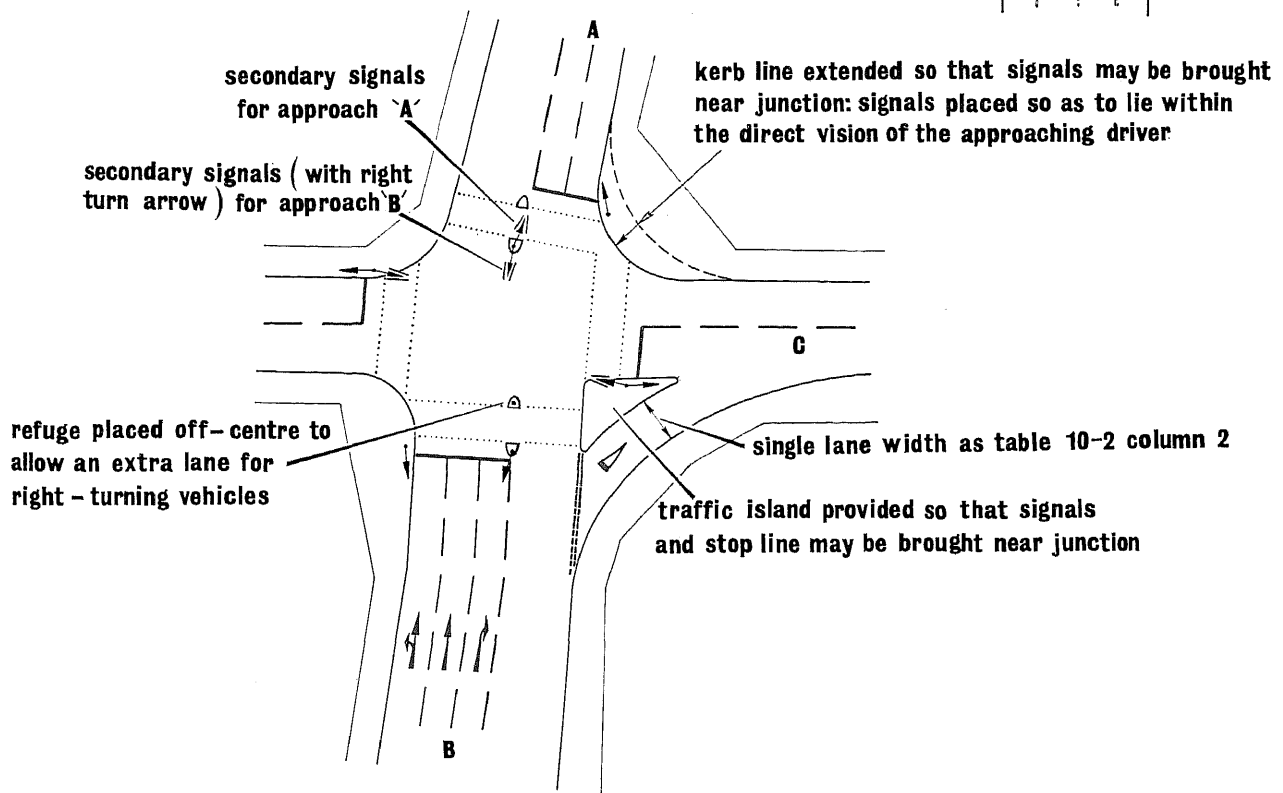


note : arrows indicate direction of traffic, not carriageway markings

Fig. 11-3 Division of carriageways



(1) typical layout showing carriageway markings



(2) layout of junction with special features

Fig. 11-4 Layouts for signal-controlled junctions

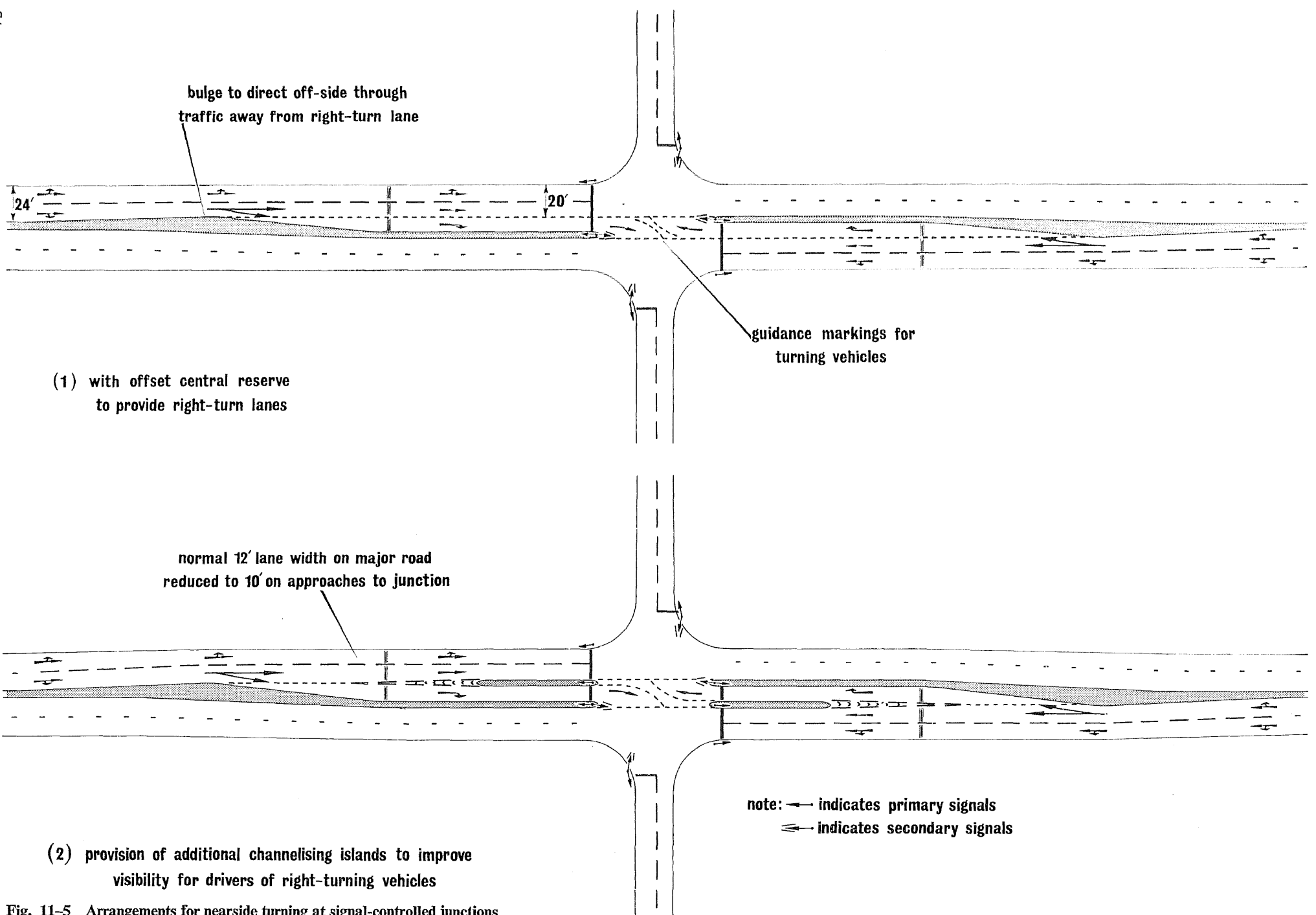


Fig. 11-5 Arrangements for nearside turning at signal-controlled junctions



Junction with double right-turn lanes

12 Roundabouts

Some of the circumstances which may favour provision of a roundabout instead of traffic signals are:

- (i) a high proportion of right-turning traffic at the junction (at a four-leg junction a roundabout may need less land than traffic signals if right-turning traffic exceeds about 30% of all approaching traffic);
- (ii) the existence of more than four approaches to the junction;
- (iii) approach widths so restricted that it would be impracticable to provide separate lanes for through and turning traffic;
- (iv) other junctions so near that there would be insufficient space for the formation of queues;
- (v) a Y junction layout lending itself to roundabout design.

At sites where control by roundabout or traffic signals is equally feasible, a roundabout may be safer and less restrictive.

For further guidance on the choice between traffic signals and roundabouts reference should be made to the paper by Messrs. Webster and Newby published in the January 1964 Proceedings of the Institution of Civil Engineers.²⁴

12.1 Capacity

Practical capacities of weaving sections may be calculated from the formula given below or determined from the nomogram in Fig. 12-1. The roundabout dimensions referred to in the formula are shown in Diagram (1) of Fig. 12-2 together with the entry, exit and internal angles.

$$Q_p = \frac{86w \left(1 + \frac{e}{w}\right) \left(1 - \frac{p}{3}\right)}{1 + \frac{w}{l}}$$

where Q_p is the practical capacity of the weaving section in pcu's per hour (for roundabout design values see Table 1-3);
 w is the width of weaving section in feet (within range 20 to 60 ft.);

e is the average width in feet of the two carriageways e_1 and e_2 entering the weaving section ($\frac{e}{w}$ range 0.4 to 1.0);

l is the length of the weaving section in feet (range 60 to 300 ft. and $\frac{w}{l}$ range 0.12 to 0.4);

p is the proportion of weaving traffic, i.e. the ratio of the sum of the weaving streams to the total traffic on the weaving section (range 0.4 to 1.0).

The practical capacity derived from this formula is 80% of the maximum capacity found in experiments on isolated weaving sections. This provides a margin of safety to meet the effects of wet weather, possible interaction between weaving sections, variations in flow over the hour and possible interference due to pedestrians crossing the road. The ranges quoted may not be absolute ranges, but are those covered by tests; the formula is valid within these ranges provided there are no standing vehicles on the approaches to the roundabout and the site of the roundabout is level, with approach gradients not exceeding 1 in 25.

Where the layout is not conducive to uniform speeds the following arbitrary adjustments to capacity may be made:

- (i) where the entry angle is between 0° and 15° deduct 5% from the capacity of the weaving section;
- (ii) where the entry angle is between 15° and 30° deduct 2½% from the capacity of the weaving section;
- (iii) where the exit angle is between 60° and 75° deduct 2½% from the capacity of the weaving section;
- (iv) where the exit angle is greater than 75° deduct 5% from the capacity of the weaving section;
- (v) where the internal angle is greater than 95° deduct 5% from the capacity of the weaving section.

Where the pedestrian flow across an exit from the roundabout exceeds 300 per hour an arbitrary reduction of one-sixth should be made in the practical capacity of the preceding weaving section.

As roundabouts have a tendency to lock when overloaded and do not readily recommence functioning it is important that they should have adequate reserve capacity to meet future peak flows and that attempts should be made to reduce the chances of locking. One method which has given promising results is to erect signs requiring approaching traffic to give way to that already on the roundabout. Where this has been done experimentally, locking has virtually been eliminated and capacity flows have been maintained even in overloaded conditions. Delays have been reduced owing to the increased capacity, which has ranged from 6 to 14% above that obtainable with police control. The accident rate has been reduced by more than 40%.

An alternative method of dealing with roundabouts which are prone to locking in peak periods is to install traffic signals on the approaches. In the case of two simple four-leg roundabouts the capacity was increased by about 10% over that obtainable with police control, and there is some evidence of a further improvement as drivers have become accustomed to this type of control. With two more complicated roundabouts, with six legs, no measurable improvement over police control was found.

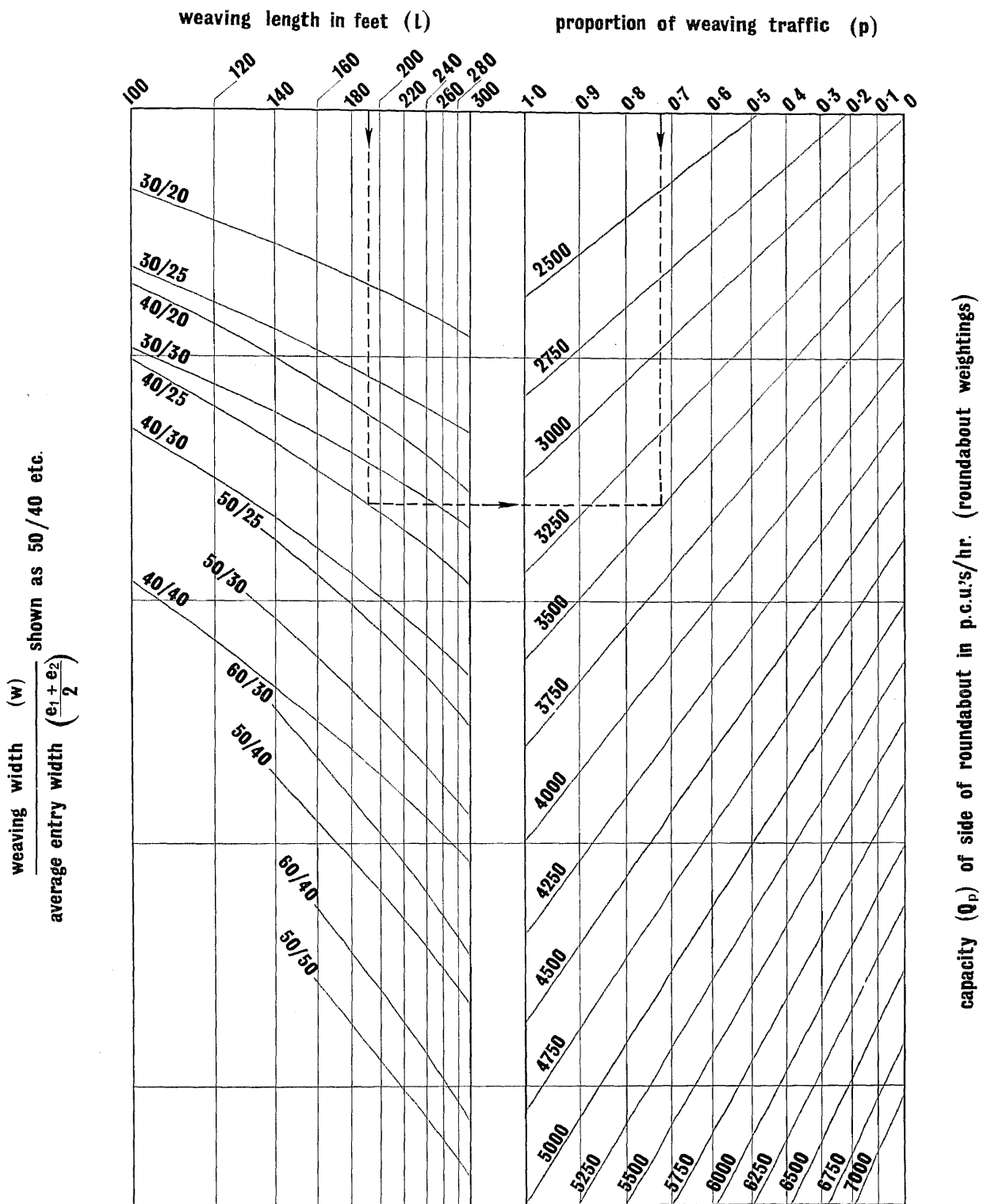
Signals did not always prevent locking of the roundabouts, but by using them in conjunction with a newly developed presence detector (now commercially available) which automatically adjusts the clearance period during each cycle to fit the traffic requirements locking was virtually eliminated.

12.2 Roundabout design

12.2.1 Shape of the central island

Simple geometric figures such as the circle or ellipse may not be the most suitable where the angles between the approach roads are irregular and the site is constricted. Asymmetric shapes, either wholly curved or with a combination of straights and curves (as shown in Diagrams (1) and (5) of Fig. 12-2) will often provide the only satisfactory solution.

Where two roads cross at or nearly at right angles the central island is usually round or square with rounded corners, as



To determine the capacity of the side of a roundabout, use the left-hand diagram to obtain the point corresponding to the weaving length, weaving width and average entry width (interpolating where necessary), extend a line horizontally to the right-hand diagram, from which the capacity is given for the proportion of weaving traffic.

To determine the dimensions of a side of a roundabout, use the right-hand diagram to obtain a point corresponding to capacity and

proportion of weaving traffic and draw a line horizontally to the left-hand diagram. This line will cut various alternatives of weaving length, weaving width and entry width, from which a suitable design may be obtained.

Example shown:

$l=190'$ $w=40'$ $e=25'$
 $p=0.73$ $Q_p=3500$ pcu's/hour

Fig. 12-1 Roundabout design chart

illustrated in Diagrams (2) and (3). The corners of a square island should be adequately rounded off, with a corner radius of at least 60 ft. The elongated central island shown in (4) will be appropriate for a scissors junction. For some junctions, particularly those with more than four approaches, irregularly shaped roundabouts may be required (5). It will be noted that in these designs there are no 'dead' areas of carriageway on the periphery of the roundabout, as shown by cross-hatching in Diagram (6). Such areas are rarely used by traffic and contribute little to the capacity of the weaving sections; they should therefore be avoided in design.

Gyratory systems with exceptionally large central islands are sometimes formed from existing streets and may surround buildings or development (7). In such cases the shape of the central island will probably be less important than the adequacy of the weaving sections.

Street lighting columns and traffic signs on the central island and the periphery of a roundabout should desirably be sited where there is little risk of their being hit by out-of-control vehicles. To minimise danger to vehicles, kerbing around the central island should not be high; splay kerbs are preferable to vertical kerbs.

12.2.2 Entry and exit layouts

A pedestrian refuge or channelising island is usually sited on each approach to a roundabout to assist pedestrians and guide traffic into the weaving section at a suitable angle. Merging manoeuvres can be made easier by confining entering vehicles to definite paths. To achieve this the channelising islands should be made as large as possible without encroaching on the desired paths of vehicles.

To achieve smoothness of flow the entrance radii should be similar to or slightly less than those of the central island. Entrance radii of between 40 and 75 ft. will usually be suitable for urban designs, the smaller dimensions being used approaching short weaving lengths or where space is restricted. A slight dominance can usefully be given to the flow around the central island by making its radius or radii slightly greater than the entry radii, with a minimum of 60 ft. To assist the clearance of traffic from the roundabout the exit radii should be greater than those of the entrances and central island. A tangential alignment may sometimes be adopted, as shown for the exit marked A in Diagram (1) of Fig. 12-2. Where, however, pedestrian flows across the exit roads are heavy, radii similar to those at the entrances should be provided to keep exit speeds reasonably low.

Where possible, layouts should not include sharp exit angles, obtuse internal angles around the roundabout and tangential entrances to the weaving sections. If these undesirable features cannot be avoided the capacity of the weaving sections should be adjusted as indicated in Section 12.1.

12.2.3 Weaving sections

On roundabouts in rural areas, weaving widths are normally about 30 ft., but in urban areas designs are less standardised, perhaps because achievement of the required capacity within the space available is more of a problem, and widths range from 24 ft. up to about 60 ft.

A study of over 400 weaving sections on existing roundabouts shows that mean $\frac{l}{w}$ ratios range from 3.4 in town centres (where land tends to be scarce and speeds are fairly low) to 3.9 in the suburbs and to 4.8 in rural areas (where land is more readily available and speeds are higher). When designing a roundabout it may be useful as a first step to calculate the weaving width

required for an appropriate $\frac{l}{w}$ ratio. If $\frac{l}{w}$ is denoted by r and $\frac{e}{w}$ is taken as unity, w can readily be estimated from a rearranged version of the formula in Section 12.1:

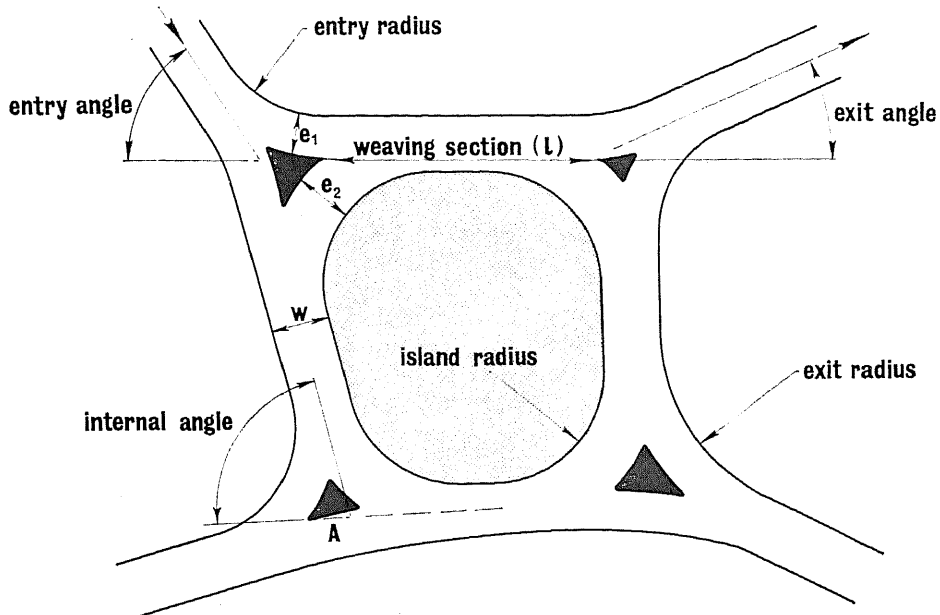
$$w = \frac{\left(1 + \frac{1}{r}\right) Q_p}{172 \left(1 - \frac{p}{3}\right)}$$

This will enable a suitable standard width to be chosen for the weaving section (which should be greater than that of the approach carriageway) and the weaving length can then be calculated from the assumed $\frac{l}{w}$ ratio.

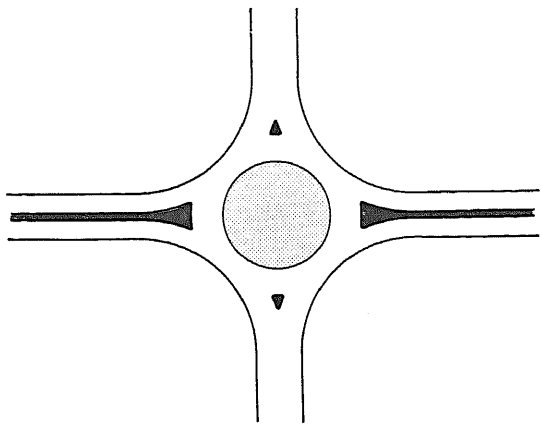
12.2.4 Pedestrians

Pedestrian crossings of the zebra type are frequently sited at the entrances and exits of roundabouts. Although subways would often be safer and cause less delay to traffic, the presence of pedestrian crossings on the approach carriageways is unlikely to have an adverse effect on the operation of the roundabout. On the other hand, zebra crossings on the exit carriageways may delay vehicles and cause a queue to extend back into the roundabout, thereby increasing the risk of locking. Sometimes that part of the crossing on the exit carriageway can usefully be sited further from the roundabout, provided this does not unduly inconvenience pedestrians. Guard rails should be erected where necessary to guide pedestrians to suitable crossing points and to discourage crossing via the central island.

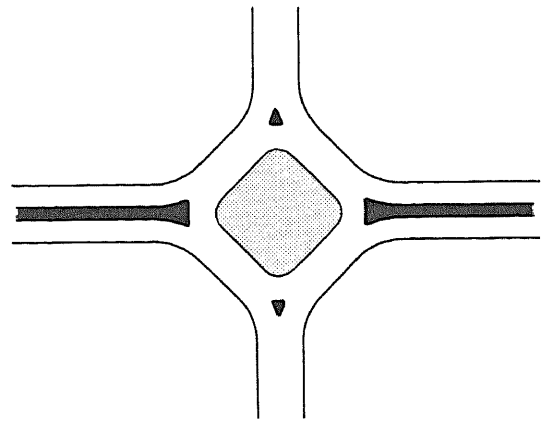
The provision of grade separation for pedestrians (and possibly cyclists) will sometimes be warranted to enable them to negotiate the junction safely and without delaying other traffic.



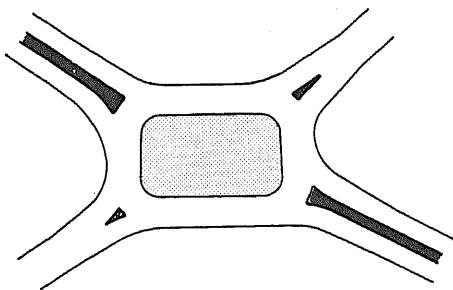
(1) roundabout dimensions



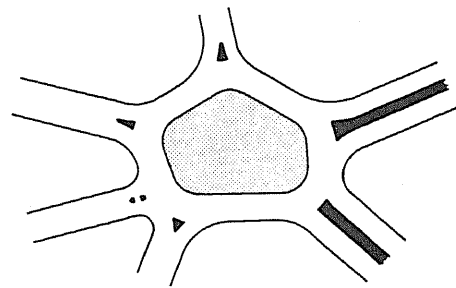
(2) circular central island at normal 90° crossroads



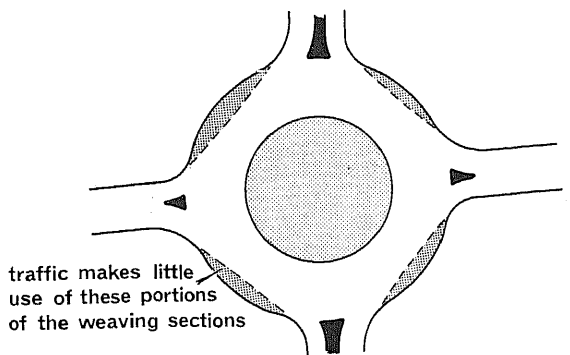
(3) square central island at normal 90° crossroads



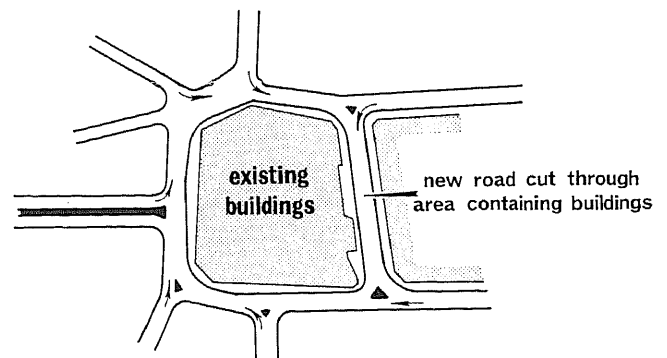
(4) roundabout at a scissors-type intersection



(5) complex intersection with many approaches



(6) with this layout the weaving section is partly wasted



(7) gyratory system formed mainly from existing streets

Fig. 12-2 Roundabout layouts

13 Interchanges

Interchanges are junctions with grade separation and will normally be appropriate on urban motorways and at more important junctions on all-purpose *primary distributors*.

To justify the high cost of grade separation there must be appropriate benefits such as increased capacity, less delay, fewer accidents and reduced operating costs. In view of the restricted space available in urban areas and the high cost of interchanges it is particularly important that designs should be adequate for long-term traffic requirements. Interchanges are large and often conspicuous; as far as possible, designs should be chosen to minimise any adverse effect on amenity. Designs should be as compact as possible to reduce delays to vehicles changing from one road to another, but curves should not be so tight as to be dangerous.

13.1 Capacity

13.1.1 Through carriageways

The practical capacity of through lanes 11 or 12 ft. wide should be taken as 1,500 pcu's per hour. Capacity should be reduced by 10% where lane widths of only 10 ft. can be obtained.

13.1.2 Slip roads

Slip roads form the link between one major road and another at an interchange. As their gradients and curvature are likely to be less favourable than those of the major roads their practical capacity will be lower and should normally be taken as 1,200 pcu's per lane per hour. As the traffic flow on slip roads may depend on the capacity of their junctions with the major roads it is important that designs should be properly balanced.

13.1.3 Merging traffic

Unless an extra lane is provided on the major road beyond an entry fork, the volume of traffic joining from a slip road and acceleration lane cannot exceed the capacity of the gaps in the nearside traffic stream. American experience²⁵ suggests that in peak conditions maximum merging flows (flow on nearside lane upstream of fork plus that from slip road) may range from about 1,300 to 2,000 vehicles per hour. Fig. 13-1 has been derived from observations in the United States and indicates how entry volumes (shown as 90% maximum) are likely to be affected by flows on the major road approaching the entry fork. If the merging capacity is inadequate an additional lane will be required on the major road beyond the fork.

If there is an exit fork a short distance downstream from the junction, vehicles intending to turn off may so increase the volume of traffic on the nearside lane that the entry flow may be seriously reduced unless an auxiliary lane can be provided between the entry and exit slip roads. This length of the major road will need to be checked for adequacy as a weaving section as indicated in Sub-Section 13.1.5.

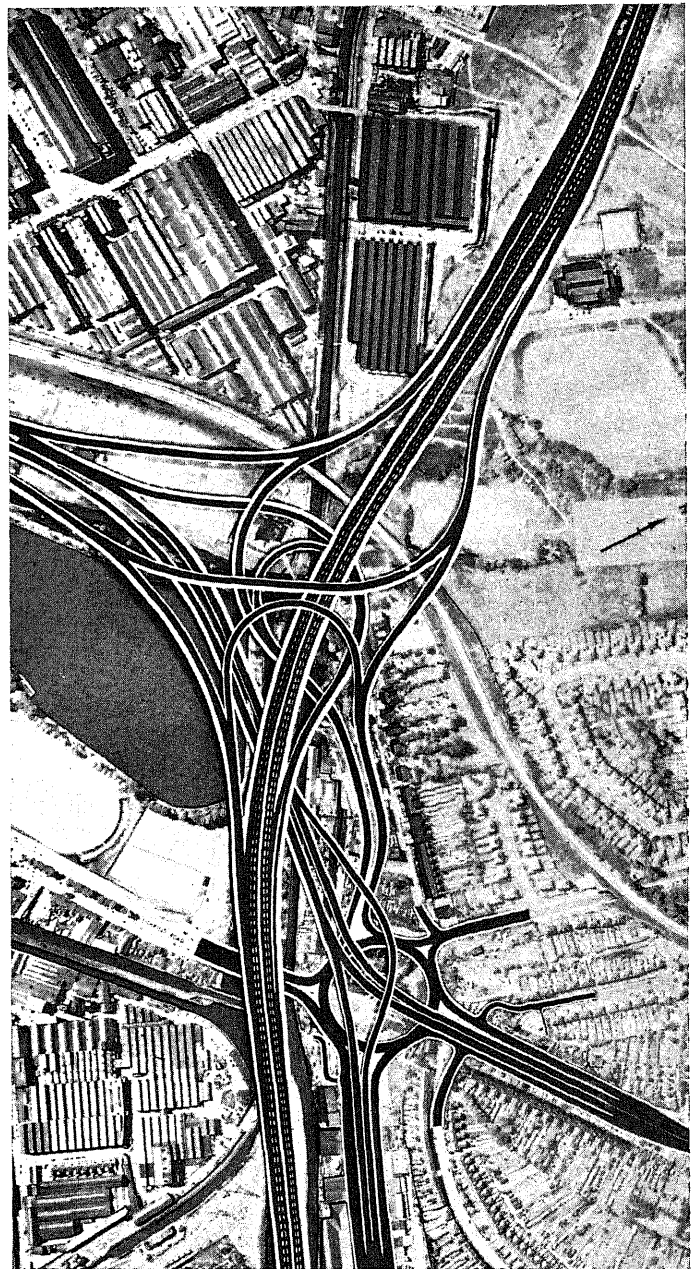
13.1.4 Deceleration lanes

The capacity of a single-lane exit may be taken as about 1,200 pcu's per hour provided the deceleration lane is well designed and the exit is clearly signposted well in advance of the junction.

13.1.5 Weaving sections

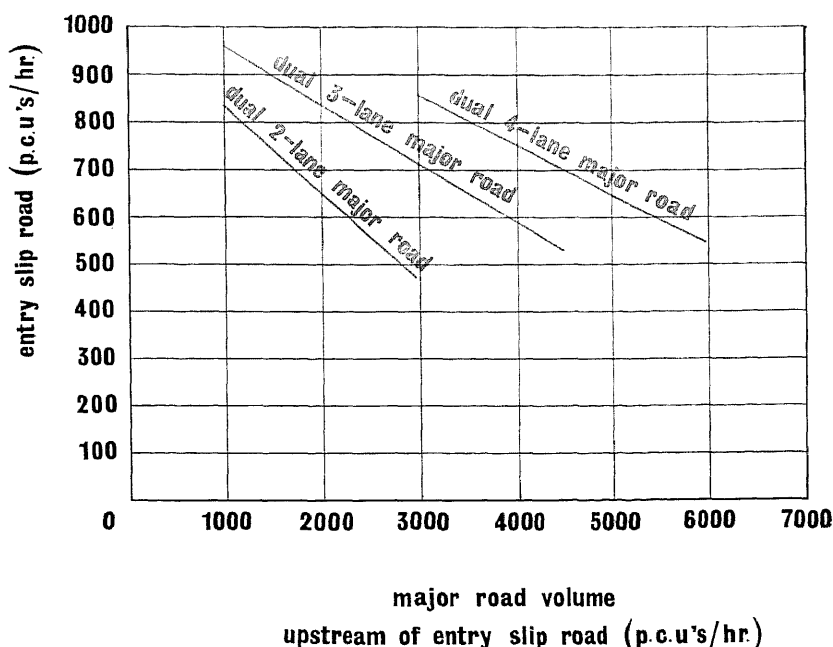
Weaving manoeuvres are required not only at roundabouts but at interchanges such as the cloverleaf and on motorways between successive entry and exit slip roads. It is important that designs should be checked to ensure that the widths and lengths of all such weaving sections are adequate.

The dimensions and capacities of weaving sections on roundabouts are considered in Section 12.1. Suggested minimum lengths for longer weaving sections (allowing weaving at about 30 mph as required on urban motorways) are given in Table 13-1, which is based on American experience.²⁶ Where weaving takes



Proposal for a multi-level interchange at Gravelly Hill, Birmingham

Fig. 13-1 Merging flows



place on slip roads instead of on the motorway, speeds will be lower and the weaving lengths may be halved.

Table 13-1 Weaving lengths

Weaving volume pcu's per hour	Minimum length of weaving section ft.
1,000	250
1,500	400
2,000	650
2,500	950
3,000	1,350
3,500	1,850

The number of lanes required for minimum weaving sections may be estimated from the formula given below. To allow for mixed traffic, hourly flows should be given in urban pcu's (see Table 1-3).

$$N = \frac{W_1 + 3W_2 + F_1 + F_2}{C}$$

where N is the number of lanes;
 W_1 is the larger weaving flow;
 W_2 is the smaller weaving flow;
 F_1 and F_2 are outer non-weaving streams;
 C is the normal lane capacity of the major road.

When N is less than 3 for a total flow with an outer stream exceeding 600 pcu's per hour, an additional lane should be provided for the outer stream. Similarly, when N is less than 4 for a total flow with two outer streams each exceeding 600 pcu's per hour, an additional lane should be provided for each. If separate provision is made for outer streams they should be omitted from the formula when calculating the remaining number of lanes.

Where a longer weaving length than that indicated can be provided it may be possible to reduce the width required. The formula for the number of lanes should be adjusted by substituting the following expression for the term $3W_2$:

$$\left(\frac{2 \times \text{length given in table}}{\text{actual length}} + 1 \right) W_2$$

Doubling the length would reduce $3W_2$ to $2W_2$; tripling the length would reduce it to $1.7W_2$. A useful graph for calculating

the width of long weaving sections is given in *Urban Traffic Engineering Techniques*.⁷

If the exit slip road is far enough ahead of the entry slip road the width of the major carriageway in between may be calculated in the normal manner, without regard to weaving. There is little evidence on which to assess the minimum length required, but American experience⁸ suggests that the distance in feet should be between two and three times the hourly weaving volume in vehicles per hour, the higher values being appropriate for large weaving volumes.

13.1.6 Lane balance and location

At each entry and exit fork the number of lanes provided on the major road and slip road should have regard to the future peak flows to be accommodated, in accordance with the recommendations on lane, merging and weaving capacities given in the preceding sub-sections.

Where there are a number of entry and exit forks in proximity, as at an interchange, it may be desirable to increase the number of lanes beyond the minimum indicated by the capacity calculations in order to ensure efficient operation and easy movement from one carriageway to another. The number of lanes provided should have regard to the following practical considerations:

- (i) Where two traffic streams merge, the number of lanes beyond the fork should not be less than the sum of the lanes on the merging carriageways minus one. For example, beyond the junction of a two-lane slip road with a three-lane carriageway the number of lanes should be at least four.
- (ii) Where an exit slip road requires two lanes, the number of lanes on the major carriageway may be reduced by one, provided the number remaining is at least two.
- (iii) The width of the major carriageway should not be reduced by more than one lane immediately beyond an exit fork.

The distance between successive exit forks or entry forks should be at least the length of the intervening speed-change lane and should be increased as necessary to facilitate manoeuvring and signposting. Where an exit fork is located shortly after an entrance fork, weaving will take place in between and the length should be as indicated in Table 13-1, with a desirable minimum of 600 ft. Where an entrance fork is located after an exit fork on the same side of the road the design of the slip roads will usually require a length of about 600 ft. between the forks.

13.2 Acceleration and deceleration lanes

Acceleration and deceleration lanes should be provided where slip roads join an urban motorway and may also be useful at important junctions on other roads. Direct-taper layouts, as shown in Diagram (1) of Fig. 13-2 will normally be appropriate for speed-change lanes and will suit the natural path of vehicles.

Speed-change lanes should be long enough to ensure ample space for merging and diverging manoeuvres. At the end of an acceleration lane there should be no kerb or other obstruction which might be dangerous for a driver unable to merge with the traffic stream on the nearside lane. The angle between the slip roads and the through carriageways should neither be so large that vehicles enter or leave the main road too abruptly nor so small that the nose is unduly long and the length available for merging or diverging is reduced. Nose angles of about 4 to 5° (i.e. tapers of 1 in 12 to 1 in 15) should usually be suitable for urban conditions; a gradual approach from the entry slip road is particularly important to ensure good visibility and smooth merging. Where possible the entry and exit noses should be at least 150 ft. long; adjoining the nose, slip roads should be straight and approximately at the same level as the through carriageways.

Speed-change lanes are best located where the major road is reasonably straight and level and visibility standards are high. They should be carefully sited to ensure that they are not hidden from the view of approaching traffic by horizontal or vertical curves. Exits on tangent alignments on the outside of a curve, as shown in (2), may be confusing to drivers and if the deceleration lane cannot be resited away from the curve it should be designed so that a definite change of course is required on leaving the major road (3). Entrances on tangent alignments are equally undesirable, and layouts should encourage full use of the acceleration lane and avoid abrupt entry on to the major road.

Where it is required to reduce the width of the major road by one lane after an exit fork the reduction should usually be made by means of a taper at least 300 ft. long beyond the exit nose (4). This arrangement is preferable to an immediate reduction at the nose, which might entrap through traffic on to the exit slip road.

Table 13-2 Acceleration and deceleration lane lengths

Design speed of major road mph	Gradient of major road %	Acceleration lane length ft.	Deceleration lane length ft.
50	4% up	800	270
	level	560	300
	4% down	440	340
40	4% up	510	} 250
	level	340	
	4% down	250	
30	4% up	} 210	} 210
	level		
	4% down		

The lengths of acceleration lanes are particularly influenced by adverse gradients, and wherever possible they should be sited where gradients on the major road are favourable. If there are uphill gradients on the entry slip road and the major road, heavy vehicles may be unable to exceed the crawl speed and drivers may experience difficulty in joining the nearside traffic stream. If the road has paved verges they may be able to proceed along the verge until a suitable gap in the traffic occurs, but where there is no verge it may be necessary to provide an additional lane on the rising gradient.

Recommended minimum lengths for deceleration and acceleration lanes in high-volume urban conditions are given in Table 13-2. These are the lengths adjoining and open to the through carriageways; they assume a nose length of 150 ft. and should be increased as necessary if the nose is shorter.

The lengths given in the table will be suitable both for acceleration or deceleration at ordinary interchanges and for merging or diverging manoeuvres at major interchanges between motorways.

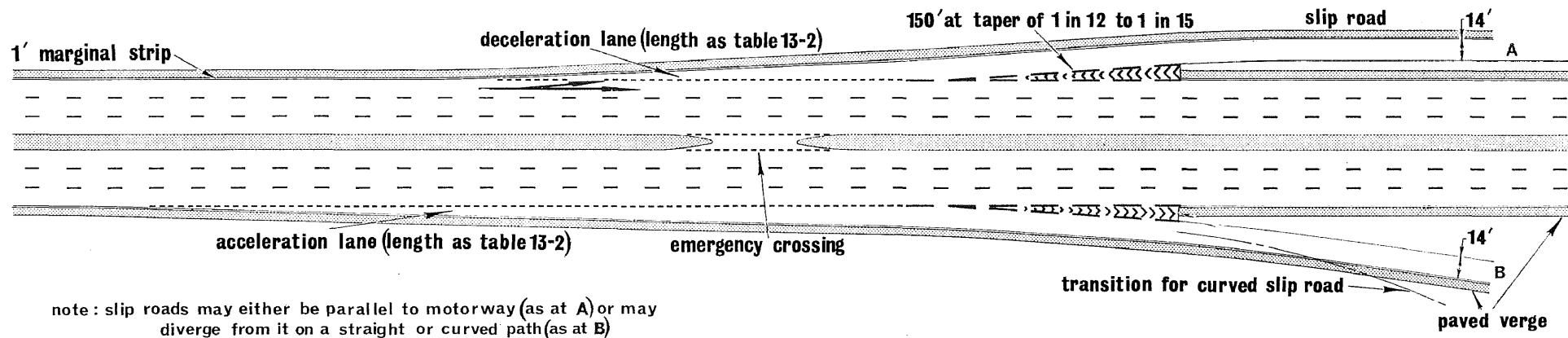
13.3 Slip roads

Slip roads may either be straight, slightly curved or looped, depending on the layout of the junction. At important junctions with both direct and loop connections the major traffic streams should if possible be routed via the direct connections. Recommended design standards for slip roads are given below:

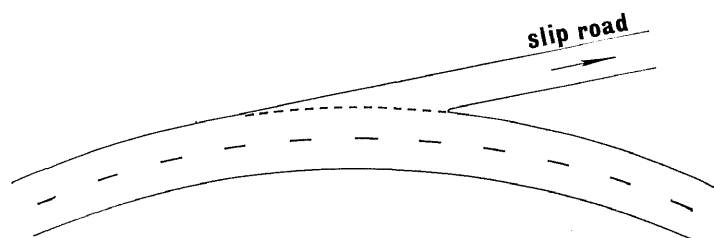
- (i) Design speed This should normally be between two-thirds and half that of the more important major road at the junction. For loop slip roads a lower standard may have to be adopted where space is restricted; 15 mph should be regarded as the usual minimum.
- (ii) Width Slip road carriageways should normally carry one-way traffic only. One-lane slip roads should have a 14 ft. carriageway bounded on the left-hand side by a 1 ft. marginal strip or lip kerb and a paved verge not less than 5 ft. wide and on the right-hand side by a raised kerb and a verge wide enough to give clearances as indicated in Table 4-2. Where traffic flows warrant the provision of two-lane slip roads, the carriageway width should be increased to 24 ft. Carriageways should be widened on bends as indicated in Table 10-2.
- (iii) Curve radii Minimum radii for various design speeds are given in the second column of Table 13-3.
- (iv) Sight distances Minimum stopping distances for various design speeds are given in the third column of Table 13-3. Stopping distances should be checked between points 3 ft. 6 in. above the carriageway along lines 6 ft. from both the nearside and offside edges of the carriageway.
- (v) Gradients Slip road gradients should preferably not exceed 5% and should nowhere be steeper than 8%. Where a slip road carries a large volume of heavy commercial traffic its gradient should desirably be limited to 4%.

Table 13-3 Minimum slip road radii and stopping distances

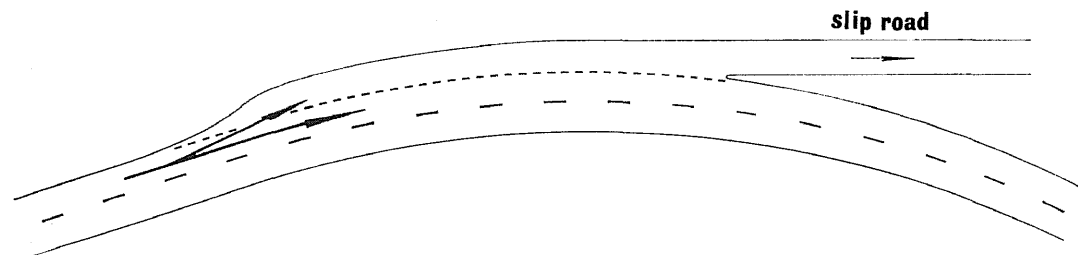
Design speed mph	Minimum radius ft.	Minimum stopping sight distance ft.
40	490	300
30	240	190
25	170	150
20	110	110
15	60	70



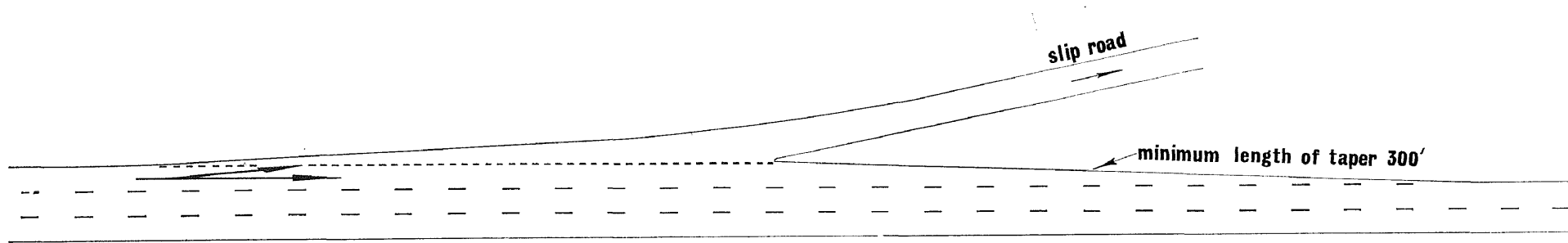
(1) interchange layout showing slip roads and speed change lanes



(2) unsuitable exit slip road alignment tangential to major road



(3) if exit slip road cannot be moved away from bend, the alignment of the deceleration lane should be altered as shown



(4) tapering of major road beyond exit slip road

Short slip roads have limited storage capacity and a temporary delay at the exit may cause traffic to back up sufficiently to block the entrance. Longer slip roads are likely to function more smoothly, but if they are very long two-lane carriageways may be needed to avoid delays due to slow-moving vehicles. The two-lane layout should be reduced to single lane before the slip road joins the motorway unless the full width is needed to ensure sufficient capacity at the entrance or exit.

Where the slip road joins the all-purpose road, junction design and visibility standards appropriate to the all-purpose road should be used.

The possible need for road heating on slip roads should be considered. Avoidance of snow and ice hazards is particularly important on steep or sharply curved slip roads.

13.4 Interchanges between *Primary* and *District distributors*

The three basic types of interchange between *primary* and *district distributors* are the diamond, the grade-separated roundabout and the partial cloverleaf. These are illustrated in Diagrams (1), (2) and (3) respectively of Fig. 13-3.

Where space is restricted and land costs are high, the diamond interchange with traffic signal control where the slip roads join the all-purpose road is probably the most useful type. With linked traffic signals and adequate storage for vehicles awaiting the green signal these interchanges function smoothly and can cope with high turning volumes.

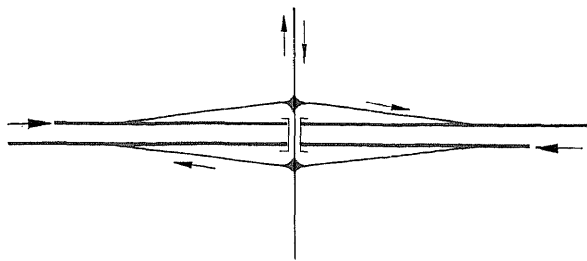
Where two parallel cross-streets are available as connections to the *primary distributor* the split diamond layout shown in (4) can be used. This layout is more efficient than the conventional diamond; traffic conflicts are reduced and fewer lanes are likely to be required. Two-phase signal control can be used instead of the three-phase control needed for the conventional layout. The most effective layout is that shown in (5), where the slip roads are linked to one-way cross-streets. With two-phase signals and one-way streets this arrangement gives the highest capacity and the least delays.

The grade-separated roundabout requires the construction of two bridges and generally needs more land than the diamond layout. It may be useful where a number of streets intersect at the interchange and in suburban areas where land values are not so high. Both the diamond and the grade-separated roundabout layouts have the advantage of embodying straight or gently curved slip roads with a substantial distance between deceleration and acceleration lanes. Where, however, the *district distributor* carries a large volume of traffic it may be impossible to provide sufficient capacity on the weaving sections of the roundabout without excessive use of land. One method of overcoming this difficulty is to provide a three-level interchange with the roundabout between the *primary* and *district distributors* and used only by interchange traffic. In view of the probable high cost of this solution it may only be practicable in special cases.

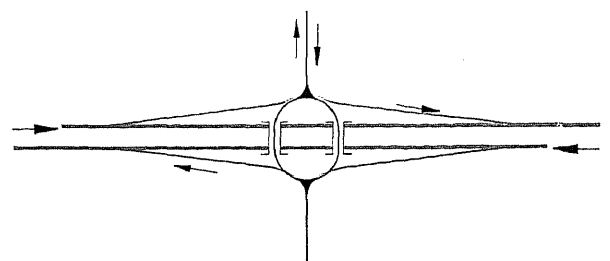
The partial cloverleaf design requires more land than the others and has sharply curved slip roads. In view of the space required for the loops it cannot be linked so easily to collector-distributor or frontage roads parallel to the *primary distributor*. Where there is an obstruction such as a railway or river immediately to one side of the *district distributor* the layout can be amended as shown in (6). This layout affords no choice of quadrants for the location of the slip roads; where a choice exists it may sometimes be possible to minimise right-turning movements at the junctions of the slip roads and the *district distributor* by



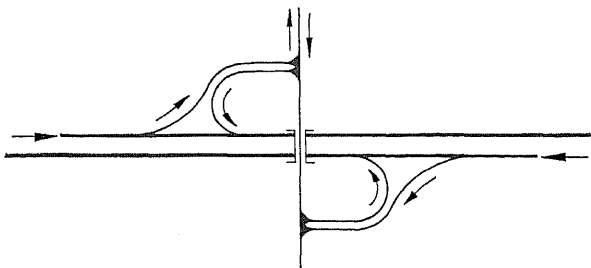
Gantry sign at exit slip road from Motorway M.4



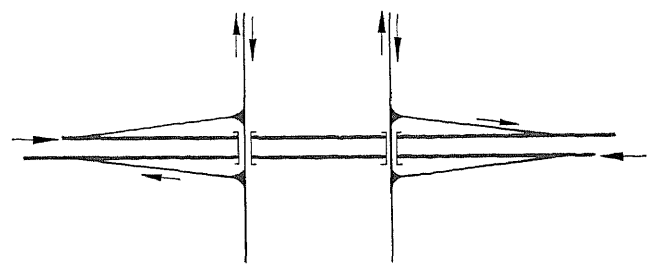
(1) diamond



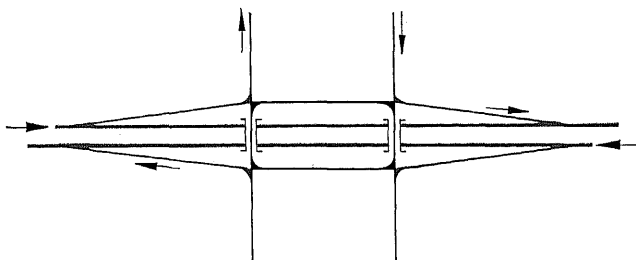
(2) grade-separated roundabout



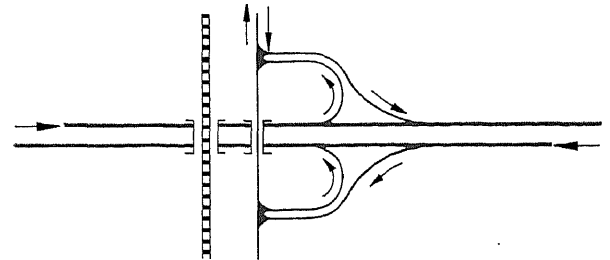
(3) partial cloverleaf



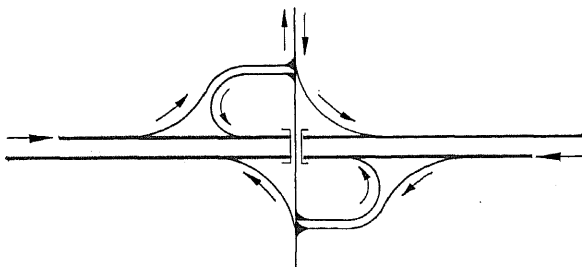
(4) split diamond



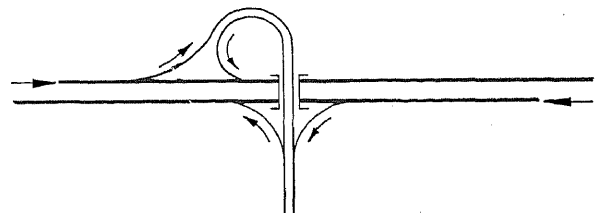
(5) split diamond with one-way streets



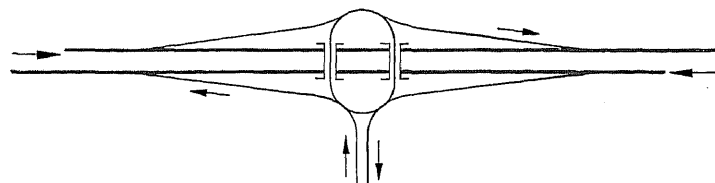
(6) modified partial cloverleaf to avoid obstruction



(7) partial cloverleaf with additional slip roads to eliminate direct right turns from the street

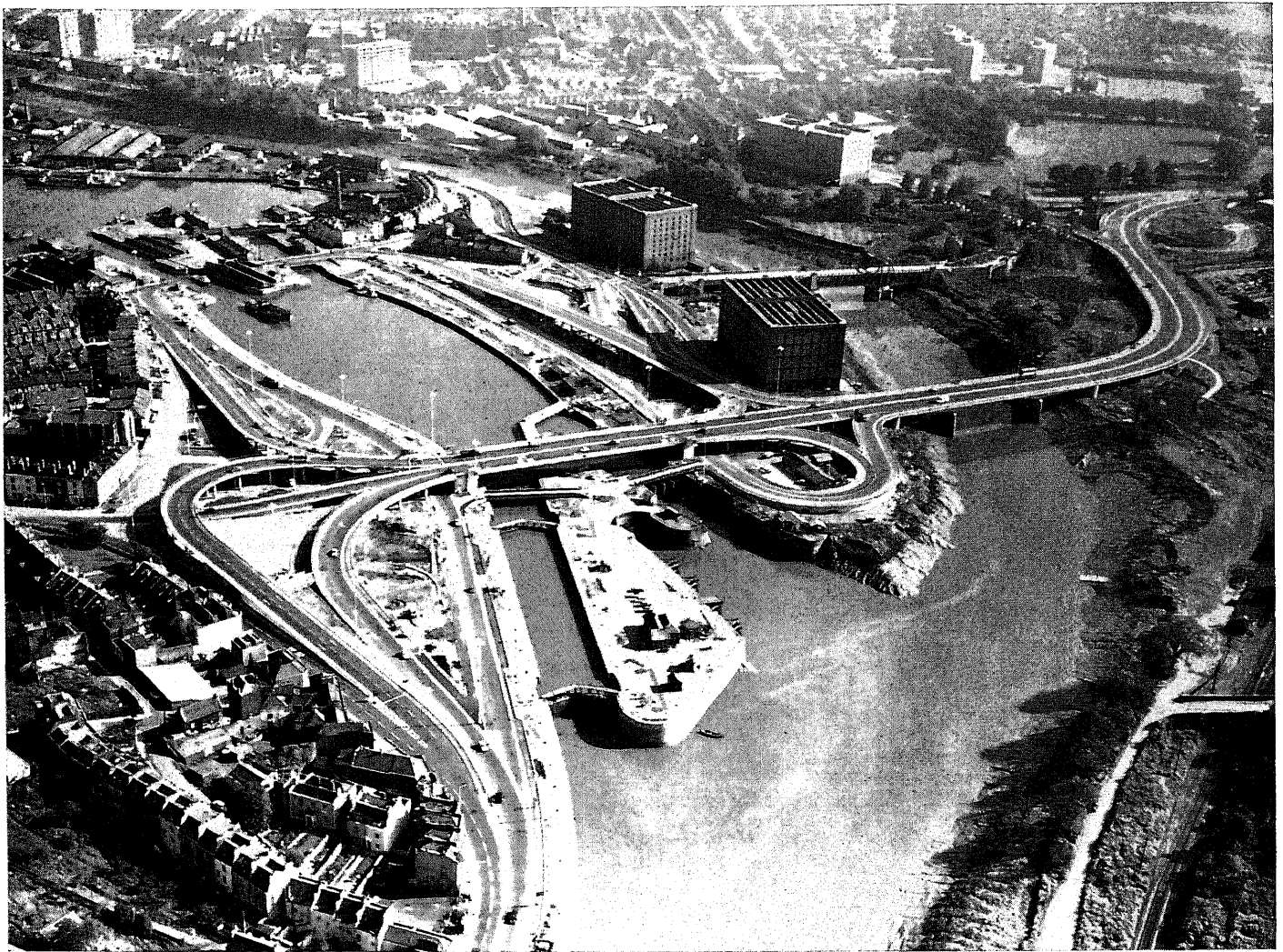


(8) trumpet



(9) T junction with grade separated roundabout

Fig. 13-3 Interchanges between *primary* and *district distributors*



Cumberland Basin swing bridge and interchanges, Bristol docks (reproduced by courtesy of the Bristol City Council)

locating the slip roads in the appropriate quadrants. If the conventional diamond layout does not have sufficient capacity and the split diamond cannot be used, the special partial cloverleaf layout shown in (7) may be useful. This layout can accept large traffic volumes; the additional slip roads eliminate direct right turns from the *district distributor*.

Where the *district distributor* forms a T or Y junction with the *primary distributor* a trumpet layout (8) or modified grade-separated roundabout (9) may be used. If the traffic volumes on the direct and loop slip roads of the trumpet differ appreciably it should preferably be aligned so that the higher volume will use the direct connection.

13.5 Three-leg interchanges between *Primary distributors*

Interchanges between *primary distributors* should be designed to allow for the continuous movement of traffic between one road and the other. Some designs require loop slip roads; some involve weaving either on the slip roads or on the *primary distributors*; some require two exits instead of one from each approach. Designs with loop slip roads should preferably be arranged so that major turning movements take place on direct or semi-direct connections. Designs which require weaving on the *primary distributors* are undesirable; the inclusion of weaving sections may limit the capacity of the junction, but if they have to be accepted weaving should take place on the slip roads and

not on the through roads. Designs needing two exits from the *primary distributor* require some drivers to make two decisions within a short space of time and to position their vehicles accordingly. The signposting of such junctions will require special care.

Some typical designs for three-leg interchanges are shown in Fig. 13-4. In Designs (1), (2) and (3) the roads cross at only two levels and only a single bridge is required; Design (3) does not allow for all turning movements but may sometimes be acceptable. Design (4) is compact, but its usefulness and capacity may be limited by the need for a weaving section on the slip roads. Design (5) has no weaving section but is less compact than (4) and has sharp curves on its jug-handle slip roads. Designs (6), (7), (8) and (9) are particularly suitable for high-volume interchanges; (6) and (7) each require three bridges, but (8) and (9) are made more compact by using a single three-level bridge. None of these designs requires more than one exit on each approach and only one embodies a weaving section. It will often be useful to extend the stem of the T, as shown by the dotted lines in Diagrams (4) and (7); this will provide direct access between north and south, but without interchange facilities for traffic from the north.

The forks where traffic streams merge or diverge should be designed in a similar manner to conventional speed-change lanes, with lengths appropriate to the design speed of the major roads or slip roads and preferably with the traffic entering or leaving the major streams from the left.

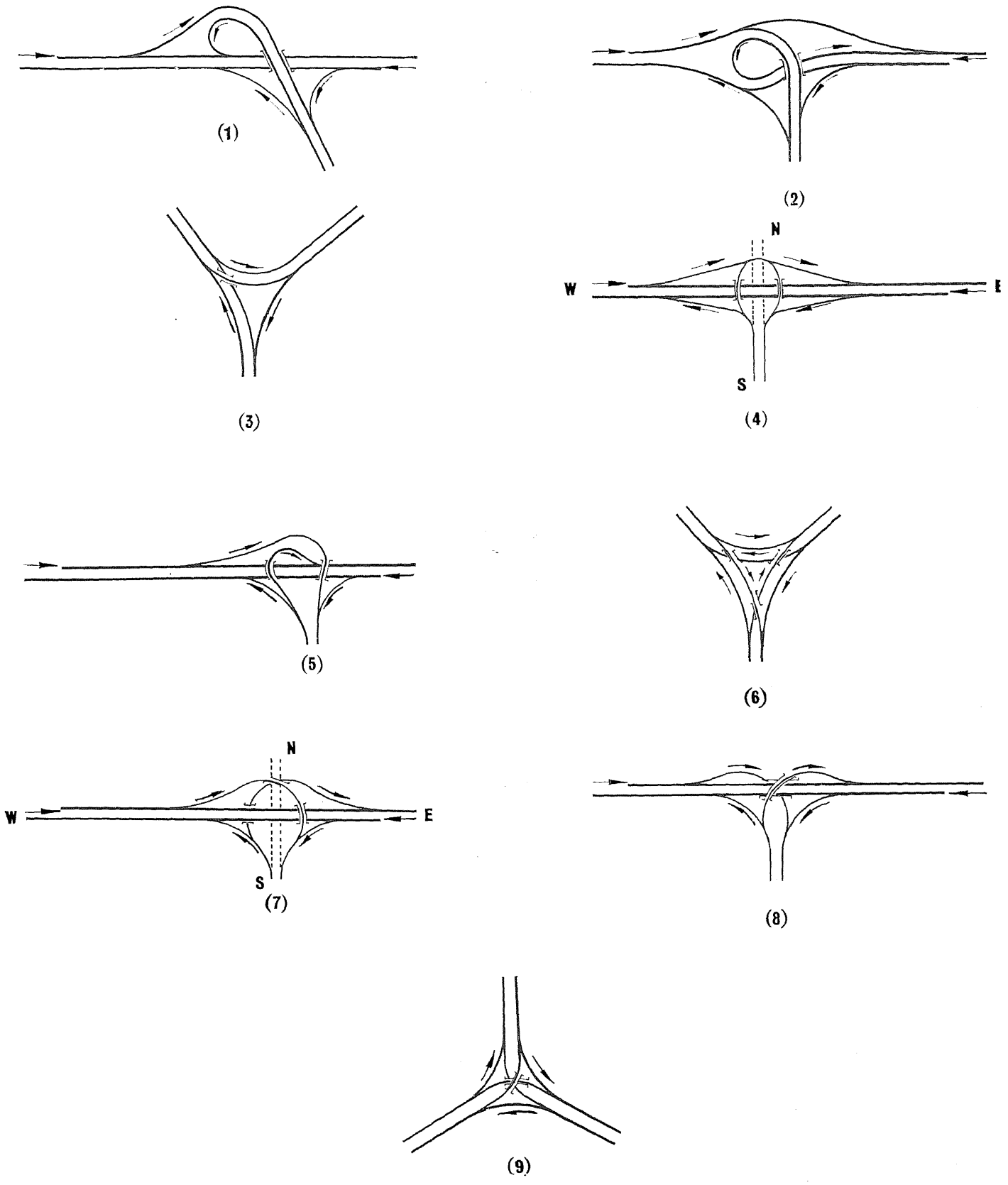


Fig. 13-4 Three-leg interchanges between *primary distributors*

13.6 Four-leg interchanges between *Primary distributors*

Some typical designs for four-leg interchanges are shown in Fig. 13-5. The cloverleaf designs (1) to (4) all have slip road loops and involve weaving. Design (2) is preferable to (1) as the weaving operations are transferred from the *primary distributors* to the slip roads and there is only one exit on each approach instead of two. Design (3) is a modified version allowing a major turning movement from south to east without requiring a loop slip road. The design can be further modified as shown in (4) to allow easier right turns from, say, south to east and north to west. Only one two-level bridge is required for Designs (1) and (2), but Design (3) has three bridges and Design (4) has four.

Design (5) has two exit slip roads on each approach; it is reasonably compact and does not involve weaving, but needs five bridges—four of them wide enough to accommodate a deceleration lane as well as dual carriageways. In Design (6) the through roads cross above and below a conventional roundabout which is used by turning traffic; this design requires five two-level bridges but can be made fairly compact provided the weaving volumes on the roundabout are not too large. Design (7) has the advantage of having no loops or weaving lengths, but requires separation of the through carriageways and eight two-level bridges and involves some joining and leaving movements on the right. Design (8) is reasonably straightforward and compact; it requires no loops or weaving but involves the construction of a central four-level structure.

There are many other four-leg interchange patterns; all will be expensive and the choice will usually lie in the design which suits the site and can handle the required traffic movements with the least possible complexity and cost. The signposting of junctions requiring two exits on each approach will need particular care. Designs requiring entrances or exits on the right-hand side of the road should preferably not be used.

Four-leg interchanges are invariably more complex than three-leg interchanges and are likely to be more costly and to require more land. It may sometimes be advantageous to design the primary network to avoid or limit the need for four-leg interchanges. Alternatively it may be possible to simplify some designs by reducing the number of turning movements.

13.7 Spacing of interchanges

As shown in Diagram (1) of Fig. 13-6, the minimum spacing between diamond interchanges will be about 1,800 ft. This allows a weaving length of 600 ft. between successive entry and exit slip roads, which will each need to be at least 600 ft. long. The 600 ft. weaving length will serve as a combined acceleration and deceleration lane and, as indicated in Table 13-1, will have a weaving capacity of nearly 2,000 pcu's per hour.

Although the spacing between urban interchanges may be as little as 1,800 ft. it should desirably be at least half a mile. This will ensure better designs with longer weaving lengths, easier slip road gradients and improved capacity. Where necessary the spacing should be increased to provide the required weaving capacity.

Where a major interchange (i.e. between two motorways) follows an entry slip road or precedes an exit slip road it is particularly important that sufficient distance should be allowed for weaving. Where possible the distance should be twice that indicated in Table 13-1, with a minimum of about 1,200 ft.; this will allow weaving to take place at about 40 mph.

Various methods of decreasing the spacing between interchanges are illustrated—in order of increasing effectiveness—in Diagrams (2) to (5). The conventional sequence of entry and exit slip roads is maintained in (2) and (5), but in (3) space is saved by grouping together two or more entry or exit slip roads. The arrangement shown in (4) permits a further saving of space by combining the grouped and criss-cross slip roads. In (5) the slip roads are at right angles to the motorway, and their junctions with the all-purpose road system must be far enough away to ensure reasonable gradients on the slip roads.

13.8 Frontage roads and collector-distributor roads

These roads are connected to the motorway system at a limited number of points but may have many connections to the street system, thereby facilitating the distribution of traffic to and the collection of traffic from busy districts such as the town centre. By reducing the frequency of access points along the main motorway they reduce weaving problems, promote free flow and preserve the high capacity of the motorway.

A frontage road system is illustrated in Diagram (1) of Fig. 13-7. The frontage roads flank the motorway; they are all-purpose, at the same level as the street system and usually one-way. They are linked to streets which might otherwise come to a dead end at the motorway. They form boundaries to environmental areas and will usually serve as *district distributors*.

Collector-distributor roads are shown in Diagrams (2), (3) and (4). They have motorway status and are grade-separated from the all-purpose street system. In Diagram (2) the collector-distributor roads flank the motorway and are at the same level; they are linked by slip roads to the streets. As a design speed of 30 mph will usually be appropriate for collector-distributor roads the lengths required for speed-change lanes and weaving will therefore be appreciably less than on the main motorway and more frequent connections can be provided to the street system. Where necessary the slip roads leading to and from collector-distributor roads may be grouped as indicated in Fig. 13-6.

In Diagram (3) the collector-distributor roads have dual carriageways and form a loop giving access to development some distance from the main motorway. In Diagram (4) the collector-distributor roads form spurs at right angles to the motorway.

Failure to provide frontage or collector-distributor roads adjoining heavily trafficked routes may lead to difficulties in the future. Without these facilities accesses may be required at such frequent intervals that, as the volume of traffic grows, the resulting weaving manoeuvres may seriously disrupt the flow of traffic on the motorway and reduce its capacity.

13.9 Consistency of layout

Where there are a number of interchanges at fairly close spacing along an urban motorway it is particularly important that entry and exit arrangements should be easily understood by drivers. Achievement of this objective will require not only good road design but also consistency of layout, carriageway marking and signposting. This will give drivers confidence and make it easier for them to identify exits and entrances in ample time to change lanes or adjust speed without inconveniencing other traffic.

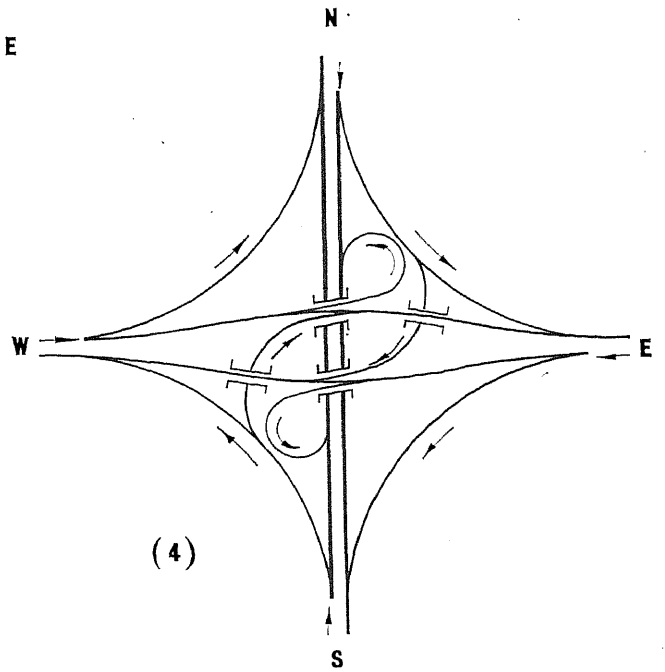
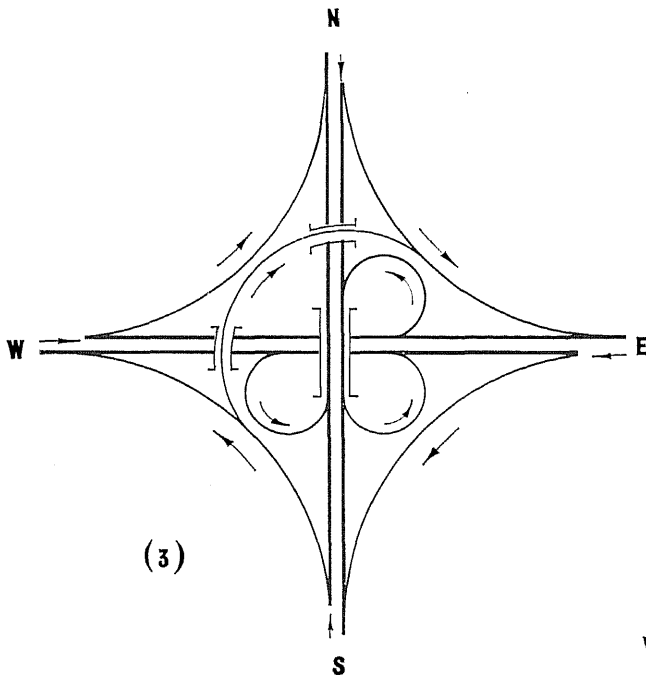
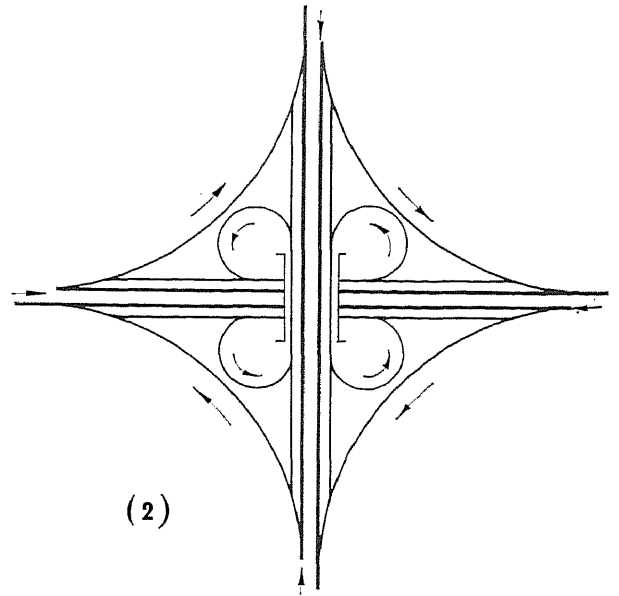
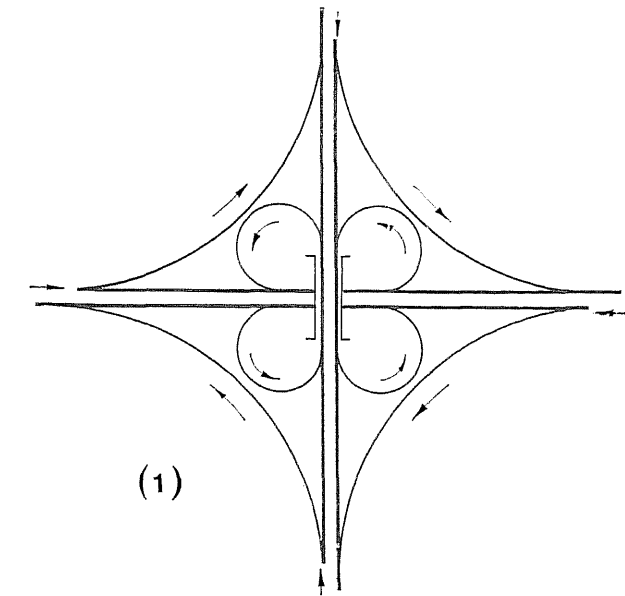
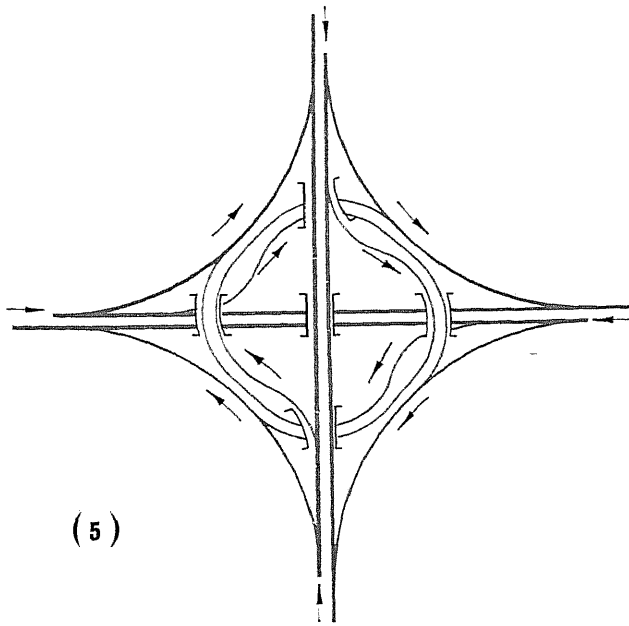
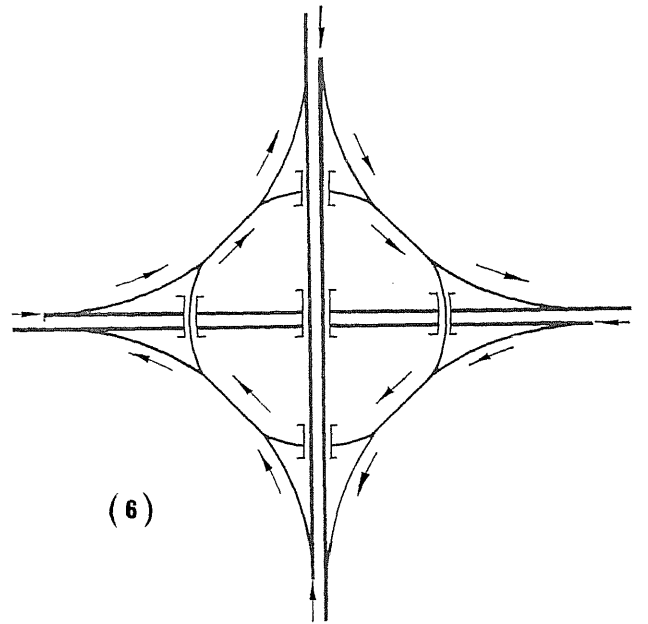


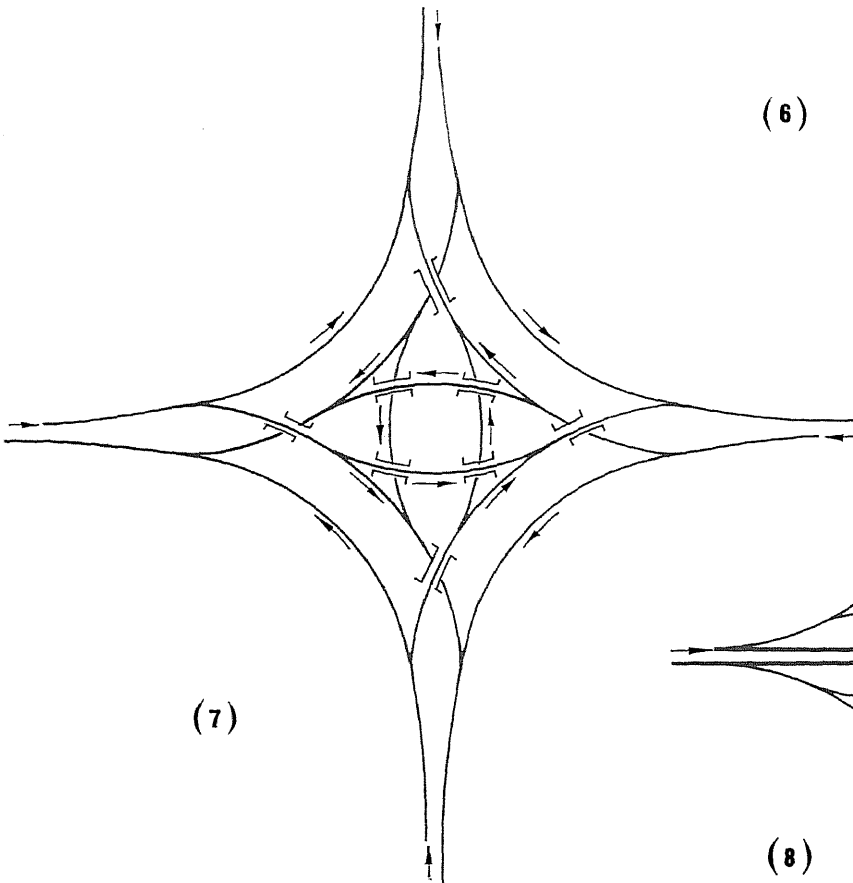
Fig. 13-5 Four-leg interchanges between *primary distributors*



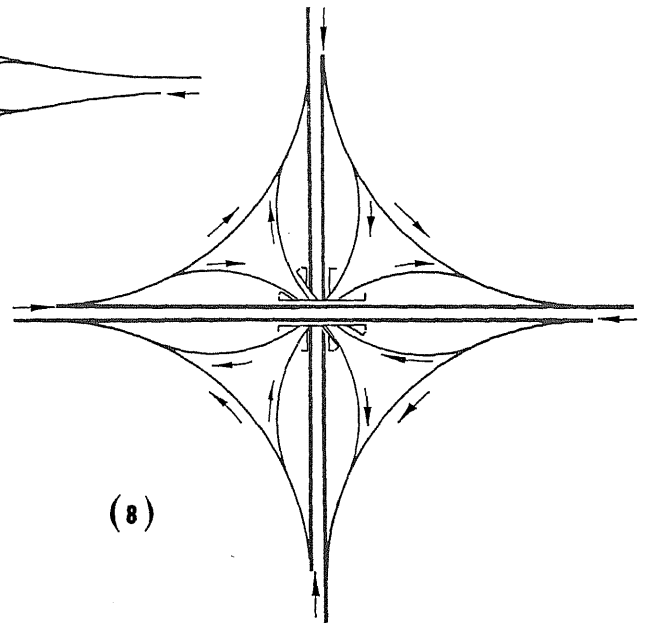
(5)



(6)



(7)



(8)

Fig. 13-5 Four-leg interchanges between *primary distributors* (continued)

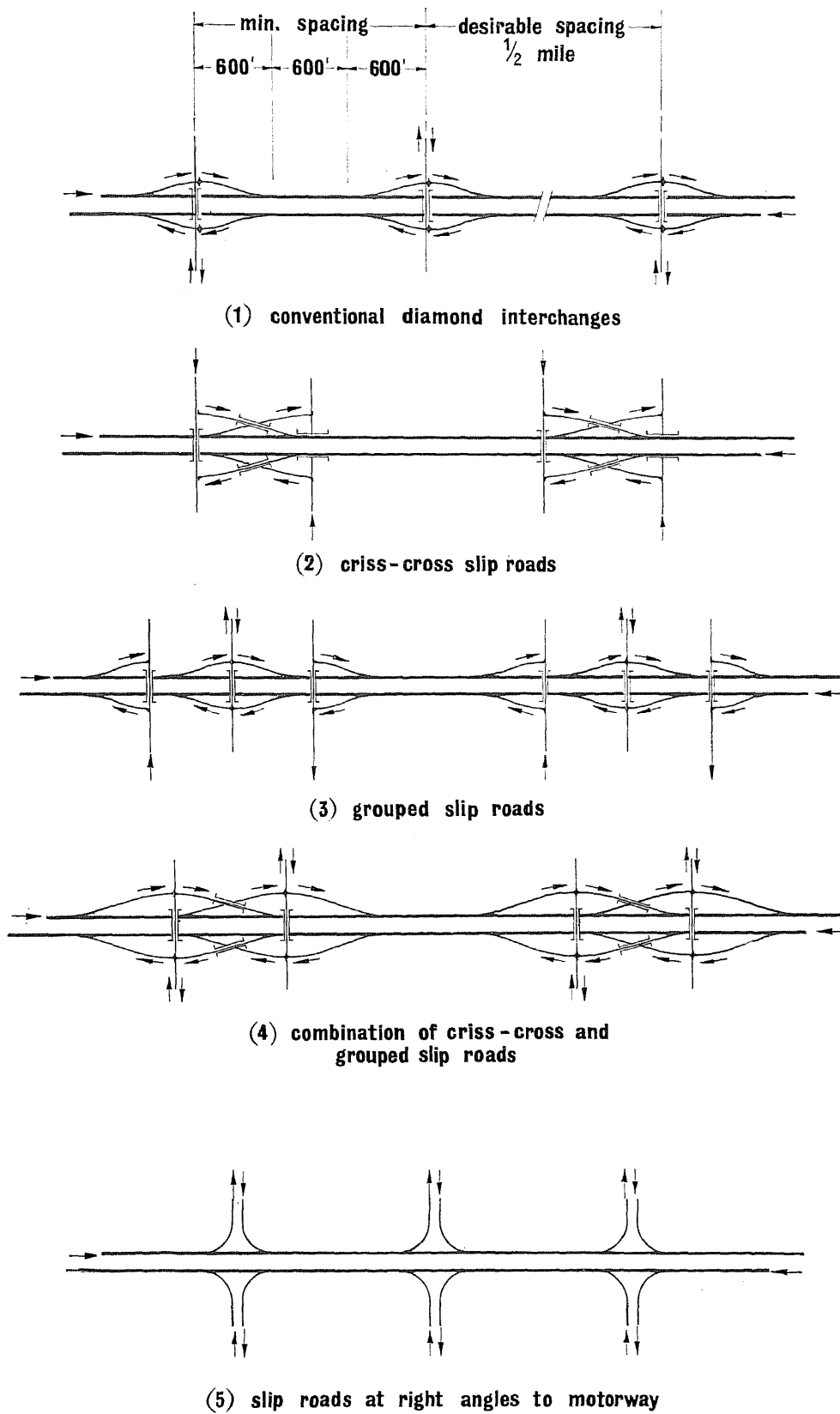


Fig. 13-6 Arrangement of slip roads at interchanges