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ROAD INTERSECTIONS
AND THE NEW FUNCTIONAL AND GEOMETRIC STANDARDS
FOR THE CONSTRUCTION OF INTERSECTIONS

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1. Introduction

A road intersection (junction) is defined as the area identified by three or more road sections (arches) that converge at the same point, as well as by the devices and arrangements designed to allow and facilitate maneuvers for passing from one section to another.

Intersections, regardless of their location, constitute critical points in the road system due to the interference that arises there between different traffic flows.

Therefore, safety issues (approximately a third of accidents recorded annually in Italy occur at intersections) and problems related to the regularity and efficiency of traffic are becoming more acute.

The multitude of factors that influence the configuration of an intersection (number and type of roads, traffic flow, local conditions, etc.) leads to an even wider range of typologies and patterns; it is therefore extremely difficult to develop a comprehensive classification of intersections, unless we resort to subdivisions so broad and numerous as to render the classification itself almost useless.

However, it is possible to make some subdivisions into general categories with reference to the territorial scope and type of intersection.

In terms of territorial scope, therefore, there are extra-urban intersections and urban intersections. For the former, defining elements include the possibility of not stopping all—or some—traffic flows; the speed of traffic passing and turning; and the often considerable distance between successive intersections. On the other hand, urban intersections are, in most cases, characterized by their short distance from each other and the presence of traffic components absent or negligible in extra-urban roads. Added to this are all the constraints arising from the built environment, which often completely, or almost completely, limit the possibility of suitable typologies and geometries.

Another classification criterion is the one that divides the intersections into three large categories:

- at-grade (or level) intersections, further subdivided into linear intersections and roundabouts, where the converging roads are coplanar, resulting in interference between traffic flows and turning traffic; - traffic-lighted intersections, which

are still at-grade intersections, but require periodic and alternating stops of traffic flows. They are used almost exclusively in urban and suburban areas;

- staggered-level intersections, where the altimetric separation between the traffic flows is achieved by means of overpasses, while the connection between the two roads is ensured by one or more ramps.

This chapter will illustrate the general selection criteria and the data required for the design; it will describe the main types of intersections and the calculation methods for all the geometric elements whose dimensions derive from kinematic considerations.

The methods for evaluating some performance indicators (average waiting times, average number of vehicles in queue, etc.) which relate to the functional design of intersections are illustrated in [4].

2. Selection criteria

The design of a new road generally corresponds to the insertion of new arches and nodes into the existing road network. The final choice of a

a given route also identifies the position of the nodes, or the location of the intersection. It must be said, however, that the most suitable location of the intersections can lead to planimetric and/or altimetric changes to a primitive choice of route and therefore contributes to the definition of the solution considered best. As regards the spacing between successive intersections on extra-urban roads, it is desirable that this distance be in the order of 500 m [12]; in [14] a minimum distance of 250 m and desirable distances as a function of speed are indicated.

operational: 600 m for V85 = 60÷70 km/h; 900 m for V85 = 80÷90 km/h; 1200 m for V85 = 100÷110 km/h.

Once the location has been identified, the choice between the three fundamental categories of intersections listed in the introduction depends directly on the types of roads that converge at the node or, better yet, on the network to which they belong.

In Chapter 6 of [5] it has already been said (§ 6.1) that the four network levels are associated with four classes of interconnections also called Primary, Main, Secondary and Local and that for the good functioning of the global network the connections must be made between roads of the same network (homogeneous connections) or with roads belonging to hierarchically inferior networks (homogeneous connections).

heterogeneous), as indicated in Fig. 5 of the aforementioned Chapter 6. Here it is specified that connections between roads of the same network must always be built, while for those between roads of different networks, provided they are permitted, the appropriateness and economic convenience of their construction must be examined.
These guidelines are valid for infrastructure projects. In fact, existing networks present different situations, such as connections between motorways and roads that, according to current regulations, may be considered secondary.

By virtue of the above, the category of intersections to be referred to in the various cases is unambiguously defined in almost all cases; Fig. 1 briefly indicates the permitted connections and the intersection category for the eight types of Highway Code roads. Note that some connections between roads in different territorial areas (e.g., CD; EC; etc.) have been indicated because in small urban areas, a single main road can serve multiple functions.

	TO the extra-urban area	In urban	B	C	D	AND	F extraurbana	F urban
In the extra-urban area	SV							
In urban	SV	SV						
B	SV	SV	SV					
C	IS	IS	IS	RS / SM*				
D	SV	SV	SV	IS	SV / SM*			
AND	IS	IS	IS	RS / SM	IS / SM*	RS / SM*		
F extraurbana	-	-	-	RS	-	RS	RS	
F urban	-	-	-	RS	-	RS / SM	RS	RS

SV = Staggered intersection with possible interchanges
IS = Staggered intersection with switch operations and at-grade intersections
SM = Traffic light intersection
RS = At-grade intersection
* In exceptional cases due to particular local situations

Fig. 1 – Matrix of possible connections between the various types of roads

At this point, it's necessary to further select the intersection type from among the many possible options within each category. The factors to consider are, of course, the same as those for road sections, namely: safety, functionality, environmental impact, construction and maintenance costs.

With reference to safety, the location of the intersection is important: it is

It is necessary that it is clearly visible and perceived by users (bumps and steep slopes should be avoided) and it is desirable that the roads intersect at angles that are not too acute and in any case not less than 70°. Furthermore, as will be shown later, all geometric elements must be sized with particularly conservative assumptions regarding user behavior. Finally, accident statistics for the various types must be considered, as they somehow represent an indicator of greater or lesser safety.

Functionality (or efficiency) is assessed by determining some particularly significant performance indicators, such as: average waiting times, average number of vehicles in queues, average total delay, reserve capacity, and, in roundabouts, simple capacity and overall capacity. For split-level intersections, the type depends on how left turns are organized (or can be organized), also in relation to whether or not all quadrants can be occupied.

With regard to environmental aspects, planimetric constraints (roundabouts, certain types of junctions) and altimetric constraints must be considered. In the case of staggered, multi-level intersections, these represent a visual intrusion that is sometimes incompatible with the surrounding landscape. Regarding traffic impacts, it should be noted that noise and emissions of exhaust gases and dust increase especially at at-grade intersections. Indeed, due to the very nature of traffic (interrupted flow), characterized by the predominance of acceleration and deceleration phases, as well as fluctuations in engine speed, the discontinuities in noise levels are particularly noticeable, on the one hand, and the polluting emissions of gases and dust, on the other.

At urban intersections, special attention should be paid to vulnerable users (pedestrians, cyclists, and small-engine two-wheeled vehicles), prioritizing the use of traffic lights and/or implementing measures known as "traffic calming."

At least in the most complex and challenging cases, the choice cannot be made solely based on regulatory requirements and the designer's experience and knowledge, but must be supported by a calculation that compares benefits and costs in the broadest sense. That is, direct and indirect benefits and costs, considering all social groups and not just users. Multi-criteria (or multi-objective) analyses are suitable for this purpose, the description of which is beyond the scope of this discussion.

3. Data for the project

The data required to choose the type of intersection and to define all its component elements are: a)
complete knowledge of the area on which the intersection must be developed; b) the geometric characteristics, near the node, of the converging branches, for lengths varying depending on the case, from one to several hundred meters;
c) the reference (or calculation) speeds, Vc , for the sizing of the geometric elements; d) the
traffic data.

Points a) and b) do not require further clarification.

As regards speeds, traffic data and the criteria to be followed for the sizing of geometric elements, reference will be made in the following to the "Functional and geometric standards for the construction of road intersections" recently issued in Italy [12], also taking into account the main foreign regulations, as well as the most up-to-date technical literature.

As reference speed Vc, the design speed can therefore be assumed, as can be obtained from the speed diagram (see standard [11]) or the speed V85 relating to the track elements of the branches that converge at the node.

For existing intersections, to be adapted or modified, it is advisable to directly acquire the speed distribution and assume the eighty-fifth percentile(1) for the reference speed **Vc .**

Traffic data is essential for choosing and designing the intersection. It is necessary to know, for each traffic flow arriving at the intersection, the percentages of vehicles in transit and those turning; it is desirable to have data disaggregated by traffic components (cars, trucks, tractor-trailers, motorcycles, etc.) to which, in urban areas, should be added the so-called vulnerable users, namely pedestrians, bicycles, and mopeds. Traffic data must refer to different periods depending on the factor being considered: thus, while for environmental analyses - noise and air pollution - periods of a few hours or even the entire day can be considered by considering the Average Daily Traffic (ADT), for efficiency and functionality it is necessary to refer to much shorter periods and take the peak hour flow rates as the basis for the checks. ____________________ (2).

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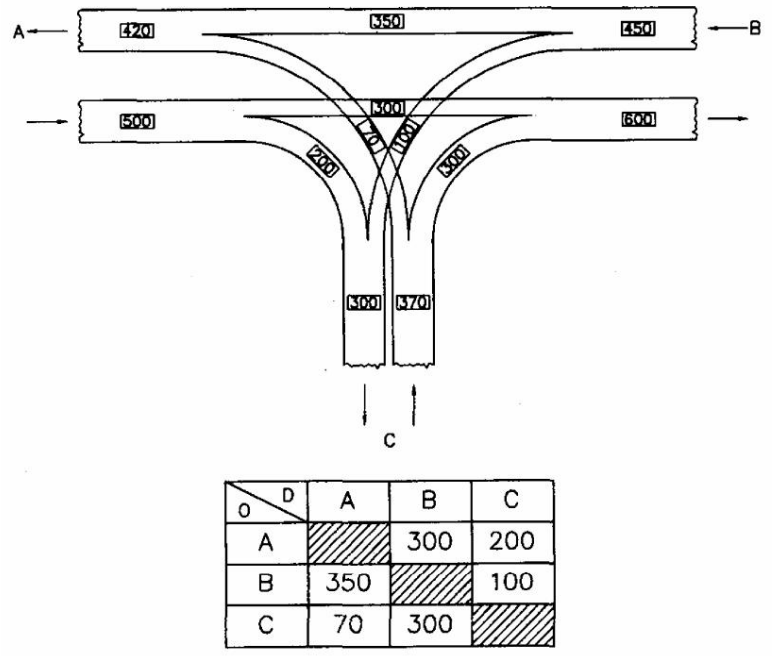
(1) It is not always prudent to refer to the legal limits placed on the approach of all the intersections.

(2) For the definitions and meaning of TGM and Q, see Chapter 1 of [4].

In any case it is advisable that the data are clearly represented and this can be done by means of flow charts or O/D matrices; in Fig. 2 the two representations for a three-arm intersection are exemplified; the meaning of the term "equivalent light vehicles" is clarified in Chapter 2 of [4]



O D	A	B	C
A	▨	300	200
B	350	▨	100
C	70	300	▨

Fig. 2 – Traffic data presentation. Flow chart and O/ D matrix. Hourly capacities in equivalent light vehicles.

4. Elementary maneuvers - Points of conflict

At an intersection, each vehicle generally carries out some maneuvers consisting essentially of changes in speed and/or trajectory.

These cannot be used freely due to the presence of other vehicles. This creates interference between traffic flows, which must be appropriately regulated to ensure maximum safety and functionality.

The overall maneuver that a vehicle performs at the intersection is made up of at least one of the following three basic maneuvers: -
diversion (i.e. exit);

- entry (i.e., entry); - crossing (i.e., intersection).

A diversion occurs when a vehicle slows down and leaves the flow of traffic it is part of to make a right or left turn; a right diversion is the simplest of maneuvers, but it still slows down any vehicles following it.

The maneuver to enter a passing flow may involve a wait, since the vehicle tending to enter will only be able to do so when there is a sufficiently large gap between the vehicles in the passing flow.

The crossing maneuver involves crossing a current and, like the previous one, can only be performed when the time interval between two successive vehicles of the current to be crossed is sufficiently long.
cross.

Finally, the exchange maneuver involves the change of lane by a part of one or more parallel currents moving in the same direction.

Regardless of the maneuver required to follow a given route, one or more traffic flow interferences occur, representing potential points of collision between vehicles and referred to as conflict points. The total number of conflict points depends on the number of branches serving the intersection, the type of intersection, and the control system. For example, Fig. 3 shows the total number and the three types of conflict points for three at-grade intersections. Note the drastic reduction in conflict points with traffic light regulation at four-arm intersections; further reductions, or even the total elimination, of crossing conflict points are achieved with altimetric staggering.

5. Visibility

For the proper and safe operation of intersections of any kind, vehicles approaching the intersection and preparing to cross or enter must be able to see each other so they can adjust their driving behavior according to the intersection's regulations. Therefore, it is necessary to identify areas, called visibility triangles, which must be clear of any obstacle greater than one meter in height that would prevent vehicles from seeing each other. The following table shows the sides of the visibility triangles for a four-arm, at-grade intersection. Visibility can then be checked in a similar manner at any other type of intersection.

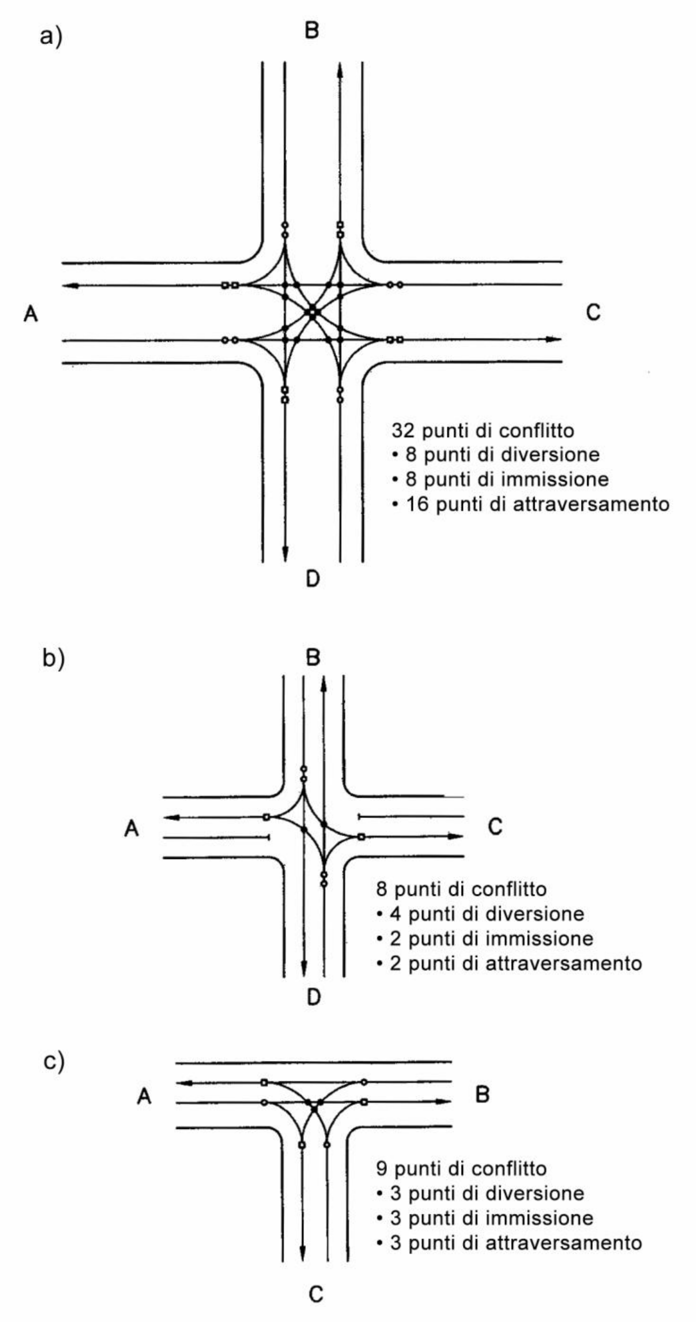


Fig. 3 – Conflict points for three types of intersections: a) and c) free; b) with traffic lights

Fig. 4a shows a schematic illustration of the intersection between two roads of modest importance and with little traffic where the only form of regulation is that indicated by the Highway Code, i.e. giving right of way; in this case it is necessary for the vehicles to see each other when they are at least as far from the potential collision point as the stopping distance; the sides of each triangle are therefore equal, for the roads indicated with 1 and 2, to Da1 and Da2. It should be noted, however, that this form of regulation is no longer permitted ([12] and [14])(3), while Canadian regulations [15] prohibit it in general, allowing it only on extra-urban roads provided that the sum of the TGM of the converging roads is less than 1000÷1500 vehicles/g and the approach speeds are less than 60 km/h.

When one of the two roads is constrained by the obligation to give way (Fig. 4 b) it is assumed that the vehicle that must give way, having reached 20 m from the edge of the main road, must see the vehicle on the main road at a distance L such as to have time to completely clear the intersection area, or turn right or left without disturbing the traffic flows. The time required to safely complete one of these maneuvers is assumed in [12] to be equal to 12 sec; from this, for L, the values L = 12v (with v, in m/s, reference speed on the main road) are derived, reported below with rounding.

V (km/h)	30	40	50	60	70	80	90	100
L (m)	100	130	165	200	235	265	300	330

Finally, in the case of STOP regulation (Fig. 4c) it is assumed that a vehicle stopped at 3.00 m from the STOP line must see the vehicles on the main road at a distance Lÿ equal to 6v [12] where v, in m/s, is the reference speed on the main road; the rounded values of Lÿ are reported below.

V (km/h)	30	40	50	60	70	80	90	100
The (m)	50	70	85	100	120	135	150	165

It should be noted that according to the current Italian Standard [12] the manoeuvring time values reported above of 12 s and 6 s must be increased by 1 s for each point

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(3) In this regard, the current Italian regulations [12] state verbatim: "In order to guarantee the regular functioning of at-grade intersections, and as a more general principle, it is always necessary to proceed with a hierarchisation of manoeuvres in order to divide the various vehicular flows into main and secondary ones; this leads to the need to introduce priority or stop signals for each point of conflict, avoiding the creation of situations of simple priority to the right without signal regulation."

percentage of longitudinal slope of the secondary branch greater than 2%.

This evidently results in an increase in the values of L and L' just mentioned.

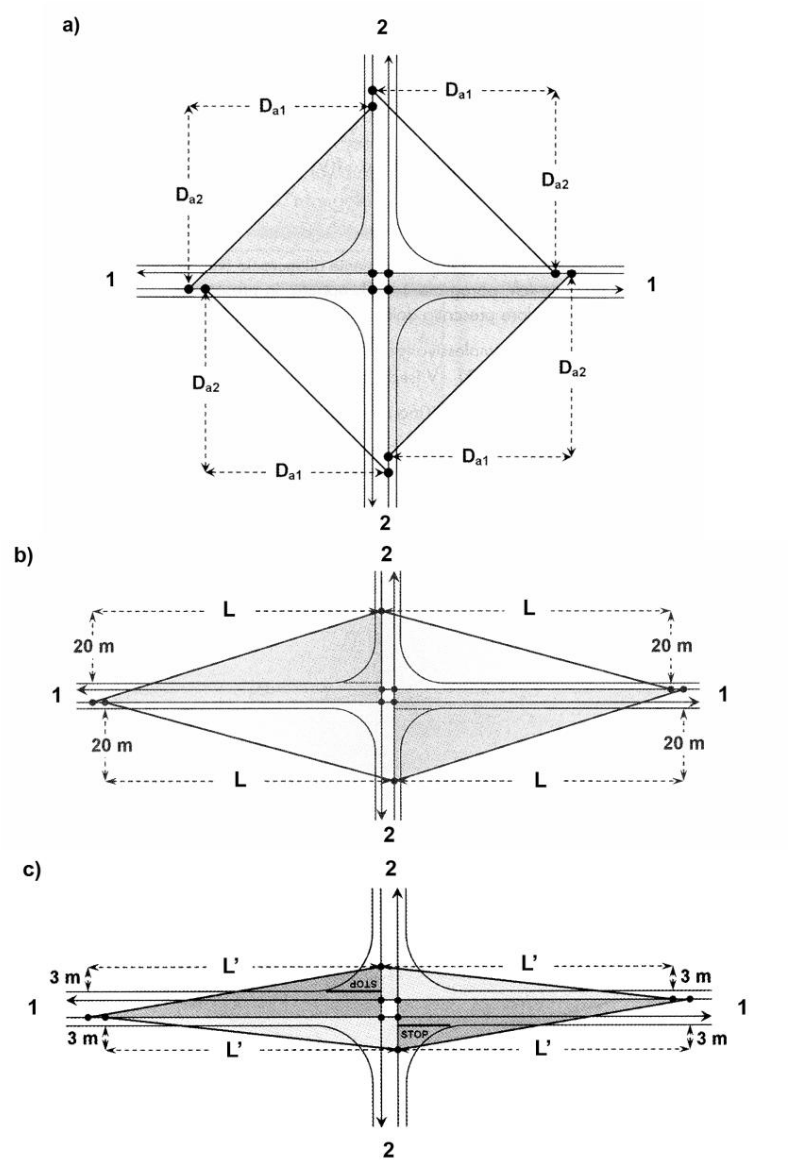


Fig. 4 – Sight triangles in the three control cases: a) free (CdS); b) with priority; c) with STOP

6. Linear at-grade intersections

This category includes all three- or four-branch non-signalized intersections: in fact, although geometrically similar, traffic-lighted intersections, due to their markedly different operation, are treated separately. Furthermore, if five or more branches converge at the junction, the roundabout solution appears preferable. Therefore, the roads to which this category of intersections refers are type C, E, and F (Fig. 1). Depending on the reference speeds and the size of the traffic flows, they can be organized differently, from the simplest to the most complex configurations. Thus, for type F roads with low traffic, one can limit oneself to rounding the edges (with radii of 7-10 m) to allow vehicles to turn, even at very low speeds (Fig. 5) or, at most, adding a teardrop-shaped traffic island on the less busy road (Fig. 6). As speeds and traffic volumes increase, to improve safety and functionality, intersections can be increasingly specialized by adding dedicated lanes—for deceleration, acceleration, and accumulation—and by channeling them using teardrop and triangular islands.

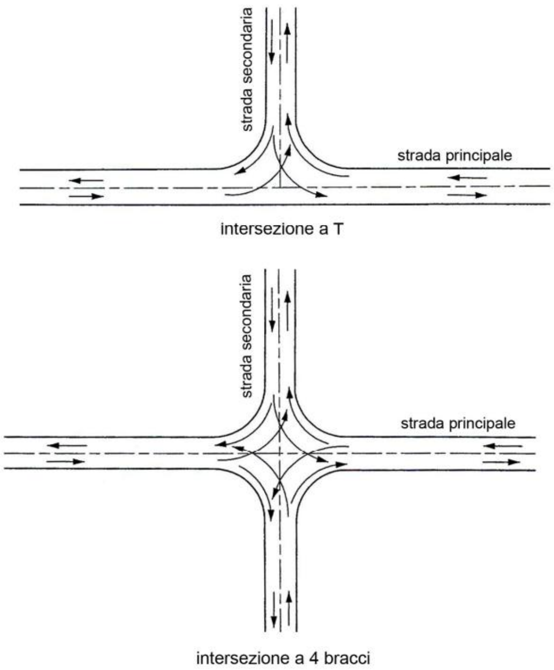


Fig. 5 – Three- and four-arm at-grade intersections between roads of modest importance

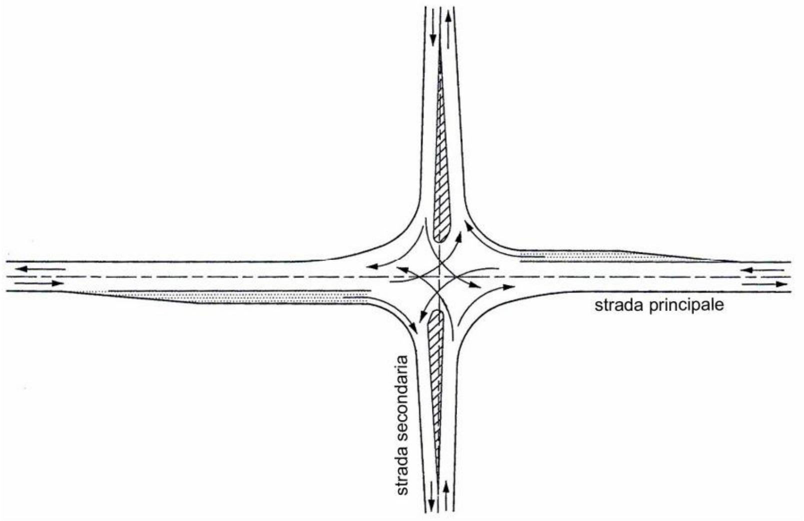


Fig. 6 – Four-arm at-grade intersections between roads of modest importance with teardrop-shaped traffic islands

Table 1 shows the requirements of the standard [12] regarding the creation of specialized lanes (entry, exit and accumulation for left turns) in linear intersections at ground level and at staggered levels; in particular, always according to [12], "the insertion of specialized lanes, in cases where these are "permitted" must be evaluated in relation to functional criteria...".

Type of main road	Specialized left turn accumulation lane type		
	exit (or diversion)	of entry (or input)	
extra-urban roads			
TO	mandatory	mandatory	not allowed
B	mandatory	mandatory	not allowed
C	admitted	not allowed	admitted
F	admitted	not allowed	admitted
urban streets			
TO	mandatory	mandatory	not allowed
D	admitted	admitted	not allowed
AND	admitted	admitted	admitted
F	admitted	admitted	admitted

Table 1 – Requirements of the standard [12] regarding the construction of specialized lanes

Fig. 7 and Fig. 8 show diagrams of three- and four-branch intersections in suburban areas where one of the two roads is considered secondary, either because it is hierarchically inferior (e.g., F compared to C), or because, given the same rank, it is less busy. Regulation is implemented with STOP signs for left-turn traffic from the main road to the secondary road and for all traffic on the secondary road, with the additional rule that vehicles stopped at STOP signs on the main road have priority over those stopped at STOP signs on the secondary road. The figures show that in all cases, waiting lanes (accumulation lanes) for left-turning vehicles have been positioned in the central section of the main road, and, again on the main road, deceleration lanes (needle or parallel) to facilitate the exit maneuver. With reference to entry manoeuvres, it should be noted that no specific acceleration lanes are foreseen because they are currently considered potentially dangerous for extra-urban C and F roads ([12], [14], [15]); they are only permitted in urban areas for type D, E and F roads (see for example Fig. 9).

As regards the possibility of introducing the permitted specialised lanes, the assessment must therefore be made on a case-by-case basis, taking into account the size of the interfering flows and the reference speed of the road. main, with the criteria and methods illustrated in Chapter 4 of [4].

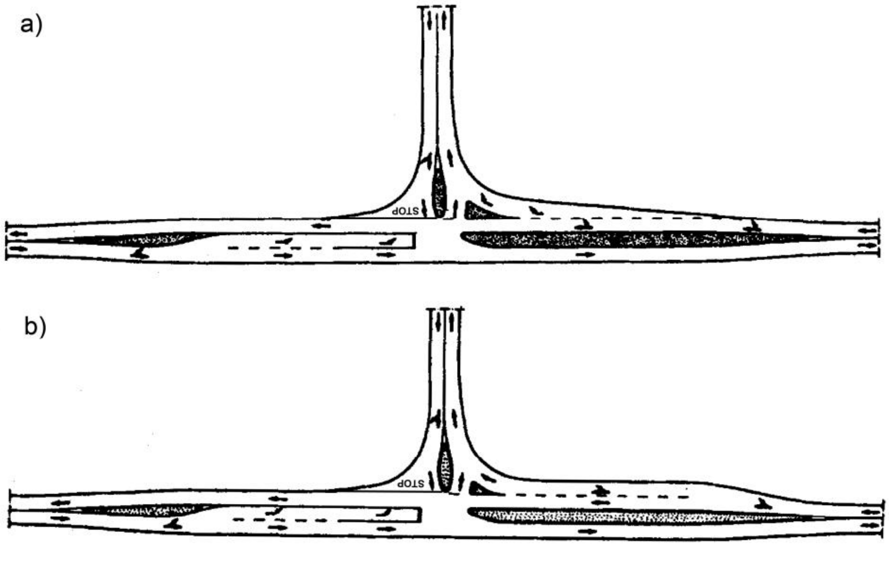


Fig. 7 – Three-arm at-grade (or T-) intersection diagrams

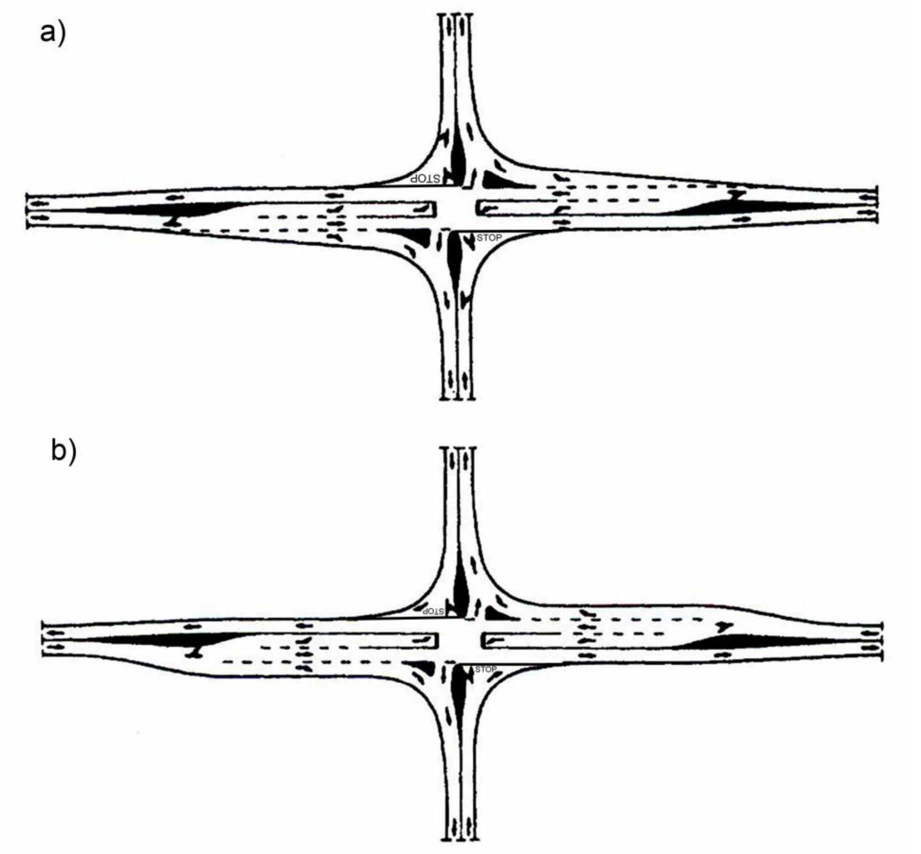


Fig. 8 – Four-arm intersection diagrams

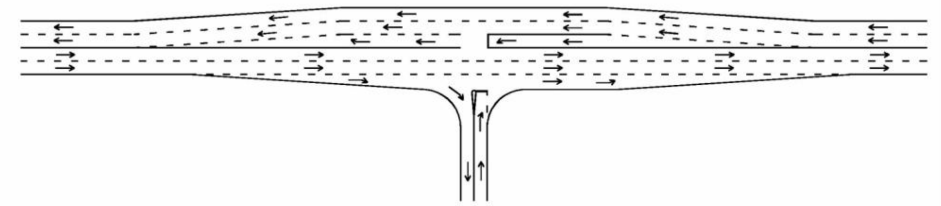


Fig. 9 – Example of an intersection for which acceleration and deceleration lanes are permitted (e.g. type E road)

However, some indications can be given, valid essentially for roads C and F, useful in the preliminary design phase; they are summarised in Tables 2 and 3 below, in which QT indicates **the total hourly flow rate on the main road, QD the hourly flow rate in a single direction on the main road and QS the hourly flow rate of turning vehicles.**

QS (vehicle/h) QT (vehicle/h)	up to 20	20÷100	over 100
up to 600	it is not necessary	to be verified	to be inserted
600÷800	to be verified	to be inserted	to insert (ÿ)
over 800	to be inserted	to insert (ÿ)	(ÿ)

(ÿ) **The possibility of changing the scheme should be verified**

Table 2 - Insertion of the accumulation lane on the main road

QS (vehicle/h) QD (vehicle/h)	up to 30	30÷100	over 100
up to 400	No	to be verified	Yes
400÷600	No	Yes	Yes
over 600	Yes	Yes	Yes

Table 3 - Deceleration lanes on the main road

Furthermore, the flow rates of secondary roads when crossing or turning left must be quite low, otherwise, especially four-arm intersections, given the numerous points of conflict, will collapse. Alternative solutions include roundabouts or, where possible, planimetric staggering, which replaces the four-arm intersection with two three-arm intersections, thus obtaining layouts similar to those shown in Fig. 10.

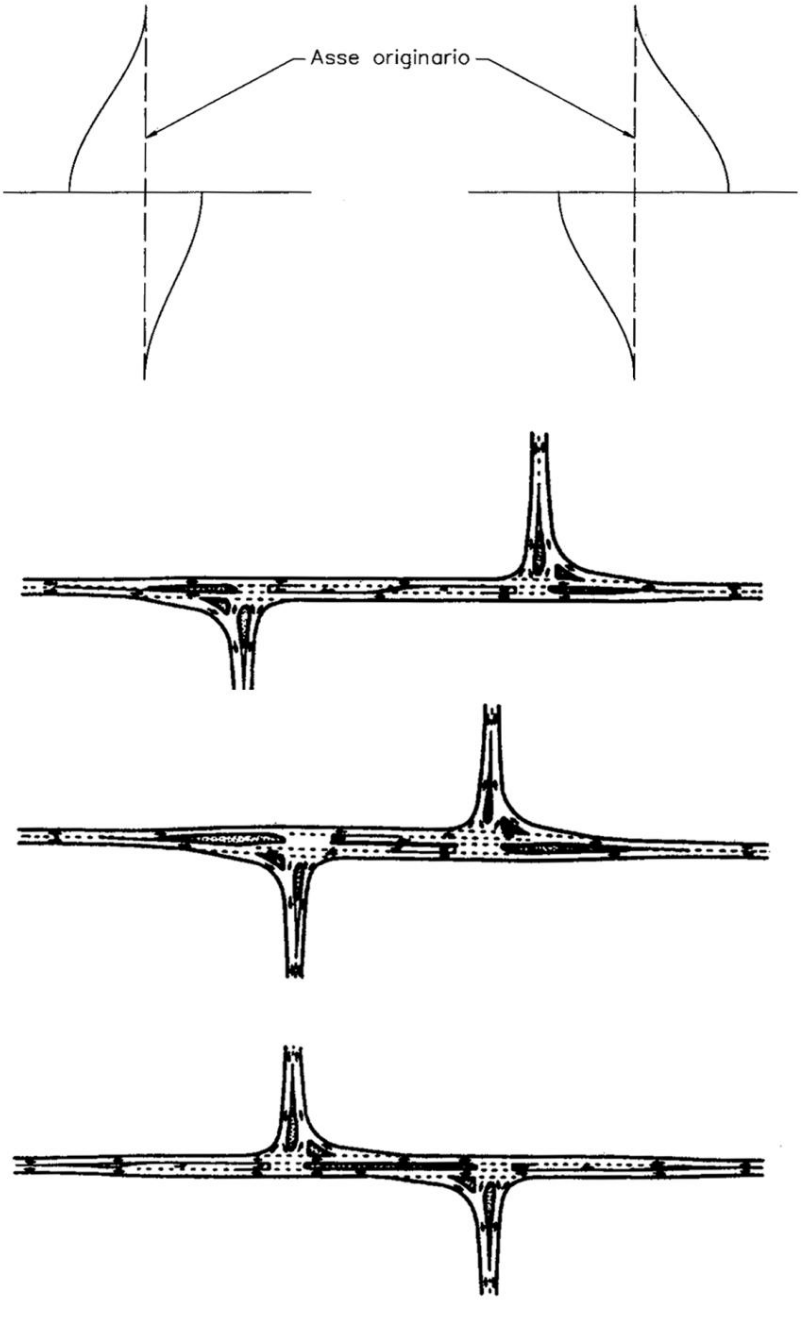


Fig. 10 – Examples of planimetric offsets

6.1. Dimensioning of geometric elements for at-grade intersections

The elements to be defined are the lane modules, the lengths of the additional lanes, the widths of the turning "channels" delimited by the islands that create the channeling, and the layout of the edges.

6.1.1. Lane modules for at-grade intersections

The lanes intended for through traffic maintain the current dimension which, however, must not be less than 3.00 m; the widths of the specialized lanes are given in Table 4, taken from [12].

As can be seen from Table 4, [12] does not provide indications on the width of the entry lanes, even for cases in which they are permitted (at the intersection between axes E and F in urban areas); according to indications prevalent in foreign technical literature, a value of 3 m can be assumed for said width.

Modular element	Extraurban roads		Urban roads	
	Type of road	Main lane width (m) in permitted cases	Type of road	Main lane width (m) in permitted cases
Lanes designated for through trajectories		(*)		(*)
Specialized exit lanes	C	3.50	AND	3.00
	F	3.25	F	2.75
Specialized lanes for accumulation in the middle of the road	C	3.25	AND	3.00 (**)
	F	3.00	F	2.75 (**)

(*) the lane widths envisaged by the Ministerial Decree of 11/5/2001 for the types of roads concerned will be maintained from the intersection

(**) reducible to 2.50 m if the lanes are not used by heavy traffic or public transport vehicles.

Table 4 – Modules of specialized lanes on the main road [12]

6.1.2. Exit lanes (deceleration) for at-grade intersections

These eliminate conflict points during diversion maneuvers; Fig. 11 shows an example of a deceleration lane. As can be seen, it generally consists of an initial section, of length Lc , along which the transverse movement occurs (the maneuvering section) and a parallel section, of length Ld, along which the deceleration takes place.

The standards give values of 30 and 20 m, respectively for extra-urban and urban roads; these values are to be considered minimums, while it may be appropriate, when possible, to assume lengths between 30 and 60 m for initial (or reference) speeds from 40 to 90 km/h.

With the usual hypothesis of uniformly varied motion, the length is then calculated of the deceleration trunk by means of the

$$L_d = \frac{v_c^2 \quad v_R^2}{2\,a\,(\pm 10/i)} \qquad (1)$$

where vc and vR are, respectively, the reference speed and the speed compatible with the turning radius R, expressed in m/sec; the deceleration “a” is normally assumed to be equal to 2÷2.4 m/sec2 ; the gradient is expressed in percent.

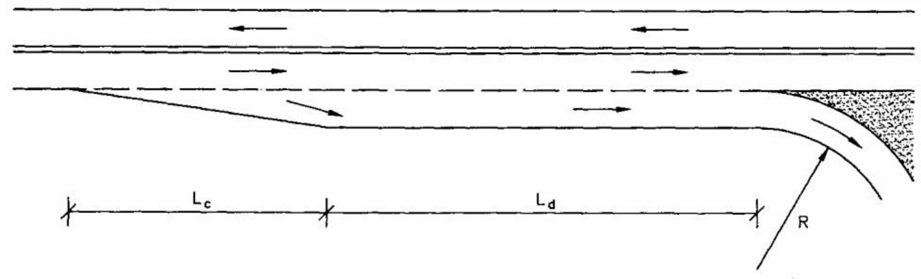


Fig. 11 – Exit lane diagram (deceleration)

It should be noted that along the turning curves the transverse slope is usually maintained at 2.5%, so that, with f 10.0 in all cases, vR = 5.2 $\sqrt{R}$ (2) t =

In cases where Ld ÿ 40 m, the “needle” shape can be adopted (in this case we speak of a pseudo-lane) as indicated in diagrams a) of Fig. 7 and Fig. 8.

With specific reference now to the current Italian regulations on intersections [12], the exit lanes, where it is considered appropriate to adopt them, must be configured as in Fig. 12; they are composed of the following sections (the symbology of [12] is adopted): -

manoeuvring section, of length Lm,u; -
deceleration section, of length Ld,u (including half the length of the manoeuvring section Lm,u) parallel to the main axis of the road, in the case of the parallel typology (Fig. 12a), or coinciding entirely with the variable curvature element, in the case of the needle typology (Fig. 12b).

The length Lm,u of the manoeuvring section must be set equal to 30 m in the area extra-urban and 20 m in urban areas.

The length Ld,u of the deceleration section must be sized with kinematic criteria, using (1) with the values of v to be determined as already mentioned, i = 0 and a =2.0 m/s2 .

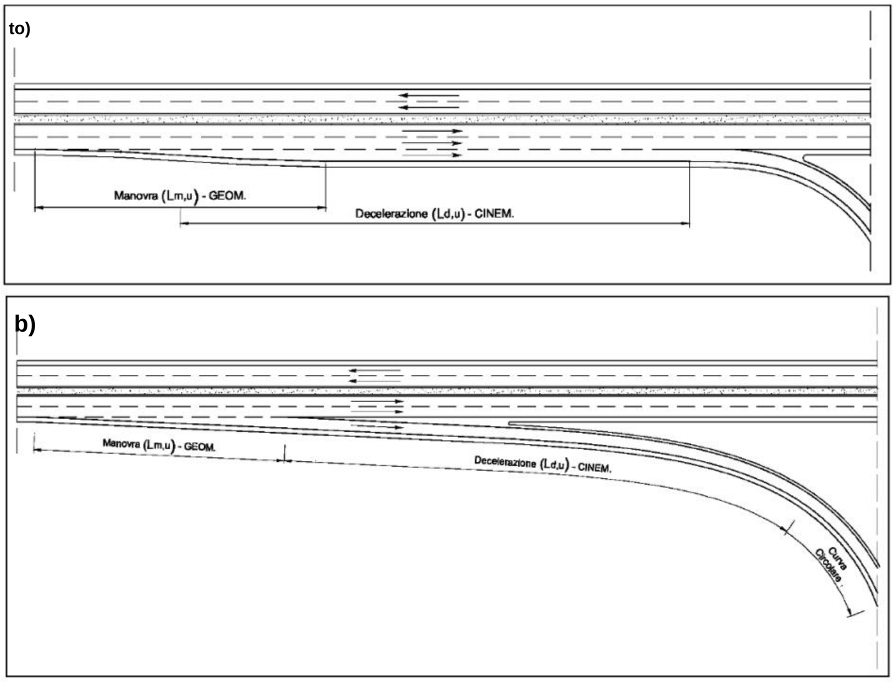


Fig. 12 – Possible configurations of exit lanes according to Italian regulations [12]

6.1.3. Entry lanes for at-grade intersections

With the adoption of these lanes, permitted by the Regulations [12], as mentioned, only for some types of roads (urban E and F type roads - see Table 1), the inconveniences (conflicts) arising from the entry manoeuvres are attenuated, or even eliminated.

An example is shown in Fig. 13.

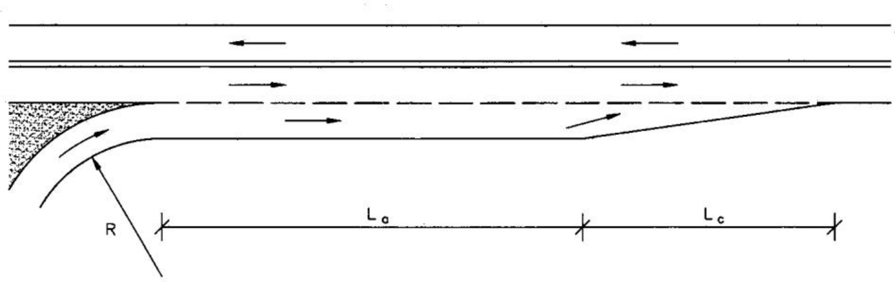


Fig. 13 – Entry lane diagram

Improperly called acceleration lanes, the entry lanes are, in effect, moving waiting lanes; in fact, vehicles travel along them at a nearly constant speed while waiting for a gap between the vehicles in the main flow to allow them to enter without fear of being hit from behind; the manoeuvre is easier the smaller the difference in speed between the vehicles in transit and those tending to enter. The occurrence of a sufficient gap is, in any case, a random event, so the waiting time, and therefore the length La , must be determined using the methods illustrated in §4.10 of [4]. It is advisable, however, that the length La of the parallel section is such as to allow the vehicles travelling along it to reach a speed close to the reference speed before it ends;

for this purpose, (1) is still used, in which, however, a = 1.0÷1.2 m/s2 and Vc is assumed **to be approximately 80% of the design speed of the main road.**

As regards the length of the Lc manoeuvring section , **the following can be adopted: values equal to those indicated for the exit lanes.**

With specific reference now to the current Italian regulations on intersections [12], the entry lanes must be configured as in Fig. 14, resulting in being made up of the following sections (the symbology of [12] is adopted): - acceleration section, of length La,e; - entry section, of length Li,e; - connection element, of length Lv,e.

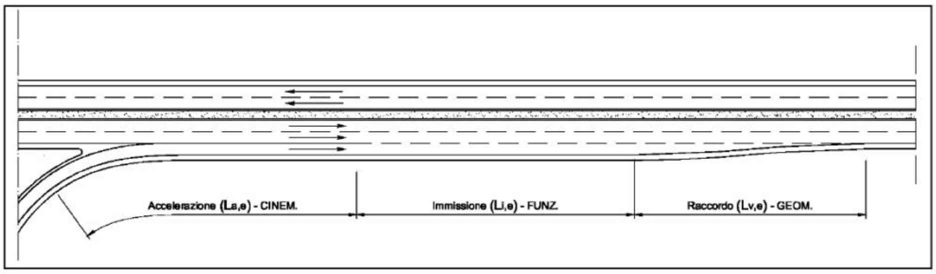


Fig. 14 – Configuring the entry lanes according to Italian regulations [12]

The length La,e of the acceleration section must be determined with kinematic criteria, with (1) assuming Vc equal to 80% of the design speed of the road onto which the lane enters, vR equal to the speed compatible with the turning radius at the starting point of the acceleration section of the entry lane, i = 0 and a = 1.0 m/s2 .

The length Li,e of the entry section must be sized with functional criteria "according to procedures based on the probabilistic distribution of the temporal distances between the vehicles in motion, on each lane"

As regards the sizing of the length Lv,e of the connecting element in at-grade intersections, the [12] exclusively prescribe that it must be carried out with geometric criteria without providing any other indication.

Since the length Lv,e, like the homologous one in Fig. 11 and Fig. 13, depends on the amount of the transverse displacement (i.e. on the modulus of the lane) and on the speed, the values already mentioned in §6.1.2 for **Lc can be used .**

6.1.4. Accumulation lanes for at-grade intersections

These are intended to accommodate vehicles making a left turn onto a secondary road, which must give way to the oncoming flow of the main road.

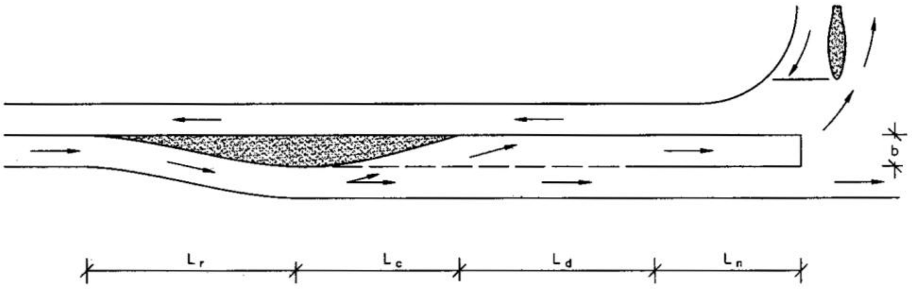


Fig. 15 – Accumulation lane diagram

Fig. 15 shows that an accumulation lane is made up of three sections: the first is necessary for the deviation, whose length Lc can be evaluated as indicated for the previous lanes; the second is intended for deceleration, whose length Ld is still evaluated with (1) in which however vR = 0 (stop) should be set.

However, considering that the length Ln of the accumulation section is normally calculated with reference to the 95th percentile of the queue length, vRÿ0 can be assumed; **in particular in [12] vR = 6.95 m/s (25 km/h) is assumed. In the third section, vehicles stop waiting to turn: this maneuver is possible when in the opposite flow to be crossed there is a gap (interval) of a size sufficient to allow the maneuver itself without risk of collision. If during the wait the vehicle stopped at the STOP sign**

others arrive, a queue forms and the section Ln must be long enough to accommodate, with sufficient probability, all the waiting vehicles. Both the occurrence of the useful interval and the arrival of vehicles are random events for which the length Ln, as already mentioned, must be determined with the theory of waiting phenomena (see § 4.10 of [4]). For preliminary studies, one can use the suggestion of the Canadian standards [15]:

$$Ln = \frac{Q\ \ddot{y}\ l}{30}\ (m)$$

where Q is the design hourly flow rate and l is the average length of the vehicle to be assumed to be 6.00 m (7.00 m for high percentages of heavy traffic).

With specific reference now to the current Italian regulations on intersections [12], the entry lanes must be configured as in Fig. 16, resulting in being made up, in extra-urban areas, of the following sections (the symbology of [12] is adopted): - connecting section, of length
Lv,a; - manoeuvring section, of length Lm,a;
- deceleration section, of length Ld,a; -
accumulation section, of length La,a.

In urban areas, the configuration of the accumulation lanes only includes connection and accumulation sections.

The lengths Lv,a of the connecting section and Lm,a of the manoeuvring section must be determined with geometric criteria.

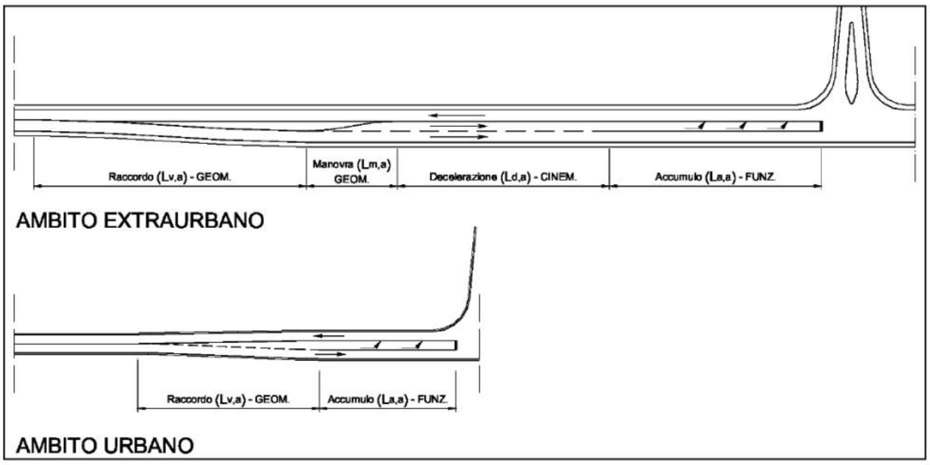


Fig. 16 – Configurations of accumulation lanes according to Italian standards [12]

In particular, always according to [12], "the length of the connecting section Lv,a depends on the design speed Vp [km/h] and the widening d [m] to be achieved" (see Fig. 17), "equal to the width of the accumulation lane increased by 0.50 metres (width required for the materialisation of the separating element for the two directions of travel)" using the relation

$$L_{v,a} = 0.6 \, V_p \sqrt{d'} \; [m]$$

Furthermore, the Italian standards [12] prescribe that a minimum length Lv,a of 20 m must be ensured, but do not provide criteria, once the length Lv,a is known, for profiling the section. For this, for example, the criteria set out in the following §6.1.5 dedicated to the geometry of the margins can be followed.

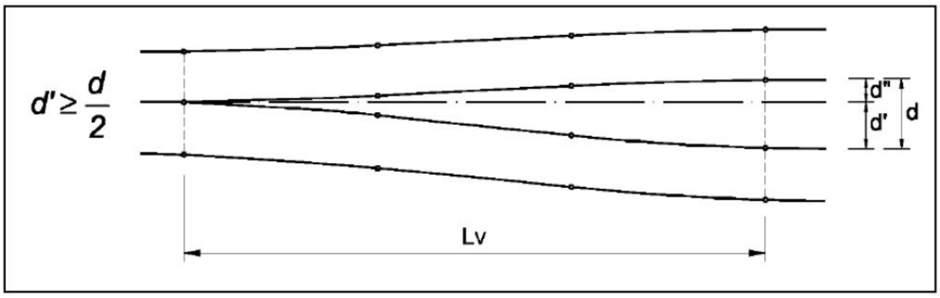


Fig. 17 – Connecting section in the accumulation lanes for left turns

The length Lm,a of the manoeuvring section is determined based on the value of the design speed as reported in Table 5 taken from [12].

Vp [km/h]	Lm,a [m]
ÿ 60	30
< 60	20

Table 5 – Determination of the length of the maneuvering section in accumulation lanes

The length Ld,a of the deceleration section must be sized with kinematic criteria, using (1), assuming for Vc the design speed from which the turning flow originates, determined by the speed diagrams, vR = 6.95 m/s, i = 0 and a = 2.0 m/s2 .

The length La,a of the accumulation section must be determined with functional criteria; in particular [12] prescribe to assign to these sections a length double that corresponding to the average number of vehicles in

waiting time (to be determined according to the rules and criteria of traffic technology) and considering a space occupied by each vehicle of an average of 6 m.

As regards the use of accumulation lanes in linear intersections at ground level, Italian regulations [12] always provide that they must always be built in the case of intersections of roads with 2 lanes in each direction, while in the case of intersections of roads with 1 lane in each direction, the provision of accumulation lanes is related to traffic flows.

6.1.5. Edge geometry To

insert specialized lanes in the center of the main road, the latter must be widened, which involves a detour with a curve and counter-curve maneuver (Fig. 15); the length Lr of the section along which the detour occurs depends on the lateral displacement, i.e. the widening, and the speed. To deduce the length Lr, for simplicity, we assume that the vehicle's trajectory consists of two circular arcs traveled in opposite directions (Fig. 18) of radius R such that the transverse acceleration is equal to 0.86 m/s2 .

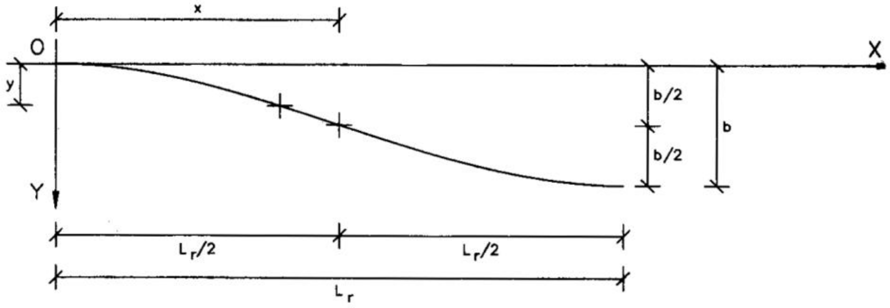


Fig. 18 – Shaping of the outer edge for widening the roadway

It turns out

$$\ddot{y}\,\frac{THE_r}{2}\,\ddot{y}^2\,\ddot{y} = \ddot{y}\,\ddot{y}\,\frac{b}{2}\,\ddot{y}\,2R\quad \frac{b}{2}\,\ddot{y}\,\ddot{y}\,\ddot{y}\,b\,R$$

$$\frac{2\,v}{R} = \frac{v^2\,4b}{THE_r^{\,2}} = 0.86$$

from which

$$Lr = \frac{2v\sqrt{b}}{0.92}\;\ddot{y}\;\frac{2V\sqrt{b}}{3.6\;0.92}\;\ddot{y}\ddot{y}\,6.0\;V\;b\,\sqrt{\;}\qquad (3)$$

The edge is however shaped according to two parabolic arcs and can be traced as indicated in

Fig. 18 using the expressions:

$$y = \frac{2b}{\text{THE}_r^{2}}\, 2x \qquad \text{for } 0\ x\ ÿ\ ÿ\ \frac{\text{THE}_r}{2}$$

$$yb =ÿ\ \frac{2b}{\text{THE}_r^{2}} (L\ x)^{2} \qquad \text{For } \frac{\text{THE}_r}{2}\ ÿ\ ÿx\ L \qquad (4)$$

In [16] it is proposed to divide the length Lr into three parts: the first and the third, both equal to Lr /4, have a circular trend, while the central part (Lr /2) has a rectilinear trend.

The accumulation lane, instead of being on the right, as in Fig. 15, can be inserted symmetrically with respect to the axis of the road; this involves a decrease in Lr , since in (3) b/2 must be placed in place of b, but the need to divert both currents of the main road.

With the criteria set out so far for the shaping of the accumulation lanes for left turns, the manoeuvring sections of the exit and entry lanes can be outlined (e.g. Lm,u and Lv,e junctions of the Italian standards [12] – see.
Fig. 12 and Fig. 14).

Outside shoulders for right turns are typically designed with small radii, accepting modest speeds to keep the intersection area small.
Rather than single-radius curves - possibly connected with short clothoid arcs - it is preferable to use a connection formed by three circular arcs known as a tricentric curve (Fig. 19); this is because it is quite close to the "tractor" curve.

Generally the following ratios between the angles and between the radii are suggested: ÿ ÿ;

$$ÿ = 5.5\ ÿ;\ R_1 : R_2 : R_3 = 2.5 :1: 5.5$$

Other standards [15] admit slightly different values and even the tricentric one does not symmetric (ÿ ÿ ÿ).

For the minimum radius R2, values between 6 and 8 m and 20 and 30 m can be assumed, depending on the importance of the intersection and the expected number of very bulky vehicles. For ease of tracing, the formulas for calculating the length of the tangents T1 and T2 are given below: ÿ

$$T_1 = (R_1 R_2)\,\text{sen}\,\frac{ÿ}{2} + \frac{R_3 (R_3 R_2)\cos ÿ}{\text{sen}\,ÿ}\ \frac{R_1 (R_1 R_2)\cos ÿ}{\text{news}\,ÿ}$$

$$T_2 = (R_3 R_2)\,\text{sen}\,\frac{ÿ}{2} ÿ + \frac{R_1 (R_1 R_2)\cos ÿ}{\text{sen}\,ÿ}\ \frac{R_3 (R_3 R_2)\cos ÿ}{\text{news}\,ÿ} \qquad (5)$$

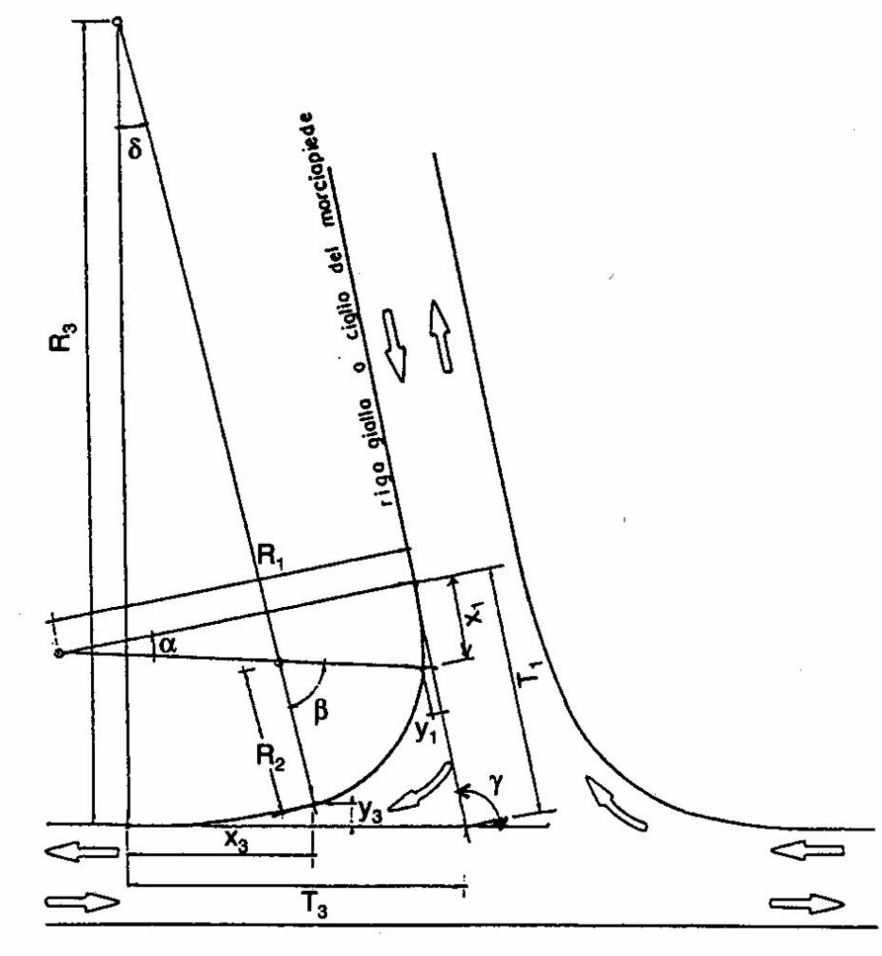


Fig. 19 – Elements of the tricentric curve

6.1.6. Traffic islands. At-grade

intersections often have very large areas due to the widening of additional lanes and roundings for turns. If this entire surface were paved, leaving drivers free to choose their trajectories, conflict points would multiply, jeopardizing the safety and operation of the intersection itself. It is therefore necessary to require drivers to follow specific trajectories, so as to collect and organize conflict points. This goal is achieved through traffic islands, which precisely channel traffic.

In this way, numerous advantages are obtained such as:
- reduction of the paved area; - separation
and spacing of the conflict points; - control of the angles
between the trajectories which, if they intersect (possibly
between 70° and 110°);
- speed control; - pedestrian
facilities in urban areas; - areas for the installation of vertical
signage.

Based on their primary function, water islands can be divided into: divisional, directional, and refuge (or pedestrian), although the same island often serves two or all three functions. Regarding shape, despite the variety of configurations that can occur, three types can be identified: elongated rectangular, triangular, and teardrop. Dimensions vary from case to case, but as a general rule, channelization should be implemented with a few large islands and not with many small ones that would confuse users. Thus, rectangular islands must be no less than 1.20-1.50 m wide and at least 6.00 m long; the sides of triangular islands must be at least 3.50 m long.

As an example, Fig. 20 shows two teardrop-shaped islands; for one of them, the main geometric elements are shown and the asymmetry with respect to the road axis is highlighted; for the other, some construction details are shown. Fig. 21 shows two triangular islands and a long divisional island inserted along a main road with a left-turn lane.

The islands can be made with simple painting and in this case the
Their function depends on drivers' compliance with the rules.

Additionally they can be outlined by studs, delineators or be
paved differently from the walkable areas, for example with cubes or other materials, so that there is a better visual and acoustic perception of the island. Defining areas with kerbs are undoubtedly more effective.
they can be surmountable (in which case the height is less than 20 cm) or, if deemed necessary, non-surmountable (barrier type); some types of kerbs are shown in Fig. 22.

Inside, the raised island can be paved, mainly if it also serves as a pedestrian shelter, or laid out as a lawn.

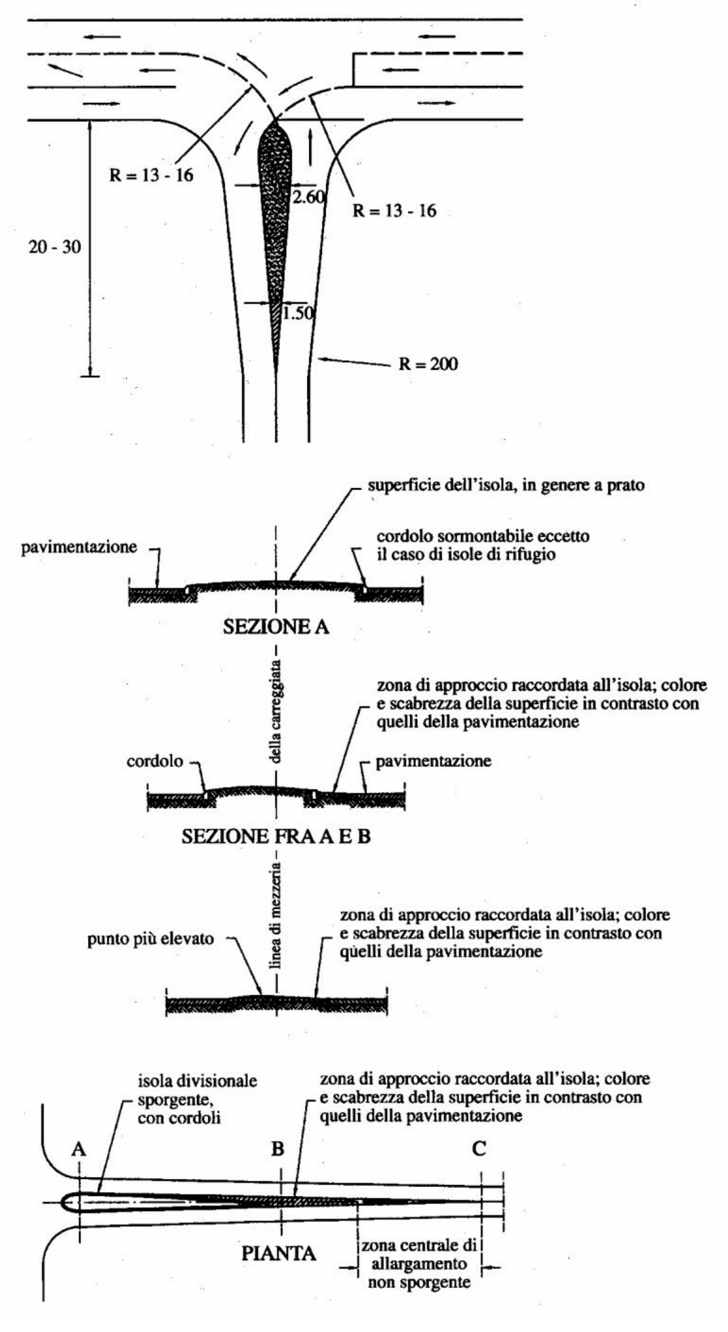


Fig. 20 – Examples of drop-shaped islands

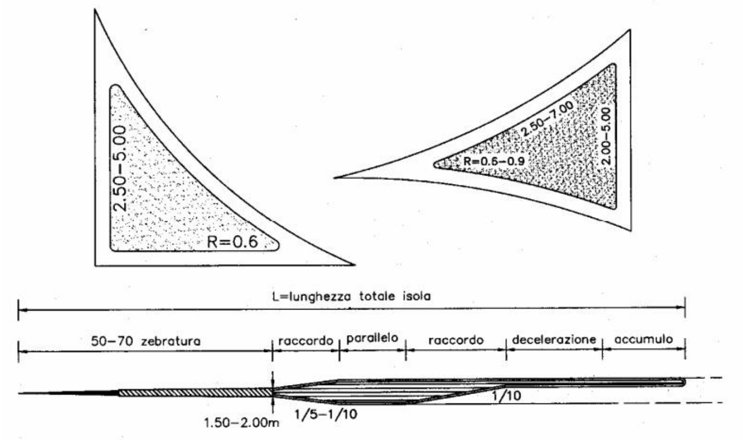


Fig. 21 – Triangular islands and divisional island on main road with accumulation lane for left turns

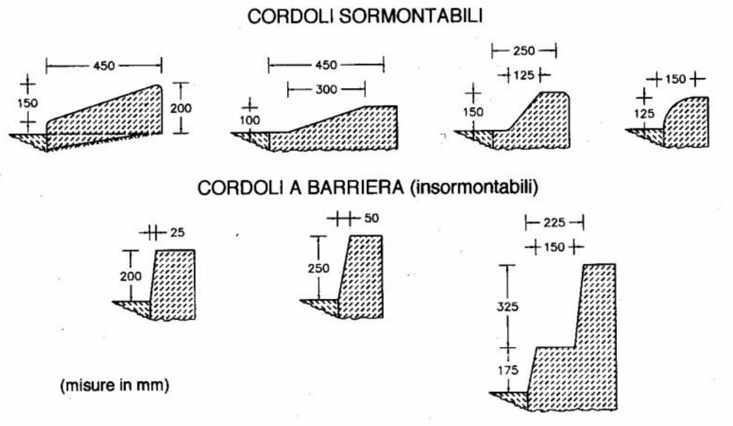


Fig. 22 – Some types of curb

Finally, particular attention must be paid to the width of the "channels" delimited by the islands in consideration of the deviation angles (often greater than 90°) and the modest radii of curvature of the turns; dimensions of 4.50÷5.00 m are required provided that the presence of large trucks and articulated vehicles is entirely exceptional, otherwise greater widths are required. In this regard, the transparent sheets attached to the "Carrefours" (Intersections) chapter of the Swiss Standards [16] may be useful, two of which - for a truck and a tractor-trailer - are shown in full in

In them the dimensions of the vehicles are drawn in full lines for different deviation angles expressed in hundredths of degrees; the dotted lines indicate

the trajectories of the external front wheel, while the radius RH identifies the virtual trajectory of the centre point of the front axle; from the graph it is possible to determine the maximum overall dimensions of the vehicle when cornering and, by adding the appropriate clearances (50÷60 cm), the width of the channel.

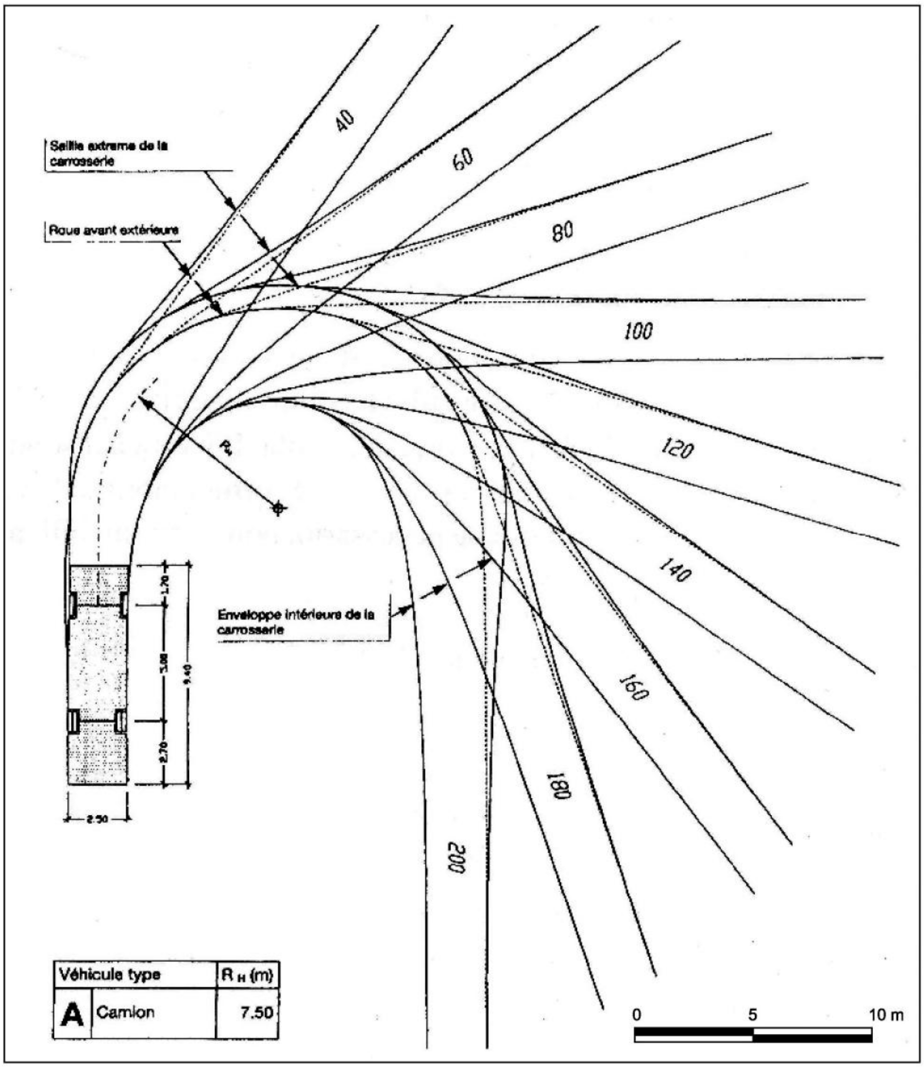


Fig. 23 – Curved clearance of a commercial vehicle without trailer according to Swiss standards [16]

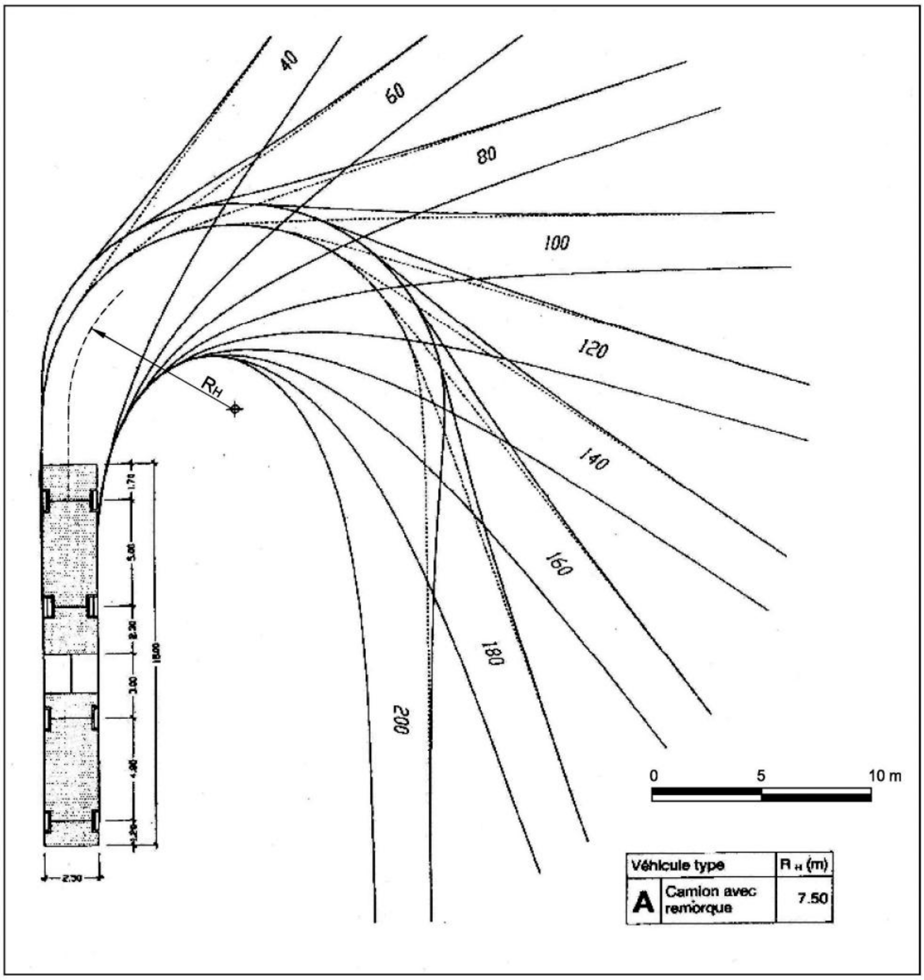
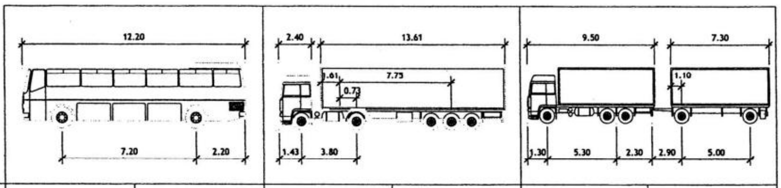


Fig. 24 – Curved clearance of a commercial vehicle with trailer according to Swiss standards [16]

The maximum channel widths (b), as a function of the radius of the internal edge (R) and the deviation angle (ÿ), for three types of heavy vehicles can also be obtained from Table 6 [13].

Finally, a very detailed procedure is reported in [3].



Raggio R[m]	Angolo α [°]	Larghezza α [m]	Angolo α [°]	Larghezza α [m]	Angolo α [°]	Larghezza α [m]
6	70°	*	70°	*	70°	*
	90°	*	90°	*	90°	*
	120°	*	120°	5.76	120°	*
8	70°	*	70°	7.00	70°	*
	90°	*	90°	6.49	90°	*
	120°	5.33	120°	5.57	120°	*
10	70°	*	70°	6.46	70°	*
	90°	*	90°	6.10	90°	*
	120°	5.15	120°	5.35	120°	4.97
15	70°	5.07	70°	5.37	70°	4.81
	90°	4.93	90°	5.22	90°	4.79
	120°	4.68	120°	4.77	120°	4.52
20	70°	4.50	70°	4.86	70°	4.32
	90°	4.41	90°	4.57	90°	4.32
	120°	4.31	120°	4.42	120°	4.17
25	70°	4.11	70°	4.25	70°	3.94
	90°	4.11	90°	4.22	90°	4.06
	120°	3.96	120°	4.15	120°	3.90

* Raggio non compatibile

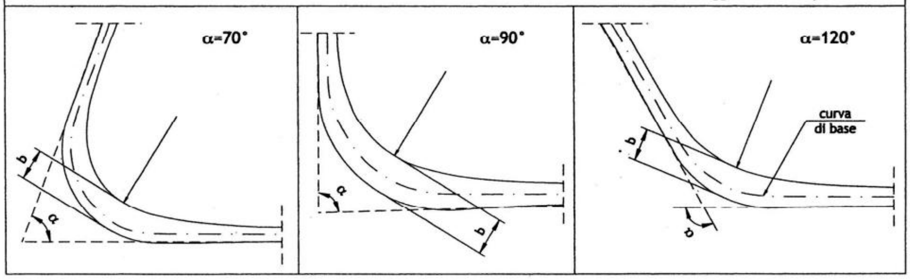


Table 6 – Indications for the construction of clearance bands for typical vehicles

7. Roundabouts

The roundabout, as a particular type of at-grade intersection, originated in the early twentieth century. It was during this period, in fact, that the French architect Enard, while renovating, among other projects, the Etoile roundabout in Paris for better traffic management, introduced the one-way (counterclockwise) rule along the ring road.

This rule then spread to other countries, first in urban areas due to the presence of squares with a central furnishing element and then on extra-urban roads.

As traffic increased, this type of arrangement began to show its functional limits, mainly due to the traffic rule referred to: vehicles coming from one of the arms, having legal priority over the flow circulating along the ring, induced frequent phenomena of

self-saturation.

The inconvenience did not occur in Anglo-Saxon countries where traffic regulations required driving on the left and clockwise traffic along the ring road, while still giving priority to the right (and therefore to traffic flows on the ring road).

In the 1950s and 1960s, following numerous experimental studies, it was recommended in the USA that roundabouts be designed for total hourly traffic of no more than 3,000 vehicles per hour. Optimal operating speeds were considered 25-40 km/h in urban areas and 50-65 km/h in extra-urban areas. To facilitate interchange maneuvers at the indicated speeds, average central island radii of around 70-100 m were required, resulting in significant increases in costs or, often, making the layout impossible to implement due to lack of space. This explains the skepticism (and often the preclusion) of many engineers regarding this type of intersection until the early 1980s, with the exception, as mentioned, of Great Britain. At this point, the change in traffic rules, which gave priority to traffic on the ring road over vehicles arriving at the intersection, proved to be an innovative decision.

**This has resulted in an increase in overall capacity.
of the intersection, while reducing its size, which also increased safety by reducing speeds. The new traffic rule must be explicitly and effectively communicated to users, and in fact the definition of a roundabout (borrowed from French law) now accepted is as follows: "A roundabout is an intersection consisting of a central area surrounded by a ring (carriageway) accessible in a one-way,
anticlockwise direction by traffic coming from the opposite direction.**

from multiple entrances, announced by specific signs. These are to inform users that they are entering a particular intersection where priority is given to vehicles traveling on the ring road, regardless of the type of road they are coming from.

For the reasons mentioned above, since the 1980s, many roundabouts have been built in numerous countries (in addition to England, France, Germany, the Netherlands and Scandinavian countries) and a large number of theoretical and experimental studies have been carried out.

In Italy, the diffusion of this scheme occurred somewhat late, but, currently, we are also moving towards recognizing the advantages of this rapidly spreading cross.

7.1. General considerations on roundabouts

Until the 1980s, the functioning of a roundabout was seen as a succession of interchange zones between two adjacent accesses (Fig. 25).

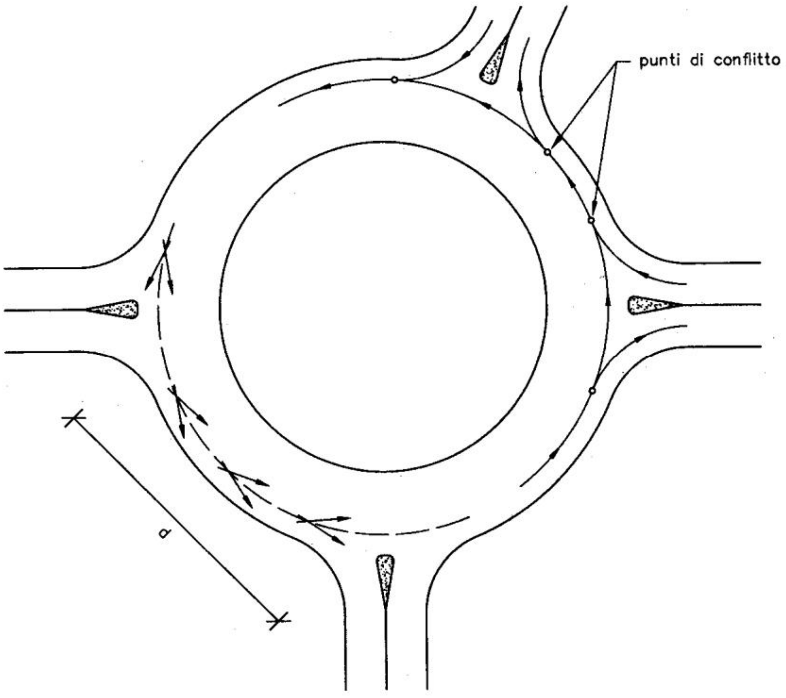


Fig. 25 – Diagram of the operation of a roundabout as a succession of interchange zones (before the priority rule) and as a succession of T-junctions

The speed along these zones, i.e. along the ring, is commensurate with the The speed of the merging roads required often long interconnection zones and, consequently, central island radii of up to 100 m. For example, the AASHO (American Association of State Highways Officials) suggested, based on the highest speed on the access roads Vb, the corresponding speed along the ring Va and the minimum distance d between two successive roads indicated below.

Vb (km/h)	50	65	80	95
Go (km/h)	40	50	55	65
d (m)	46	57	65	75

The modification of the traffic rule has allowed the operation to be interpreted, even in the presence of switch maneuvers, as a succession of particular T-intersections with priority to the ring; therefore, at each arm, there is a diversion conflict point and an entry conflict point; the difference in terms of number and type of conflict points with the four-arm linear intersection is evident (Fig. 3).

It has been noted, however, that a reduction in the size of the central island and, therefore, in speeds, while leading to cost reductions and increased safety, leaves the capacity practically unchanged, therefore the current orientation is not to exceed values of 15÷20 m for the radius of the island.

The main advantages that can be achieved by resolving an intersection with a roundabout are: - easier turning and overall reduction of waiting times which are balanced for the different flows as there is no hierarchy between the flows; - better management of traffic fluctuations compared to fixed-time traffic-lighted intersections for which the cycle is designed for rush hour; - increased, in general, the level of safety; - effective connection from fast extra-urban routes to suburban areas and then

urban;

- possibility of reversing without dangerous or illegal maneuvers; - reduction of air and noise pollution; - flexibility and ease of urban insertion where many squares already prefigure the roundabout layout.

However, there are contraindications to the use of roundabouts in the following cases:

- absolute lack of space; - highly
unbalanced flows (in these cases traffic light regulation can
be more functional); - when
you do not want to penalise, with significant reductions in speed, the
main flow; - in the
presence of public transport; - with
the simultaneous presence of heavy vehicles and two-wheeled vehicles, the roundabout
layout has proven to be remarkably dangerous; - pedestrian
flows are disadvantaged as their journeys are increased.

In any case, the undeniable advantages have encouraged engineers to adopt roundabouts even in limited spaces; typically urban solutions called semi-controlled islands and mini-roundabouts have therefore been proposed, in which the radius of the central island is reduced to 1.50-3.00 m.

7.2. Geometric Configuration of Roundabouts

Fig. 26 shows the elements that define the geometry of the roundabout. For some of them, the range of variation in which they are most frequently found is reported below, based on the prevailing indications in international technical literature, while for others, the minimum values are indicated, with the understanding that, primarily in urban areas, in many cases it is necessary to adopt different values.

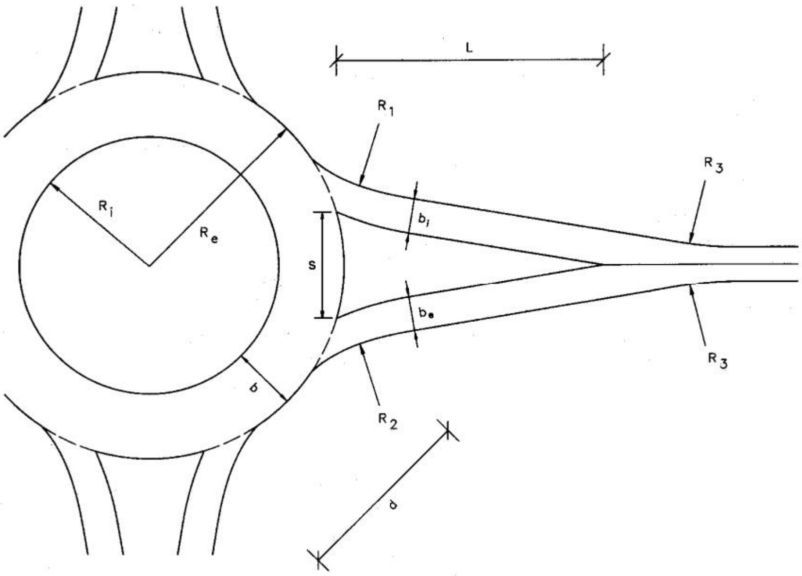


Fig. 26 – Geometric elements of a roundabout

- R<u>adius of the internal island Ri : w</u>e reiterate what was said previously regarding the shape, which must be as close as possible to a circular one, and that in any case elongated ovoid ones are not recommended.

  Following the most recent guidelines, the following values are suggested:
  - extra-urban roundabouts (m) ÿ ÿ 15 R 20 (m) (m) (m)
  - urban roundabouts 8 Rÿ ÿ15 i
  - semi-controlled islands 3 R 5 ÿ ÿ
  - mini-roundabouts 1 R 2.5 ÿ ÿ
- Av<u>erage external radius Re : i</u>s equal to the internal radius increased by the width of the ring.
- W<u>idth of the ring b: for b, val</u>ues between a minimum of 7.00 m and a maximum of 12.00 m are suggested; it is not advisable to exceed this value because the vehicles would arrange themselves in too many rows, increasing interference. If the demand between two consecutive arms is high, rather than increasing the width of the ring in just one section, the solution shown in Fig. 27 is adopted.

- W<u>idth of the entrance bi : for a s</u>ingle row we assume bi = 3.50 m or, better, bi = 4.00 m ; with two rows b 7.00 m. =
- Ex<u>it width be : the recomm</u>ended and most frequently used width is between 4.50 and 5.00 m.

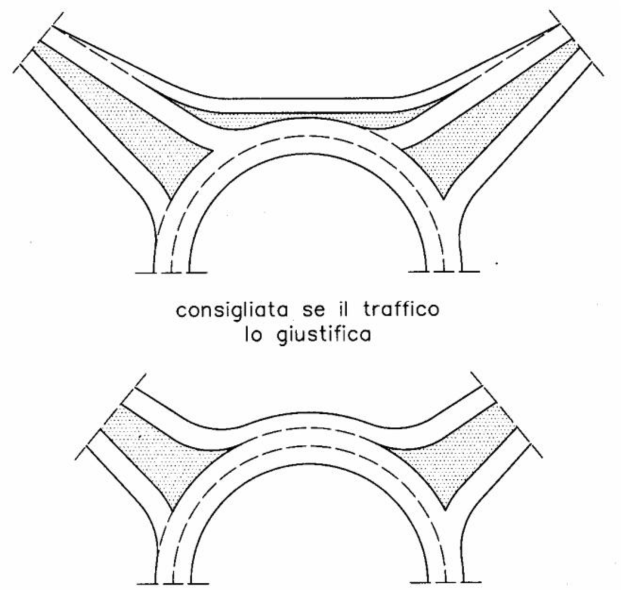


Fig. 27 – Link road between two successive branches in case of high demand between them

- Radii R1 and R2: these are the radii of curvature of the edges at the entrances and exits, respectively. Minimum values for R1 are between 15 and 20 m, while slightly larger values (25-35 m) are appropriate for R2 . The radii R3 of the connecting curves where the widening begins are in the order of 200-300 m.

- Distance d: the distance d between one entrance and the next exit, measured between the vertices of the flowerbeds on the arms, should be no less than 20÷30 m.
- Traffic islands on the arms: particular attention must be paid to the definition of these elements, whose width s significantly influences the capacity of the arm. The dimensions depend on the speed of the access lane and the type of roundabout: the width s therefore ranges from minimum values of 1.00 to 2.50 m for mini-roundabouts or semi-controlled islands, to values between 4.00 and 12.00 m for larger roundabouts; the length L is generally equal to 5s.

	Dext = 2 Re [m]
MINI-ROUNDABOUTS	14 ÷ 25
COMPACT ROUNDABOUTS	25 ÷ 40
CONVENTIONAL ROUNDABOUTS	> 40 ÷ 50
INTERSECTIONS WITH ROUNDABOUT TRAFFIC (LARGE ROUNDABOUTS)	> 50

Table 7 – Classification of roundabouts according to Italian standards [12]

Modular element	Dext = 2 Re [m]	Lane width [m] 6.00
Lanes in the roundabout for single-lane entrances (*) ,	ÿ 40	7.00
	between 25 and 40	
	between 14 and 25 ÿ 40	7.00÷8.00
Lanes in the roundabout for multi-lane entrances (**) ,	< 40	9.00
		8.50÷9.00
Input arms (**)		3.50 for one lane 6.00 for two lanes 4.00
Output arms (*)	< 25	4.50
	ÿ 25	

(*) must always be organized in a single lane.
(**) organized with a maximum of two lanes.

Table 8 – Widths of modular elements of roundabouts according to Italian standards [12]

	DIRECTIONS ITALIAN Dext = 2 Re [m]	DIRECTIONS GERMAN Dext = 2 Re [m]	
MINI ROUNDABOUTS	14 ÷ 25	13 ÷ 25	
ROUNDABOUTS COMPACT	25 ÷ 40	26 ÷ 60	urban: 26 ÷ 35 – 1-lane ring road outside urban areas: 26 (better 30) ÷ 45 – 1-lane ring road
			urban and extra-urban: 40 ÷ 60 – 2-lane ring
ROUNDABOUTS CONVENTIONAL	40 ÷ 50	-	
INTERSECTIONS WITH CIRCULATION AT THE ROUNDABOUT (LARGE ROUNDABOUTS)	> 50	55 ÷ 80	
	DIRECTIONS ITALIAN	DIRECTIONS GERMAN	
Ring width (b)	6 ÷ 9	4.5 ÷ 10	

Table 9 – Comparison between Italian and German signs regarding roundabout intersections

The current Italian regulations on road intersections [12] prescribe for roundabouts (see Fig. 26) the nomenclature of Table 7 and the widths of the modular elements reported in Table 8.

Table 9 provides a comparison of Italian and German guidelines for roundabout intersections. This shows that, despite the same nomenclature, the geometric standards adopted in the two countries do not coincide.

Again according to the current Regulations [12], a further distinctive element between the types of circular intersections in Table 7 "is represented by the arrangement of the central island, which can be made partially passable for heavy vehicle manoeuvres, in the case of mini-roundabouts with an external diameter between 25 and 18 m, while it becomes completely passable for those with a diameter between 18 and 14 m; compact roundabouts are instead characterised by non-surmountable edges of the central island".

Based on the matrix of possible connections shown in Fig. 1, still according to Italian regulations, in extra-urban areas the adoption of mini-roundabouts is limited to F/F type intersections between local roads, while compact circular layouts are permitted for intersections between C/C and C/F axes.

It has been said that, among the other advantages of roundabouts, there is the increase in safety that comes from the low speeds at which the ring is travelled; for this to happen, a geometric organisation is necessary that excludes trajectories

small curvature “tangents”. The objective is achieved by constructing, for each arm, the deflection trajectory, i.e. the deviation angle ÿ; the first [14] is a conventional trajectory, formed by three circumferential arcs, the construction of which is clearly indicated in Fig. 28.

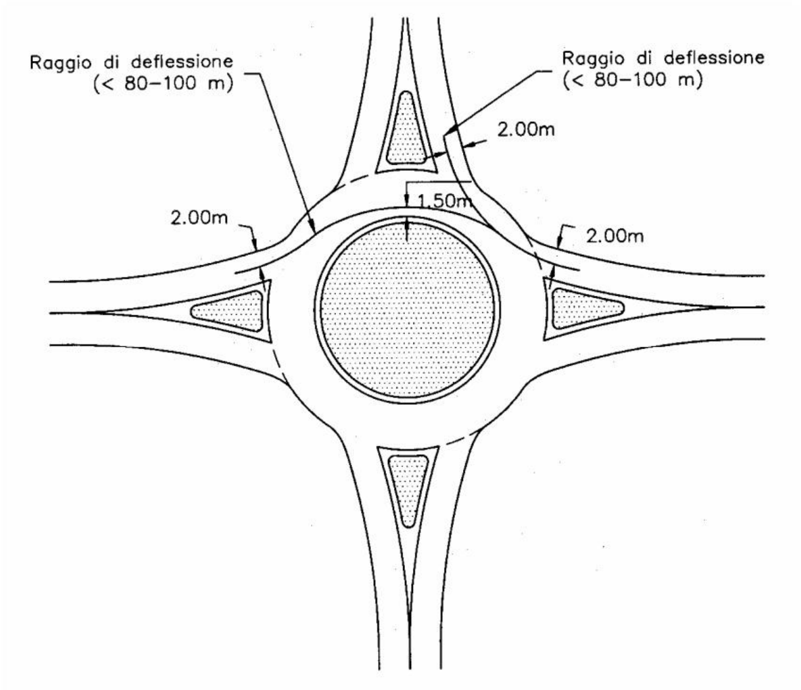


Fig. 28 – Deflection trajectory of the roundabout

To determine the deviation angle ÿ, following the indications contained in [12] and referring to Fig. 29, the circular arcs of radius R1+b1 and R2+b2 are drawn **and then the tangents to these circular arcs and to the central island; this identifies the deviation angle** ÿ **which should not be less than 45°. It must be said however that when the central island has a diameter less than 6÷8 m the conditions required for the deflection trajectory and for the deviation angle cannot be respected.**

Fig. 30 shows the cross-section of a roundabout: it can be seen that the slope for rainwater drainage faces outwards, which is unfavourable for vehicles travelling along the ring, while those exiting are favoured. This configuration is generally accepted because, in addition to being, as just mentioned, advantageous for the removal of water from the platform, it is structurally better with regard to the connection of the groundwater levels.

Correspondence of the branches that graft onto the ring. Only in the case of very wide rings can a double-pitched shape be used, which, however, presents the aforementioned drawbacks.

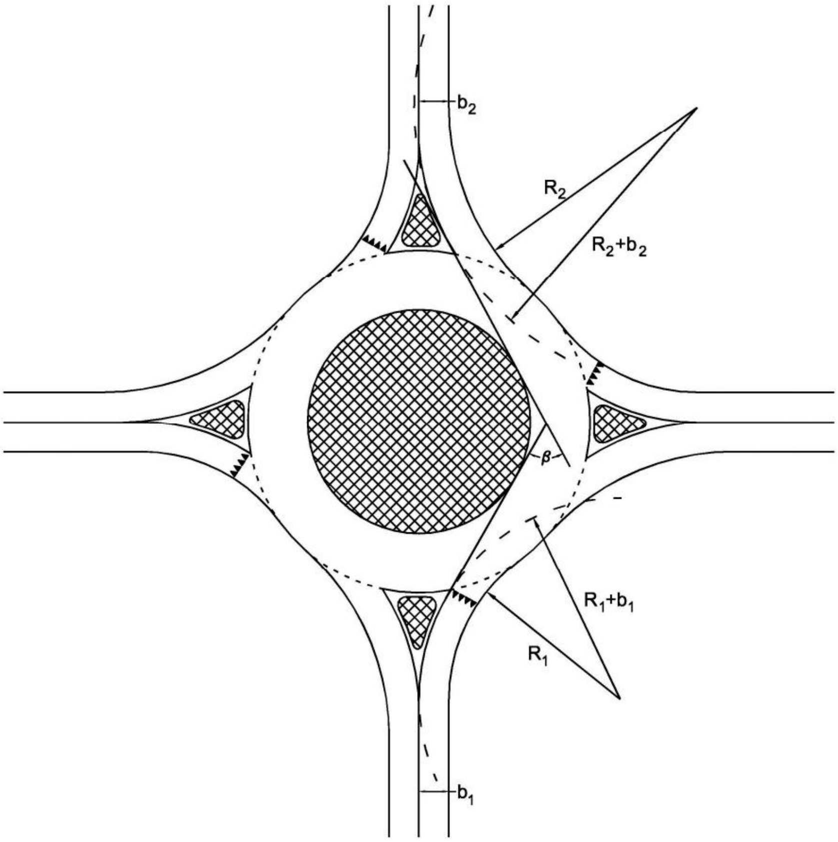


Fig. 29 – Determination of the deviation angle ÿ

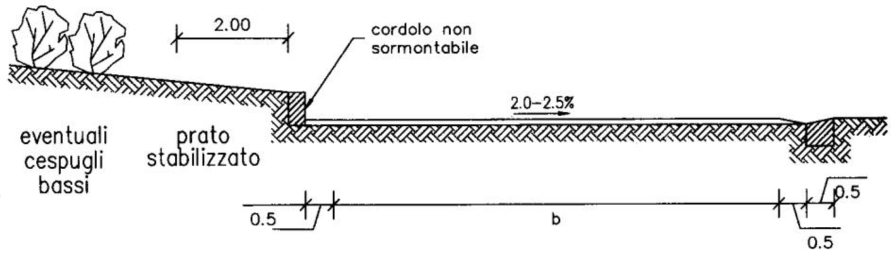


Fig. 30 – Cross-section of a roundabout

Fig. 31 shows the cross-section of a semi-controlled island roundabout (Ri ÿ 5.00 m): the central ring serves to facilitate turning by public transport and large trucks; it must be delimited by an easily surmountable kerb and paved differently to indicate, also visually, that it should be used only by large vehicles and not by cars and two- and three-wheeled vehicles.

Finally, Fig. 32 shows the construction of the visibility triangle with the area to be kept clear of obstacles higher than 1.00 m.

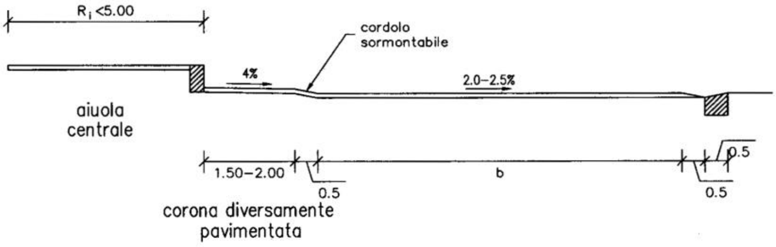


Fig. 31 – Cross-section of a semi-controlled island roundabout with a small central island radius

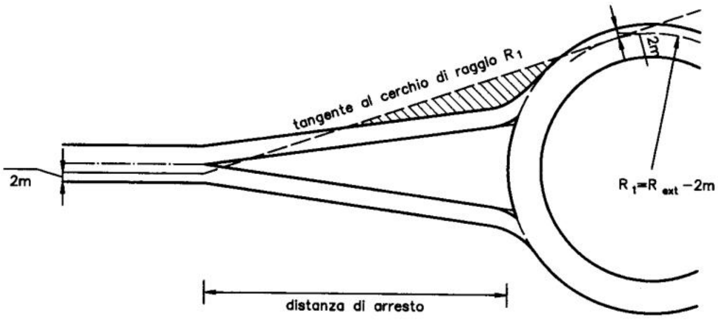


Fig. 32 – Construction of the visibility triangle

Finally, attention is drawn to the role that the correct mutual positioning of the arms and the ring plays in the safety of a roundabout. In particular, with regard to the distribution of the arms on the ring, configurations that favor the concentration of flows on limited parts of the ring should be avoided (see Fig. 33a). With regard to the position of the arms with respect to the central island (see Fig. 33b), they must converge toward the center of the layout (tangential trajectories should, in principle, be avoided); if an eccentricity must be tolerated, it must be located on the exit side.

Furthermore, accesses with long straights are not recommended, so it is advisable introduce curves and counter-curves to reduce speed (see Fig. 34).

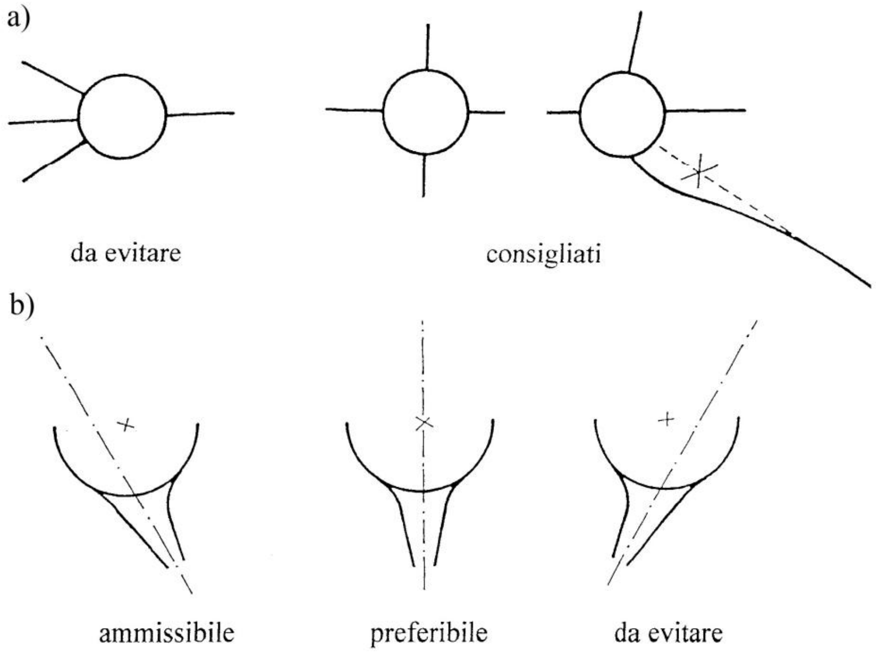


Fig. 33 – Mutual positioning of the arms and the ring

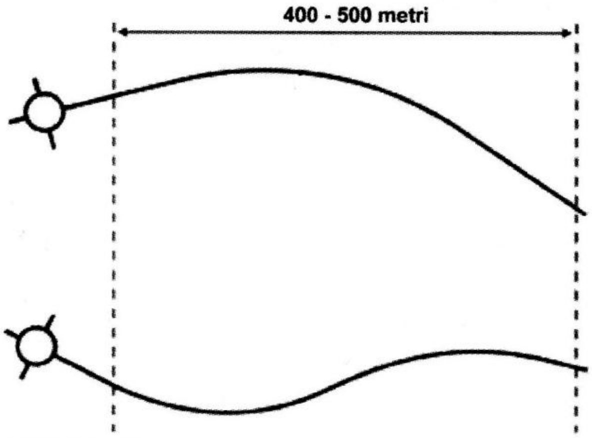


Fig. 34 – An example of profiling of the entrance branches to a roundabout

8. Traffic light intersections

From a geometrical point of view, these intersections do not present appreciable differences compared to linear ones and therefore one can certainly refer to what was said in §6, obviously keeping in mind that, in general, all traffic flows are stopped at alternate phases. The functional aspects (determination of the cycle and evaluation of delays) are discussed in [4].

9. Altitrical staggered intersections

An altimetrically staggered intersection is one in which two roads cross at different heights and are connected to each other by short sections of road (usually called ramps) which allow vehicles to pass from one road to the other. Therefore, at least one overpass is necessary. Between the underlying road surface and the intrados of the structure above there must be a distance of no less than 5.00 m at every point (see also Figs. 14 and 15 of Chapter 9 of [5]); the difference in height between the two roads therefore depends on the span and the type of structure which creates the crossing, but is, in most cases, between 6.00 and 7.00 m.

By staggering the levels, it is always possible to eliminate conflicting crossing points between the traffic flows, while the others can be eliminated partially or completely (in this case we speak of junctions) depending on the typology adopted: this depends on the number and type of ramps, as well as their location.

Recalling what was said in § 2, this type of intersection is mandatory for connections (Fig. 1) A/A; A/B; A/D; A/C; A/E; B/B; B/C; B/D; B/E; D/D; D/C; D/E, although staggering should not be ruled out a priori even between secondary extra-urban roads if the following considerations are taken into account: - with the staggering, the speeds of the traffic flows on one or both roads remain practically unchanged; the same applies to the quality of traffic (Level of Service) and to capacity; - turning maneuvers, or at least some of them, occur without excessive stops or slowdowns, being made up only of diversion and merging maneuvers;

- the partial or total elimination of conflict points leads to an increase of safety.

On the other hand, it should be kept in mind that: - the staggered level crossing is more expensive due to the presence of one or more works overpass, ramps and occupied space;

- the required difference in altitude will require changes to the altimetric profile of at least one of the two roads, with a consequent increase in costs; however, if the two roads already run at different altitudes, a staggered-level solution with one or two ramps could prove competitive, if not more cost-effective;
- the staggered intersection has a greater visual impact than the at-grade ones, but seems preferable with regards to air and noise pollution.

All of the above leads us to affirm that at least in some cases - particularly for C/C, D/E and even D/D connections - the choice cannot be derived exclusively from a Standard: particular local situations, the size of traffic flows in transit and turning, and above-average accident rates (for existing intersections) can lead to solutions that are not in line with the Standard; it is desirable that the designer be left with the option to opt, with the necessary justifications, for the overall most suitable solution.

9.1. Connecting ramps

The ramps connecting two roads, despite their variety of shapes resulting from the need to adapt to local situations, can always be classified into three basic types (Fig. 35):

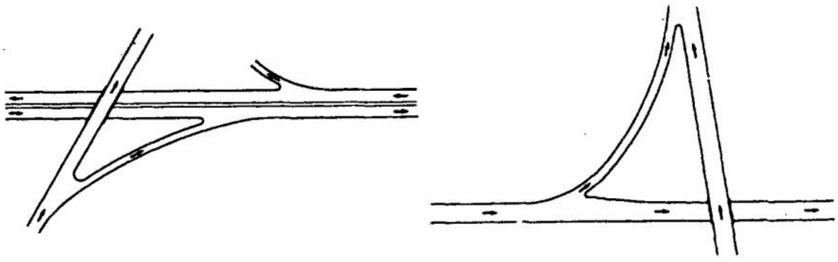
- direct ramp, which allows for a right or left turn in the most natural way and with the shortest route; it must be said that using this ramp for a left turn involves exiting and entering the left lane, as well as crossing over the oncoming lane and, possibly, other ramps;

- semi-direct ramp, which allows exit on the right side of the road with a right curve that gradually turns into a left curve;
- indirect or loop ramp, which converts the left turn into a right turn with a central angle close to 3/2 ÿ ; it does not cut off any traffic flow, but is not very intuitive and requires a longer route than the other two types.

The ramps can be unidirectional (with one or two lanes) or bidirectional. The dimensions of the platform elements are determined according to the road of the higher hierarchical level among those converging on the node and are reported in Table 10 taken entirely from [12]; as regards the marginal elements, reference will be made to what is reported in §9.2 of [5].

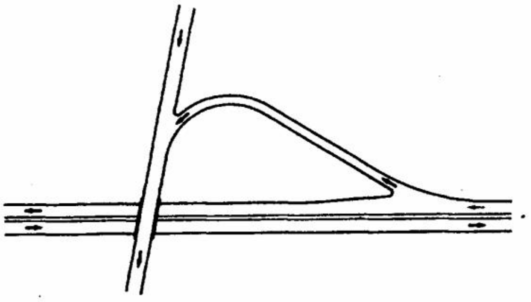
The planimetric and altimetric characteristics derive, as always, from the speed: even if some suggest values around 60÷70% of the speeds of the intersecting roads, it must be said that this is possible for direct ramps,

whereas, especially for loop lines, it is advisable to refer to lower speeds, not only for cost reasons, but also because lengthening the routes would cancel out the advantages of a high speed.

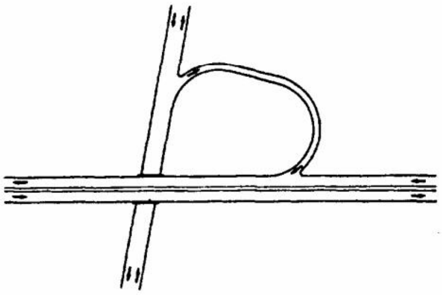


Rampa diretta per la svolta a destra

Rampa diretta per la svolta a sinisra



Rampa semidiretta



Rampa a cappio

Fig. 35 – Types of ramps

Extra-urban roads				
Modular element	Type of main road	Lane width (m)	Width of right platform (m) 2.50	Width of the left dock (m)
Specialized exit and entry lanes	TO	3.75	1.75	-
	B	3.75		-
One-way ramps	TO	1 lane: 4.00 2	1.00	1.00
		lanes: 2 x 3.50 1		
	B	lane: 4.00 2	1.00	1.00
		lanes: 2 x 3.50 1		
Bidirectional ramps	TO	lane: 3.50 1	1.00	-
	B	lane: 3.50	1.00	-

Urban roads				
Modular element	Type of main road	Lane width (m)	Width of right platform (m) 2.50	Width of the left dock (m)
Specialized exit and entry lanes	TO	3.75	1.00	-
	D	3.25		-
One-way ramps	TO	1 lane: 4.00 2	1.00	1.00
		lanes: 2 x 3.50 1		
	D	lane: 4.00 2	1.00	1.00
		lanes: 2 x 3.50 1		
Bidirectional ramps	TO	lane: 3.50 1	1.00	-
	D	lane: 3.50	1.00	-

Tab. 10 – Dimensions of the ramp platform elements [12]

Table 11 contains, according to the Italian Standard [12], the design speeds for the types of ramps based on the categories of intersecting roads, while Table 12 reports the minimum values of the geometric characteristics as a function of the aforementioned speeds.

Crossroads / Types of ramps	A/A; A/B; A/D	A/C, A/E; B/B; B/C; B/D; B/E; A.D; D/D;D/E	
Live	50÷80 km/h	40÷60 km/h	
Semi-direct	40÷70 km/h	40÷60 km/h	
Indirect (noose)	exiting from A 40÷70 km/h	exiting the road of higher ger. level entering	40÷60 km/h
	entering A 30÷70 km/h	the road of higher ger. level	30÷60 km/h

Table 11 - Design speeds for ramp types based on intersecting road categories

Design speed (km/h)		30	40	50	60	70	80
Minimum planimetric radius (m)		25	45	75	120	180	250
Longitudinal slope Maximum climb (%)		10	7	7	5	5	5
	Descent	10	8	8	6	6	6
Vertical connections Rmin (m)	Convex 500		1000 1500 2000 2800 4000				
	Concave	250	500	750	1000 1400 2000		
Cross slope (%)	Minimum	2.5					
	Maximum	7					
Minimum clear sight distance (m)		25	35	50	70	90	115

Table 12 - Planimetric and altimetric characteristics of the ramps

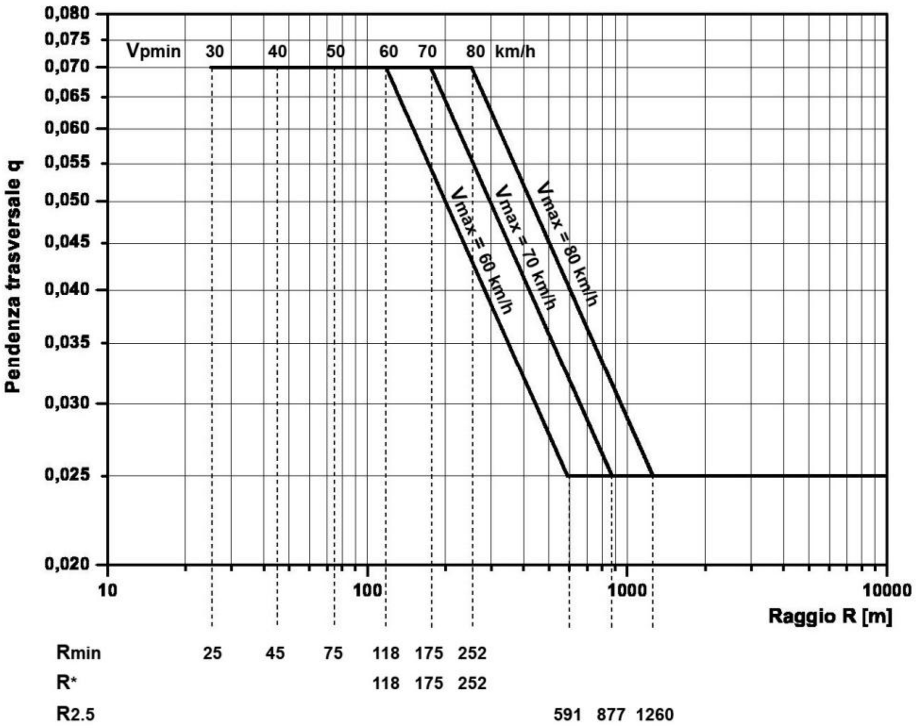


Fig. 36 – Abacus for calculating the radius of circular curves of ramps

It should be noted that, even if it would be appropriate to adopt, even for circular curves of minimum radius, a transverse slope in the curve of limited value - both for the inversions of curvature that characterise some ramps, and to facilitate the connections of the slopes to the junctions of the ramps themselves on the roads - according to the Standard [12] said minimum radii are in any case those rela

at a (maximum) transverse slope of 7%; furthermore, always according to [12], the transverse slope of circular curves with a radius greater than that indicated in Table 12 must be defined according to the "Functional and geometric standards for road construction" (DM 5/11/2001). In this direction, §7.2 of [5] can be consulted for the calculation. In Fig. 36 an abacus is represented which graphically translates the relationships between R, q and V which are drawn from the indications of the recalled Standards.

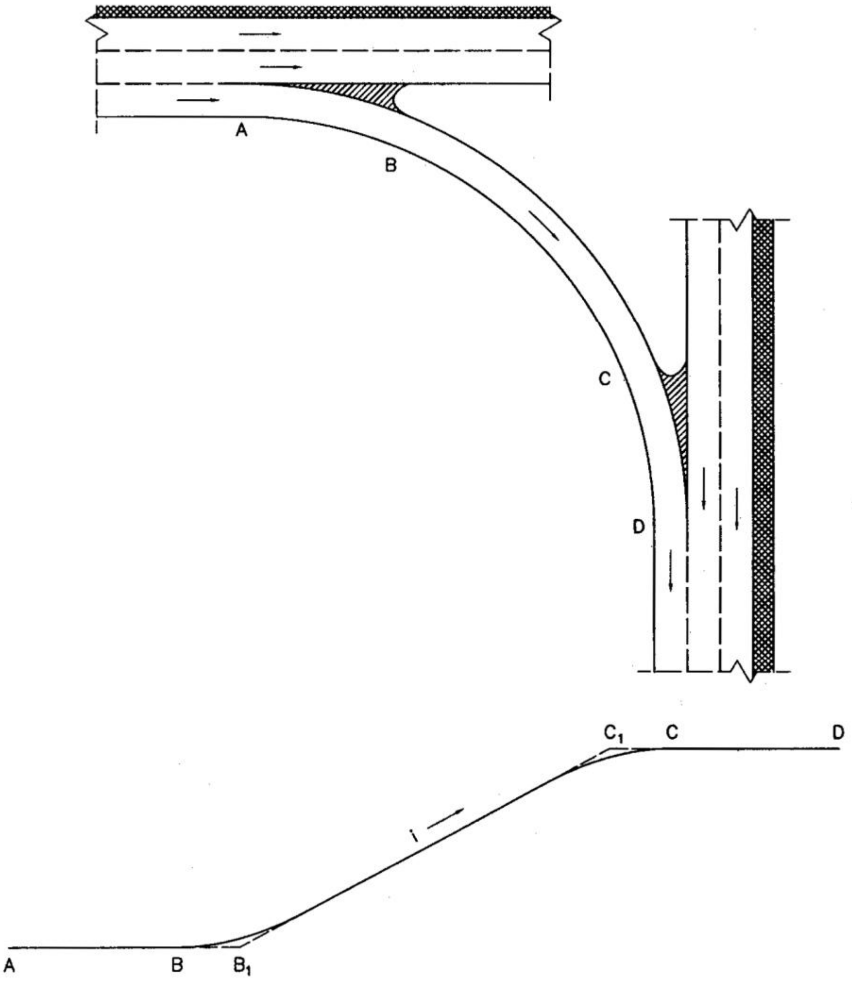


Fig. 37 – Plan and profile of a ramp

Furthermore, it is desirable, whenever possible, not to reach the maximum longitudinal slope values, both for safety reasons and because they increase the length of the vertical connections, reducing the useful length for overcoming the difference in height; this is illustrated in Fig. 37, which schematically shows the plan and longitudinal profile of a ramp. Line ABCD represents the edge of the ramp's carriageway to which the profile refers; it is advisable that sections AB and CD do not vary in height with respect to the roads and, therefore, the vertical connections must develop in section BC, therefore the slope of the ramp must be determined with reference to the length B1-C1.

For the complete planimetric definition of the ramps, the Standard [12], with reference to the adoption of transit curves, provides that "for the insertion of variable radius curves (clothoids) reference must be made to the criteria contained in the Ministerial Decree 5/11/2001. For the deceleration sections of the needle exits, and in cases where the acceleration section in the entrances develops partially with an element with variable curvature, the designer must appropriately choose a variable radius curve, even a composite one, regardless of the indications of the aforementioned Ministerial Decree".

Finally, the Standards [12] explicitly indicate that along the ramps the visibility checks must be satisfied in accordance with what is established by the aforementioned "Functional and geometric standards for the construction of roads" (DM 5/11/2001); in this case too, for the calculation, §10.2 of [5] can be consulted.

9.2. Exit and entry lanes

The function of these specialized lanes has already been discussed in §6.1.2 and §6.1.3. However, the variations relating to staggered intersections must be indicated. The widths of the lanes and shoulders, according to Italian standards [12], are reported in Table 10.

9.2.1. Exit lanes (deceleration)

A typical example of a deceleration lane is shown in Fig. 38, where it can be seen that the deceleration lane follows the manoeuvring lane, which is partly parallel and partly curved, consisting of the clothoid arc that connects the parallel section with the circular section of the ramp; the geometric construction is made with reference to the edge of the roadway.

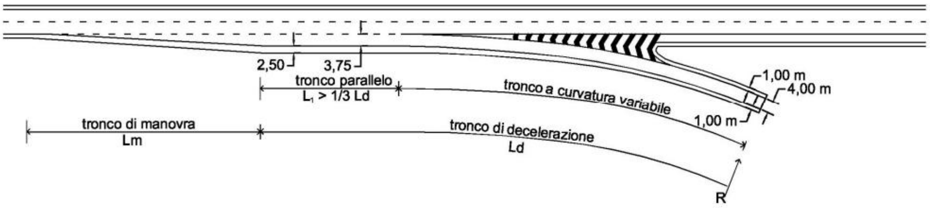


Fig. 38 – Exit lane

The length of the maneuver trunk Lm can be set to vary from 40 m for Vp = 60 km/h at 90 m for Vpÿ120 km/h.

The length of the deceleration section is calculated, as a section to be travelled in uniformly decelerated motion, with (1): for vc we assume the design speed of the road at that point; for vR the speed determined by the radius of the ramp; the deceleration is generally assumed to be in the order of 2÷3 **m/s2 , depending on the type of road, as will be explained below when illustrating the provisions of [12].**

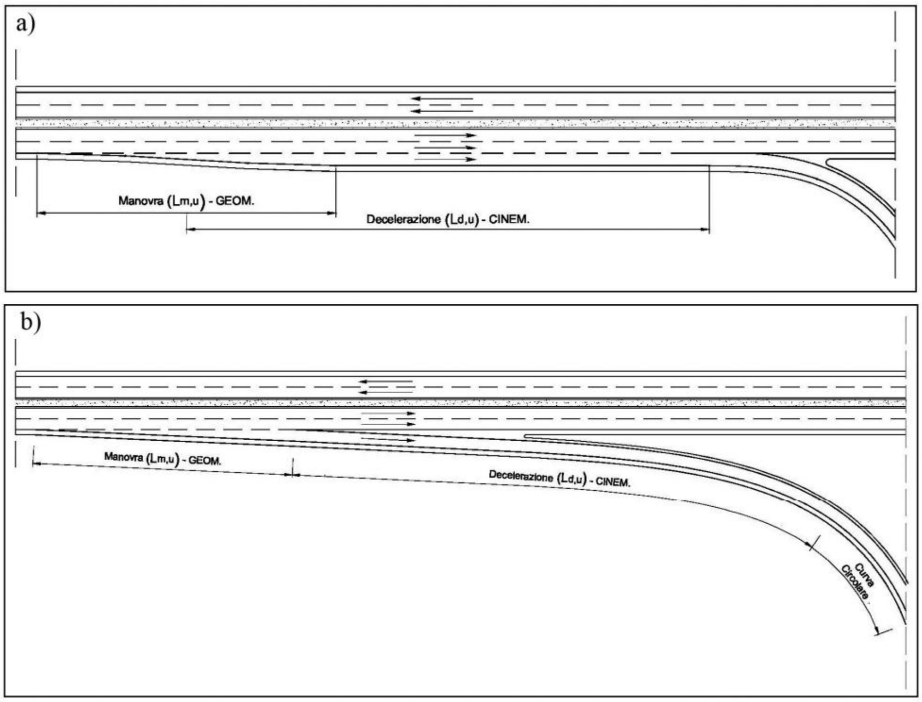


Fig. 39 – Possible configurations of exit lanes according to Italian regulations [12]

With specific reference, therefore, to the current Italian regulations [12] the configuration of the exit lanes of altimetrically staggered intersections is identical to that foreseen for at-grade intersections and reported in Fig. 12. For the reader's convenience, it is reproduced in Fig. 39.

The length Lm,u of the shunting section must be determined as a function of the design speed of the section from which the lane branches off as reported in Table 13.

Vp [km/h]	Lm,u [m]
40	20
60	40
80	60
100	75
ÿ 120	90

Table 13 – Determination of the length of the manoeuvring section at level-shifted intersections [12]

The length Ld of the deceleration section is calculated, with kinematic criteria, in an identical way to the case of linear at-grade intersections (always with (1) in which for vc the design speed of the road at that point is assumed, for vR the speed determined by the radius of the ramp, i=0 ea=3.0 m/s2 for roads A and B and a=2.0 m/s2 for the other roads).

Finally, as regards the width of the right shoulder for the exit lane, still according to Italian regulations [12], it must be assumed as a function of the type of road with the values in Table 10. From the same table it can be seen that the shoulder of the adjacent ramp is set to a different width (regardless of the type of road, always equal to 1 m). Therefore, when passing from the specialised lane to the ramp, the problem of the transition from one width to the other arises.

The Standards [12] do not provide indications on how to carry out this transition. One criterion could be to use the possible transit curve between the specialized lane and the circular curve of the ramp as an element along which to develop the variation in width of the platform.

9.2.2. Entry lanes These lanes

(still today also called acceleration lanes) are made up of an acceleration section with variable curvature (clothoid) which ends at the beginning of the parallel section; this is travelled (as shown numerous experimental researches), at an almost constant speed of the order of 70÷80 km/h, by vehicles that must enter the passing current.

A typical configuration is shown in Fig. 40.

The length of the acceleration section La is then calculated again with (1) assuming as initial velocity that allowed by the radius of the ramp and as final velocity 80 km/h. The acceleration is assumed to be a value between 1.00 and 1.20 m/s2 .

The length of the parallel section L1, which is in effect a moving waiting section, depends on the volume of traffic in transit and must be determined using models of different nature (5). We will discuss these shortly when illustrating the provisions of the Standard [12].

The length of the connecting section Lm is equal to 75 m for Vp> 80 km/h and 50 m for Vpÿ 80 km/h, where Vp is the design speed of the road you are entering.

With specific reference now to the Italian regulations [12] the configuration of the exit lanes of altimetrically staggered intersections is identical to that foreseen for at-grade intersections and reported in Fig. 53.

For the convenience of the reader, it is reproduced in Fig. 41.

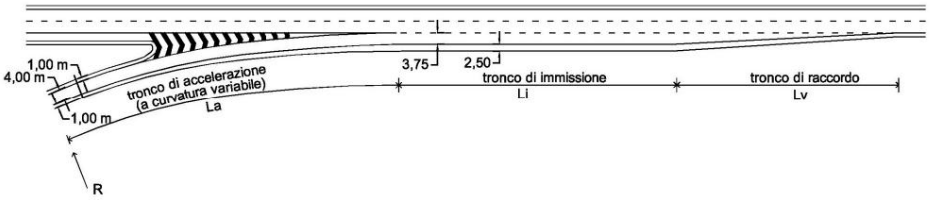


Fig. 40 – Entry lane

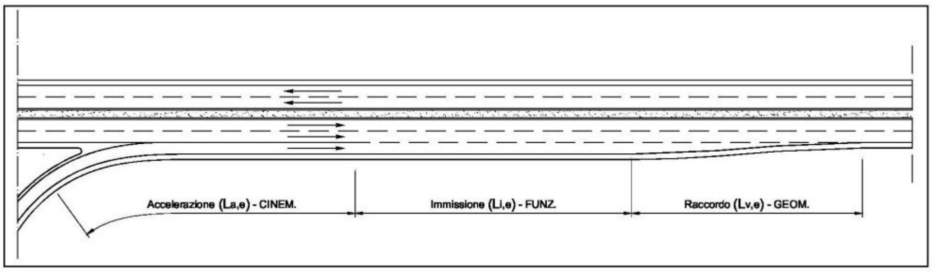


Fig. 41 – Configuration of the entry lanes according to Italian standards [12]

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(5) Typically, when there is little traffic on lane 1 of the road, the vehicle coming from the ramp enters without using the entry lane almost at all.

In an identical manner to the case of at-grade intersections, the length La,e of the acceleration section must be determined with kinematic criteria (with (1) assuming vc equal to 80% of the design speed of the road onto which the lane enters, vR equal to the design speed of the ramp at the starting point of the acceleration section of the entry lane, i = 0 and a = 1.0 m/s2); the length Li,e of the entry section must be calculated with functional criteria

("according to procedures based on the probabilistic distribution of the temporal distances between the vehicles in motion, on each lane"), and therefore using models borrowed from the theory of waiting phenomena or making use of the procedure contained in the Capacity Manual (see Chapter 3 and Chapter 6 of [4]).

The length Lv,e of the connecting element must be sized using geometric criteria: in this case, however, differently from the case of at-grade intersections, [12] provide the indications contained in Table 14 for its sizing as a function of the design speed of the road onto which the lane enters.

Vp [km/h]	Lv,e [m]
> 80	75
ÿ 80	50

Table 14 – Determination of the length of the connecting element in the entry lanes for staggered level intersections [12]

Finally, as regards the width of the right shoulder for the entry lane, still according to Italian regulations [12], it must be assumed as a function of the type of road with the values in Table 10. From the same table it can be seen that the shoulder of the entry ramp is set to a different width (regardless of the type of road, always equal to 1 m). Therefore, when passing from the ramp to the specialised lane, the problem of the transition from one width to the other arises.

The Standards [12] do not provide indications on how to carry out this transition. One criterion could be to use the possible transit curve between the circular curve of the ramp and the specialized lane as an element along which to develop the variation in width of the platform.

A different configuration of these lanes has been proposed by Canale et al. [2]. As regards the exit lanes, numerous experimental observations highlight that a very high percentage of users do not use the parallel trunk, but follow very extended trajectories occupying the lane during deceleration (Fig. 42): in consideration of these

In view of widespread practice, it is proposed to replace the manoeuvring section and the parallel deceleration section with a single "needle" section along which there is a speed decrease of approximately 15% of the initial design speed Vp, while all the remaining deceleration occurs on the curved section; suggested values for the length Lm, as a function of the speed Vp, are the following.

Vp (km/h)	80	100	120	140
Lm (m)	110	140	170	200

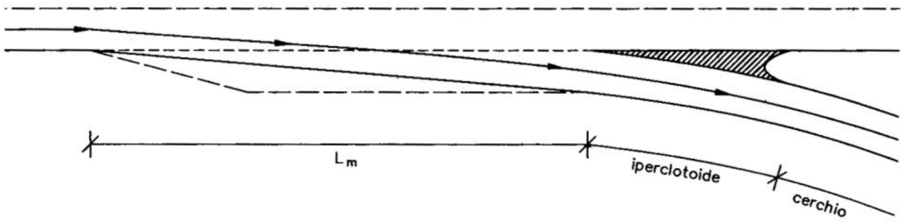

Fig. 42 – Exit lane as proposed in [2]

For the following curved section it is observed that the vehicle, in addition to the longitudinal deceleration, is also subjected to a transverse acceleration for which the (theoretical) trajectory of the vehicle is a particular curve called braking curve or Blaschke curve which was the first to study it and which is not easy to analytical treatment. However, the braking curves can be well approximated by hyperclothoids with an adequate parameter n: the latter depends on the radius of curvature and the speed at the beginning and at the end of the curve. [2] provides instructions for identifying the parameter n and for calculating the Cartesian coordinates of the hyperclothoid.

A similar indication is given for the acceleration curvilinear trunk.

Although more correct in principle, some regulations (e.g. the Swiss one) lean towards simple solutions, i.e. the clothoid, also taking into account the width of the ramps which leaves the user the possibility of following the most appropriate trajectory.

9.3. Types of staggered-level intersections

The number and type of ramps, the occupation of some or all quadrants, the number of overpasses, the partial or total elimination of conflict points can give rise to a vast range of solutions from which the designer chooses the most suitable one from time to time.

The most frequently used types are briefly illustrated below, starting with the simplest and most economical.

9.3.1. Single-quadrant or diagonal intersection.

This type of intersection features a single bridge and a single two-way ramp that allows for all turns (Fig. 43). This is a minimal solution that eliminates only the points of conflict between traffic flows, leaving the turns on both roads. It cannot therefore be adopted if at least one of the two roads is dual carriageway. Therefore, it is used as an alternative to at-grade intersections when the roads are naturally at different elevations and the aim is (with high traffic volumes) to improve safety and/or efficiency.

Note that there are two free turns (AB and DC), while, with the rule of giving priority to vehicles stopped at the STOP sign over those stopped at the STOP sign on the ramp, the most penalized turns are CD and BA. Things change if the ramp is located in another quadrant, so if there is freedom of choice, the ramp will be positioned to favor the busiest turns.

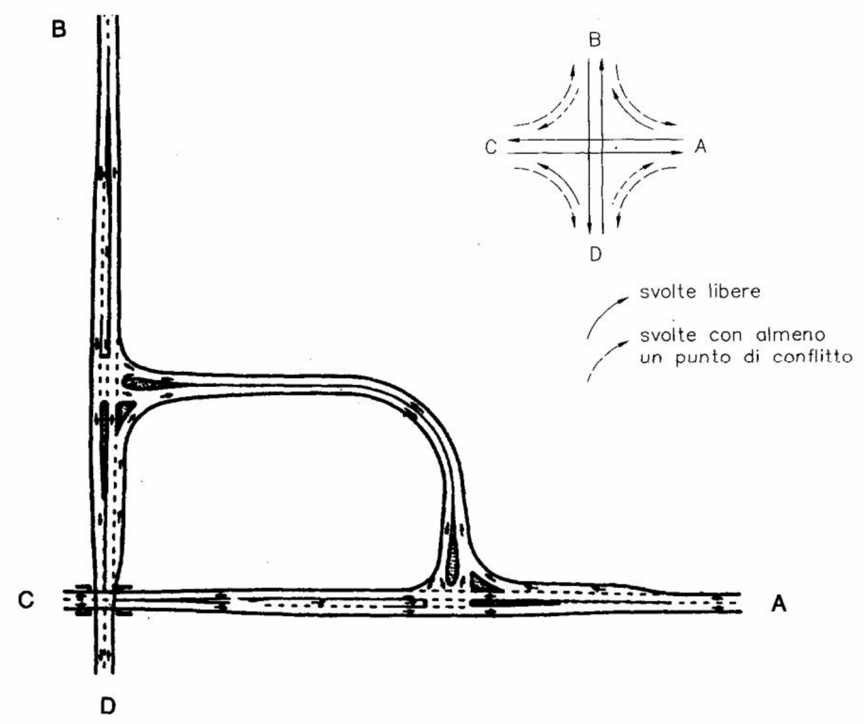

Fig. 43 – Monoquadrant or diagonal crossing

9.3.2. Partial or semi-cloverleaf intersections

With this type of intersection, whose ramps occupy two quadrants, it is possible to eliminate all points of conflict on one of the two roads; it therefore constitutes a possible solution when a road with a central reservation - e.g., type B - intersects a type C road. Fig. 44 and Fig. 45 show two possible layouts: in the first, the ramps are arranged in two opposite quadrants, while in the second they occupy two adjacent quadrants. The choice must be made firstly based on the possibility of positioning the ramp in a given quadrant or not and then taking into account the favored turns which, as shown in the diagrams in the figures, are not always the same.

The ramps are two-way and each of them, depending on the turn that allows, is simultaneously direct, semi-direct and looped.

As is clearly shown in the figures at the junction of the ramps onto the main road - the AC in Fig. 44 and the DB in Fig. 45 - exit and entry lanes must be provided, while the two connections with the secondary road are in fact two T-shaped intersections at ground level for which what is stated in §6 applies.

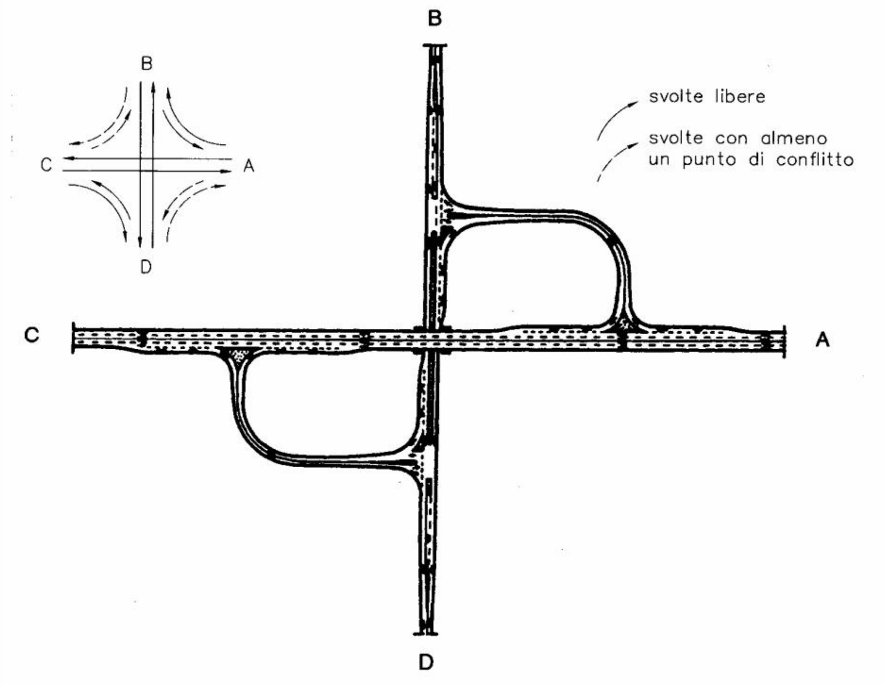

Fig. 44 – Partial cloverleaf intersection with ramps in two opposite quadrants

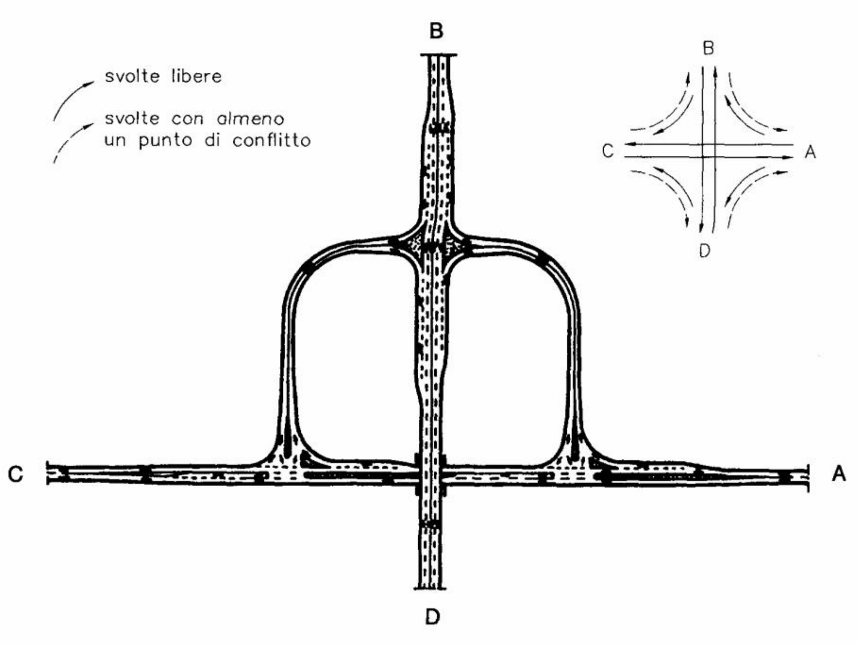

Fig. 45 – Partial cloverleaf intersection with ramps in two adjacent quadrants

9.3.3. Rhombus Intersections

The rhombus intersection (also called a diamond or Dutch intersection) is made up of four direct ramps, as shown in Fig. 46. It is used as an alternative to the partial cloverleaf intersection because it also eliminates conflict points on one of the two roads and is preferred provided it is possible to occupy all four quadrants; in fact, the ramps, all one-way, form small angles with the main road so that exits and merges can occur at high speeds, which results in shortening the exit and merge lanes. On the secondary road, on the other hand, two four-arm intersections are configured which, although some turns are prevented because the ramps are one-way, can pose some problems in terms of waiting.

The problem can be overcome by staggering the ramps, thus obtaining the scheme shown in Fig. 47. In this way we have
four free turns and four with a single crossing conflict point.

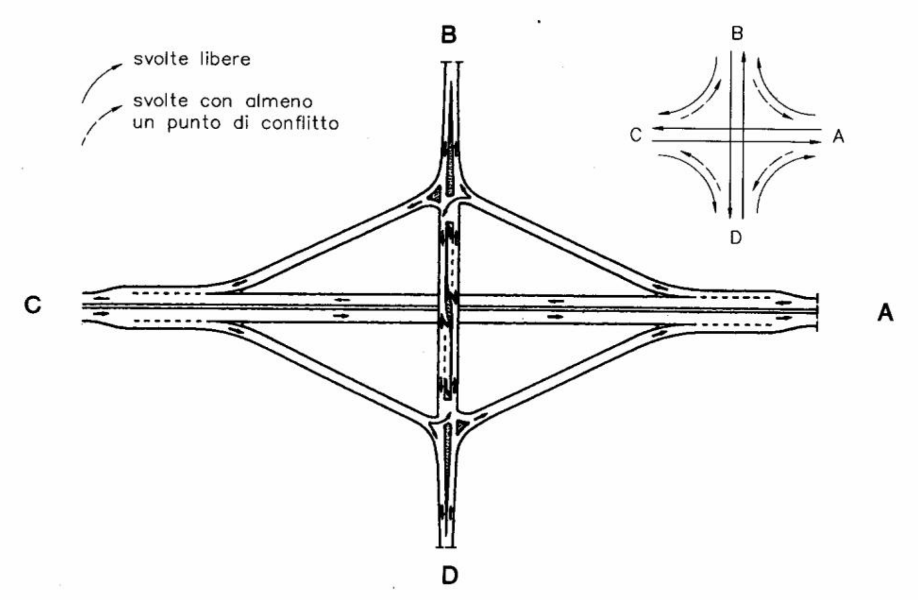

Fig. 46 – Diamond intersection

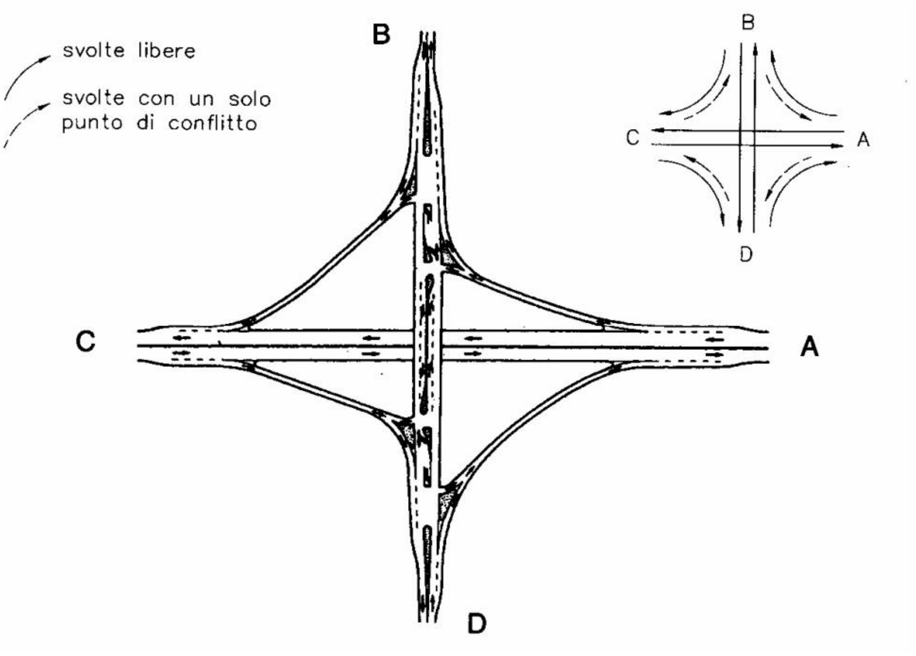

Fig. 47 – Diamond-shaped intersection with planimetric staggering of the ramps

9.3.4. T- and Y-junctions

Among three-branch intersections, the most common and well-known is the trumpet junction (Fig. 48), where two direct ramps, a semi-direct ramp, and a loop ramp allow for completely free turns. It represents the classic solution for connecting toll motorways to ordinary roads: in fact, all incoming and outgoing traffic passes through the CC section, downstream of which the toll booths are grouped.

It should be noted that the two left turns that use the semi-direct and loop ramps occur at relatively low speeds. When two hierarchically equal roads intersect and there are no toll requirements, alternative solutions that allow for high speeds on the ramps—but are somewhat more expensive—are those schematically shown in Fig. 49; in a) there is a single structure with two levels above ground level (at which point traffic therefore occurs on three levels), while in b) there are three structures.

In both cases, to keep the gradients within acceptable limits, it is necessary to "expand" the junction area; these are therefore excellent solutions from the traffic perspective, but expensive and have a significant visual impact in case a).

In conclusion of the description of the staggered level intersections presented so far, it is considered appropriate to underline that, based on the provisions of the current Regulations on road intersections [12] regarding the possibility of adopting specialized lanes (see Table 1), the intersections of Fig. 44 and Fig. 47 - in the case in which the AC axes are, for example, of type C - are not compliant, since on the aforementioned axes, at the junction of the ramps, entrance lanes are provided.

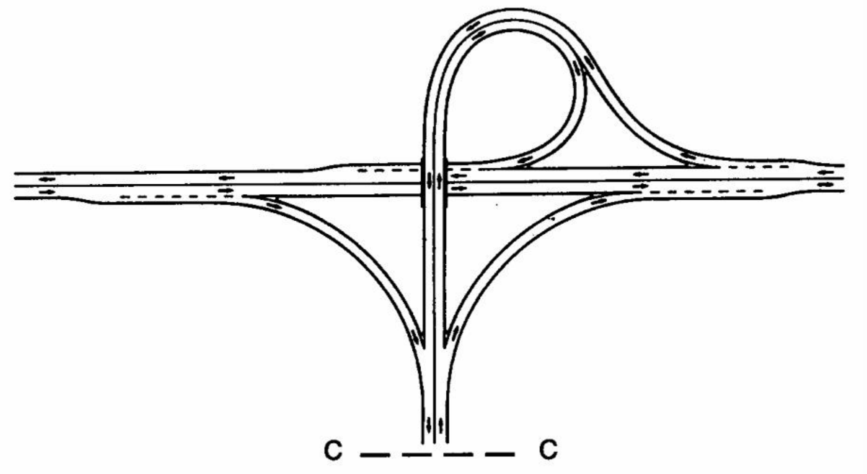

Fig. 48 – Trumpet junction

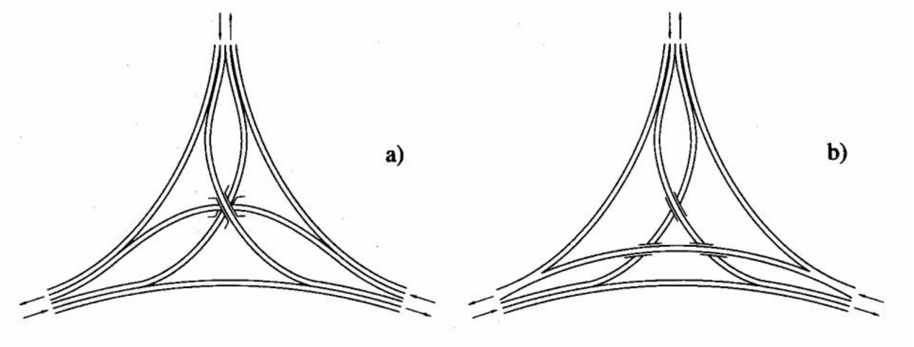

Fig. 49 – Three-branch directional junctions: a) with a single structure; b) with three structures

9.3.5. Four-leaf Clover

Junctions When two roads intersect where no intersection conflict points are permitted, the most frequently adopted solution is the complete cloverleaf (Fig. 50): it consists of four straight ramps that allow right turns, while four loop ramps allow left turns; all entry and exits are on the right. This junction, which therefore solves the conflict point problem with a single structure, does, however, present some drawbacks: the loop ramps lead to speed reductions and travel length increases (the fact that they are not very intuitive is resolved with adequate signage and in any case, users are now accustomed to them); the major drawback, however, lies in the fact that entering the road from a loop ramp precedes exiting the same road at the next loop; the entry and exit lanes often merge into a single additional lane along which there is interference between opposing flows; there is in fact an interchange area (which normally also involves the first lane of the main road) which, in order to function, must be several hundred metres long if the flow rates are high.

With reference to interchange zones, the current Italian regulations on road intersections [12] provide for the configuration of Fig. 51: on the basis of these, the length Lsc must be calculated with a functional criterion, therefore using, for example, the procedure contained in Chapter 5 of [4]. With the criteria set out therein, it is also possible to obtain an evaluation of the quality of traffic in interchange zones based on the traffic that uses them.

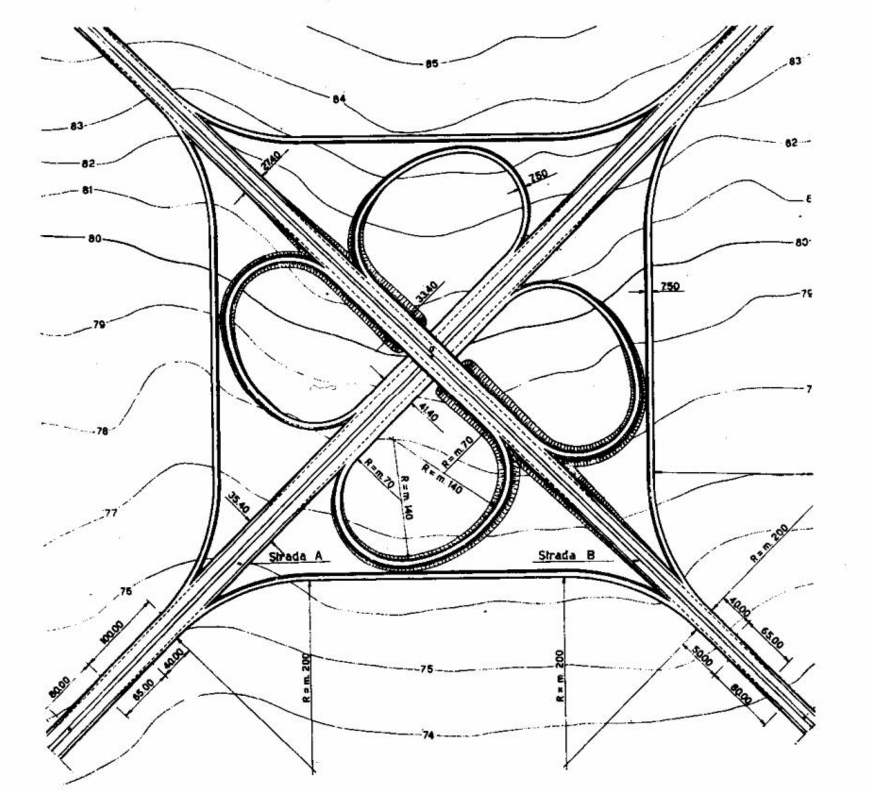

Fig. 50 – Complete cloverleaf junction

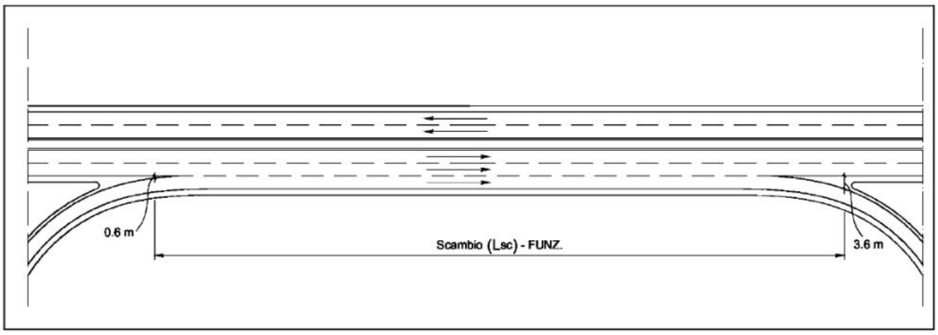

Fig. 51 – Configuration of the exchange zones [12]

As an alternative to the four-leaf clover, there are numerous other more complex and more expensive schemes that can be conceived and which are used in particular situations or for particular needs, so only a few of them will be mentioned.

Fig. 52 shows the so-called roundabout junction: right turns are usually made via direct ramps, while left turns use semi-direct ramps that merge in the central, steepest sections, creating a roundabout with four interchange zones. To avoid excessively reducing speed, to facilitate interchange between traffic flows, and, above all, to avoid excessively penalizing the altimetric profiles of the ramps, a ring radius of around 130-150 m is required. In addition to the considerable area occupied, no fewer than nine overpasses are required.

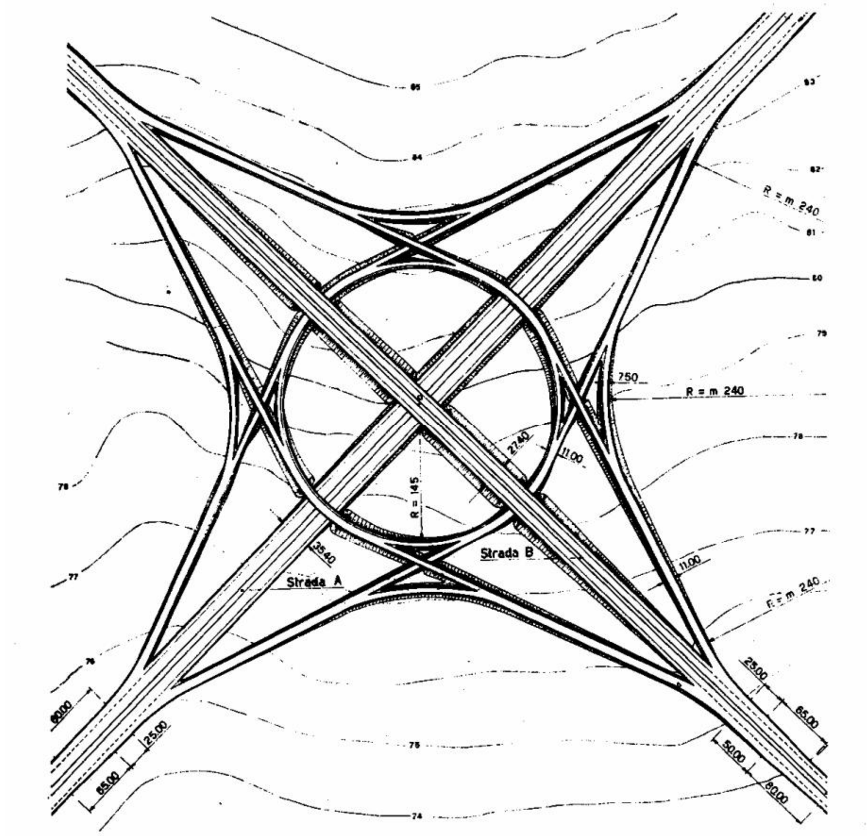

Fig. 52 – Roundabout junction

The junction called Croce di Malta, shown in Fig. 53, is very compact in plan but has a high development in height. It constitutes an excellent solution in terms of efficiency and safety with exits and entrances always on the right and with left turns obtained with ramps.

Semi-direct, very limited in length; with high throughputs (which, combined with an absolute lack of space, may justify this type of interchange), the initial and final sections, for exits and entrances, respectively, should be designed with two lanes. As shown in the figure, interference is eliminated by means of altimetric staggering, and therefore the interchange extends over four levels, reaching height differences of about 20 m between the outermost road levels. This requires careful study of the altimetric profiles and the overpass works, which, in addition to purely structural aspects, would require a certain architectural value. The strong visual impact and high cost are, in fact, the objections to this inte

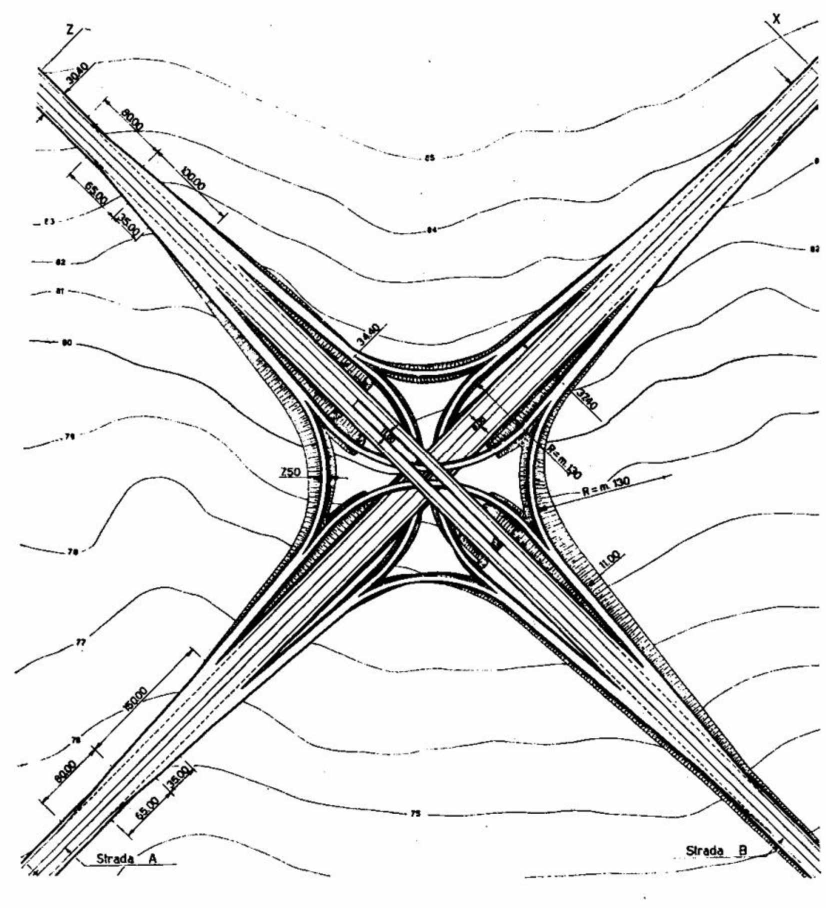

Fig. 53 – Four-level junction (Maltese Cross)

Finally, Fig. 54 shows the complete directional interchange, where all turns are made via direct ramps and are therefore intuitive and require minimal travel. However, some significant drawbacks should be noted: the high cost of both the overpasses (sixteen structures of varying spans and widths are required) is compounded by the need to space the carriageways so that the left-hand ramps overpass (or underpass) the oncoming carriageway. Furthermore, the left-hand exits and merges, i.e., into the express lane, raise concerns about the safety of this type of interchange.

Local situations and needs may lead the designer to study non-canonical solutions to be examined on a case-by-case basis.

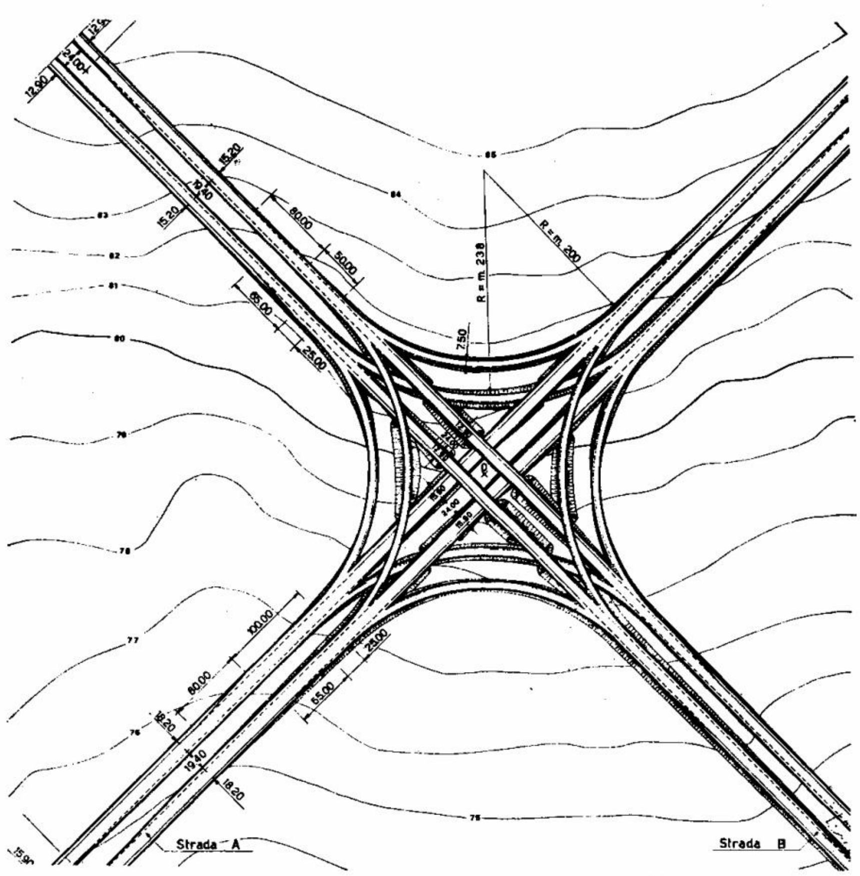

Fig. 54 – Complete directional junction

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