Coordination of Basic Intersection Design Elements: An Overview

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The complexity of intersection design can vary from that of a simple rural location to a major intersection in a dense urban setting. However, even with the simplest location, many conflicting requirements must be balanced against each other to produce a safe and efficient design. Intersections are intended to operate where vehicles often must share space with other vehicles and pedestrians. Negotiating an intersection requires many simultaneous or closely spaced decisions, such as selection of the proper lane; maneuvering to get into the proper position; need to decelerate, stop, or accelerate; and need to select a safe gap. Five basic areas should be reviewed in conjunction with these decisions to produce a satisfactory design: intersection angle; coordination of the vertical profiles of the intersecting roads; coordination of horizontal and vertical alignment for intersections on curves; improvement of operation, safety, and capacity through channelization; and drainage requirements for safe operation. Not only must the horizontal layout be carefully thought out, but the coordination of the vertical and horizontal alignment should be given more emphasis. Poor integration of these two elements often results in an intersection that is less safe and uncomfortable to use. A number of features are discussed that could be used to improve the design. With the proper coordination, the intersection will give the user a safe, comfortable, easy-to-follow layout that allows for the limitations of the people using the facility while supplying an adequate level of service in an economical manner.

The complexity of intersection design can vary from that of a simple rural location to a major intersection in a dense urban setting. However, even with the simplest location, many conflicting requirements must be balanced against each other to produce a safe and efficient design.

The basic elements that must be taken into consideration fall into four categories: human factors, traffic considerations, physical elements, and economic factors. Human factors include driving habits, ability to make decisions, driver expectancy, decision and reaction time, conformance to natural paths of movement, and pedestrian use and habits. Traffic considerations include capacity, volumes, size and mix of vehicles, variety of movements, vehicle speeds (design speed and operating speed), and safety. Physical elements include character and line of abutting property, horizontal alignment, vertical alignment, available sight distance, intersection angle, conflict area, geometrics, traffic control devices, lighting, safety features, bicycle traffic, environmental impact, and drainage requirements. Economic factors include costs of improvements, effects on adjacent property (businesses) (i.e., raised median access, etc.), and impact on energy.

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Many of these factors have been studied over the years and require further study. This paper provides an overview of the basic intersection design elements.

The essence of good intersection design requires that the physical elements be designed to minimize the potential conflicts among cars, trucks, buses, bicycles, and pedestrians. In addition, the human factors of the drivers and pedestrians must be taken into account while keeping the costs and impacts to reasonable levels.

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The horizontal aspects of intersection design have received a great deal of attention, whereas the vertical elements have been reviewed to a much lesser extent. This paper explores the coordination of these two basic elements in such a way that the human factors, traffic considerations, and economics are integrated into the design. This will produce an intersection that is safe, comfortable, and convenient for all users while providing an adequate level of service.

Five basic areas should be reviewed in conjunction with the above to produce a satisfactory design: intersection angle; coordination of the vertical profiles of the intersecting roads; coordination of horizontal and vertical alignment for intersections on curves; improvement of operation, safety, and capacity through channelization; and drainage requirements for safe operation.

The author was involved in developing many of the figures used in the Transportation Association of Canada's *Manual of Geometric Design Standards* (*1*). A number of these have been modified and used below to illustrate the various overview features in this paper.

INTERSECTION ANGLE

Figure 1A shows a simple 90-degree angle and a skewed angle intersection. The 90-degree angle provides the best operation. However, this is not always possible to achieve, and the designer has to then deal with the skewed angle.

As the angle varies from 90 degrees, a number of problems arise:

1. The area of conflict increases, as shown in Figure 1B.
2. Visibility is limited—drivers entering the intersection have difficulty seeing approaching traffic. When trucks turn

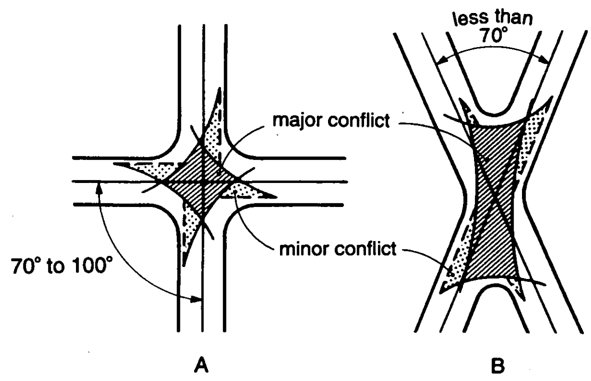

FIGURE 1 (A) Right- and (B) acute/obtuse-angle intersections.

through an obtuse angle, the driver may have a blind area to the right of the vehicle.

3. Larger turning roadway areas are required for trucks (*2,3*).
4. The exposure time through the intersection is increased. This is most critical for trucks due to their slower acceleration and for pedestrians who are unable to walk quickly.

All of this increases the potential for accidents.

AASHTO (*4*) indicates intersection angles of between 60 and 120 degrees, whereas the Canadian Transportation Association's manual (*1*) limits this to 70 to 110 degrees. Every attempt should be made to keep the angle as close as possible to 90 degrees. However, where costly or severe constraints occur, angles as low as 60 degrees are acceptable. New construction should not include skewed angles less than 60 degrees without special design and control features to mitigate the effects of the skew. These may include positive traffic control such as stop, or traffic signals. Adequate corner sight distance and extra pavement area for trucks to maneuver so that they can see oncoming traffic would have to be ensured.

IMPROVEMENT OF OPERATION THROUGH REALIGNMENT OF THE MINOR ROAD

Figures 2A to 2D show realignments to improve the skew angle and the operation through the intersection. The selection of the appropriate type of treatment will depend on adjacent property restrictions. Sufficient decision and stopping sight distance, in accordance with AASHTO (*4*), should be maintained, with special attention if the intersection is on a vertical curve. Care should also be taken to avoid too short a radius on road curves approaching the main road. The radii of these curves will depend on the design speed of the approach roadway. The first curve should be flatter than the second to provide the driver with a safe speed transition. Advance warning signs may be needed to alert the motorist, who may not anticipate the change in direction.

Where realignment as shown in Figures 2A and 2B is not possible, it may be necessary to use offset intersections.

Figure 2C shows an undesirable offset solution. Traffic must turn left off the main road a short distance after entering it. If it is necessary to use this arrangement, a left-turn bay, with

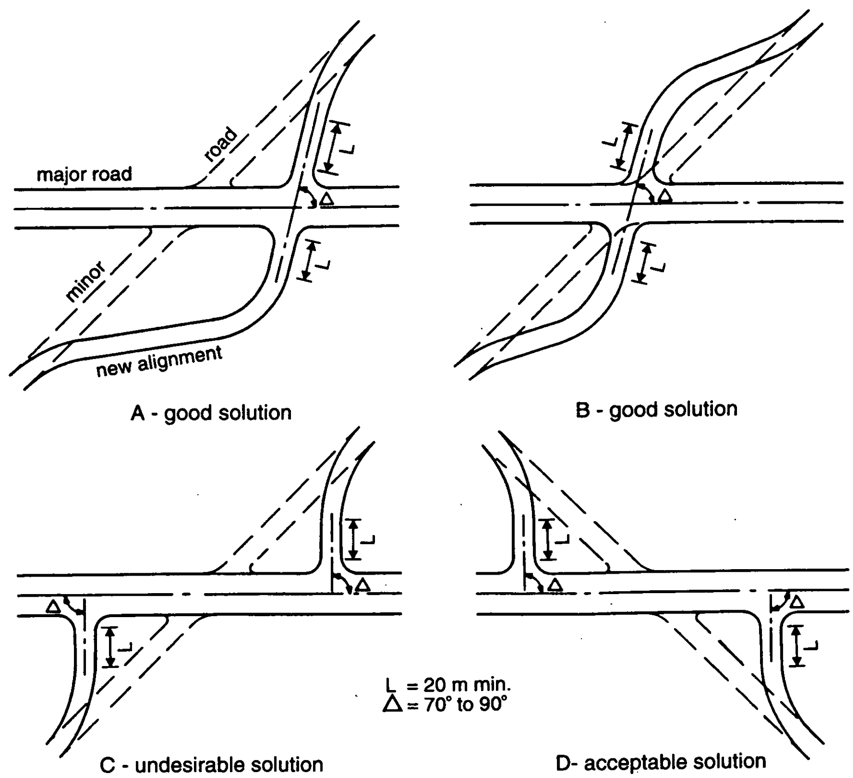

FIGURE 2 Realigned intersections.

provisions for the main road to safely bypass the left turning vehicle, should be included in the design.

Figure 2D shows an acceptable solution because it allows for a left turn onto the main road and then a right off the main road. It would also be desirable to provide a right-turn lane to reduce the conflict between the slow-moving right-turn vehicles and the high-speed through traffic on the main road.

Figures 2C and 2D are mostly applicable to rural situations. There will also be cases in which existing jogs in the urban street system will have to be eliminated to reduce congestion. In this case traffic signals would provide the control needed for the flat intersection angle.

COORDINATION OF VERTICAL PROFILES THROUGH INTERSECTIONS (BOTH ROADS ON TANGENT)

In many instances, the crown of the main road is carried through the intersection, forcing the minor road traffic to drive over the crown as shown in Figure 3A. Where the two roads are on relatively flat grades, this may be acceptable. However, in areas where traffic does not have to stop or when traffic signals are used, the minor traffic has a tendency to go over the hump at higher speeds, which increases the accident potential.

This problem is accentuated when the cross road is on a grade, as shown in Figure 3A. Here the minor road profile has been adjusted to fit the crown of the mainline. This is not a particularly good solution because it requires careful design of the sag curves to ensure that the passage over the crown is not hazardous if driven too quickly. If proper K values, adequate vertical curve lengths, and tangents are used, it will operate reasonably well. This design usually results in a costly solution. A more desirable alternative is the design shown in Figure 3B. It provides a much smoother profile. Here the major road has a reverse crown, so that it slopes in the same direction as the minor road. This will not affect the operation on the major road, but it will take the roller coaster effect out of the minor road profile. This is also a more economical solution and, with careful design, it will fit most situations.

COORDINATION OF HORIZONTAL AND VERTICAL ALIGNMENT FOR INTERSECTIONS ON CURVES

Intersections on curves should be avoided because sight distance is often restricted and turning traffic has to deal with the superelevation. Where possible, the minor road should be realigned to intersect beyond the curve. When it is necessary to have an intersection on a curve, there are a number of ways to address the problem. Figure 4A shows the easiest situation, where the grade of one road is in the same direction as the superelevation of the cross street. In this case, joining the two profiles is relatively easy.

What happens when the grade and superelevation are reversed? This often results in a roller coaster grade (Figure 4B), which can again cause operational and safety problems. K values and tangent distances on each side of the intersection as shown in Figure 4B have to be chosen to provide a smooth

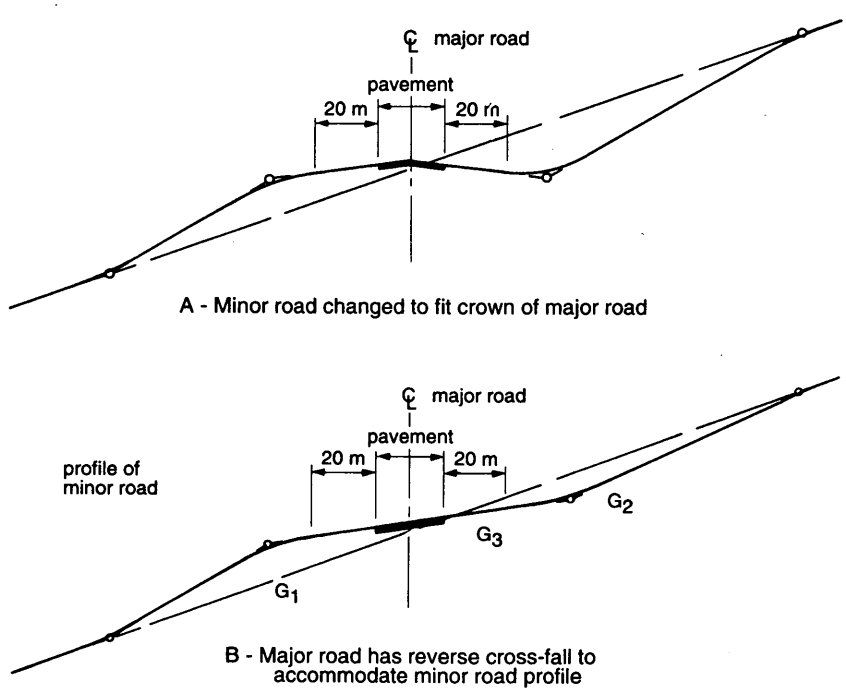

FIGURE 3 Coordination of vertical profiles through intersections on tangent.

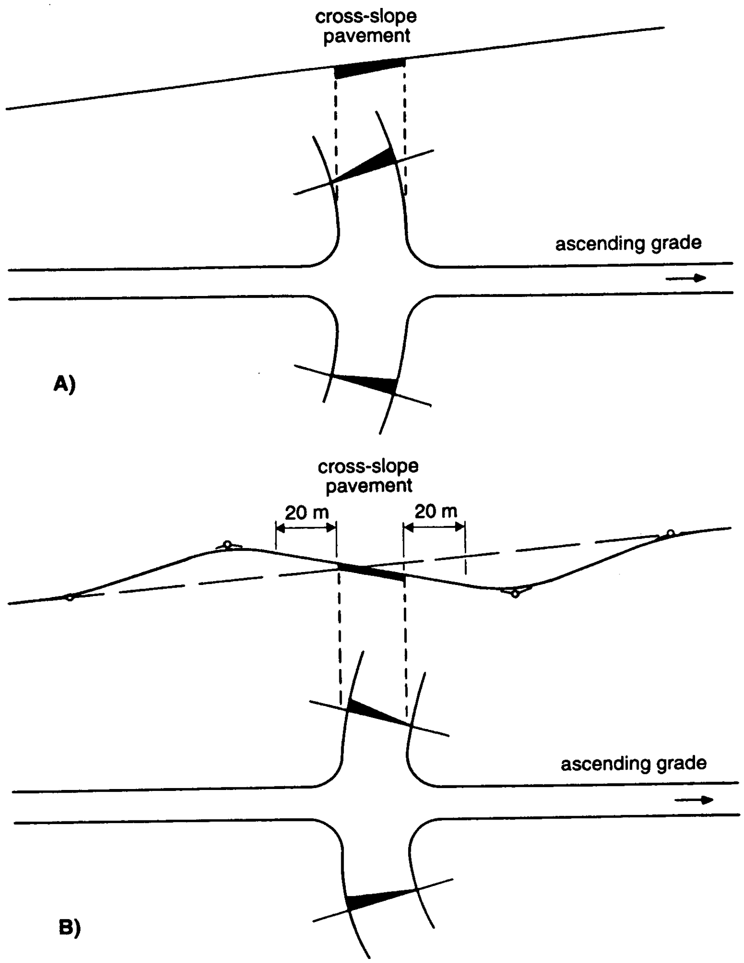

FIGURE 4 Coordination of horizontal and vertical alignments on curves.

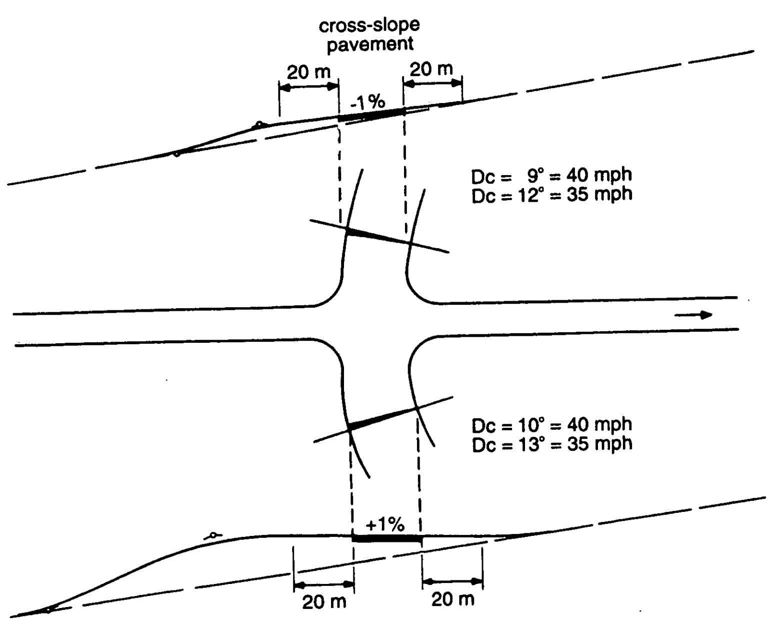

FIGURE 5 Combining horizontal and vertical design.

design. This may not always be possible due to physical limitations of the site.

This is an area where more care is needed to coordinate the horizontal and vertical alignment. The vertical alignment can be improved on the cross street if less superelevation is used on the curve. Two possible solutions are shown in Figure 5. In the lower diagram the superelevation has been reduced to +1 percent and in the upper to −1 percent. This can only be done if the degree of curve, the design speed, and resulting side friction factor allow it.

In urban settings, speeds are lower, and drivers are interrupted by traffic signals and will accept a higher level of side friction than in rural areas. AASHTO has provided friction factors for intersection design for speeds from 30 to 40 mph. Using these values in conjunction with varying superelevation rates, a series of curves for various design speeds can be used as shown in Figure 6.

For the example shown in heavy dashed lines in Figure 6, the 200-m-radius (approximately 9-degree) curve results in a 70-km/hr (43-mph) design speed with a superelevation of 2.3 percent.

By comparing Figures 4 and 5, the improvements to the grade on the cross street can readily be seen. Figure 6 is very useful for intersection design in urban areas, where drivers are willing to accept a higher side friction factor. In this case, Method 2 of AASHTO (*4*) is being used where side friction is used before superelevation. These curves are not recommended for rural situations, where speeds are much higher and drivers will not accept the higher friction factors.

IMPROVEMENT OF OPERATIONS SAFETY AND CAPACITY THROUGH CHANNELIZATION

The *Intersection Channelization Design Guide* (*5*) provides a complete analysis and description of good channelization design practice. Figures 7 to 9 show, in incremental steps, some of the features and advantages of channelization. Each layout, starting with a simple turn bay of Figure 7A, provides increased capacity, ease of operation, and safety. Channelization must be easy and natural to follow. Too many islands, or islands improperly placed, cause confusion. Each of these designs is simple and easy to follow. Selecting a particular design for any location will depend on the space available and conditions present at the intersection. Considerations for pedestrians, bicycles, bus stops, and truck types will also affect the final layout.

Intersections on rural roads can often be very hazardous, especially if there are a significant number of left turns. If no provision has been made for a left-turn bay, the through traffic has to stop. Even if there is adequate sight distance, rear-end collisions will occur. The simple flush (i.e., no curbs) left-turn layout shown in Figure 7A improves the safety aspects and operation because it provides a bypass lane for the high-speed through traffic and thus reduces the number and severity of rear-end accidents. The through traffic does not have to slow down or stop for the left-turn vehicle.

The left-turn bay shown in Figure 7A is offset from the centerline and therefore is not in line with the left-turn traffic approaching from the opposite direction. The bay for the

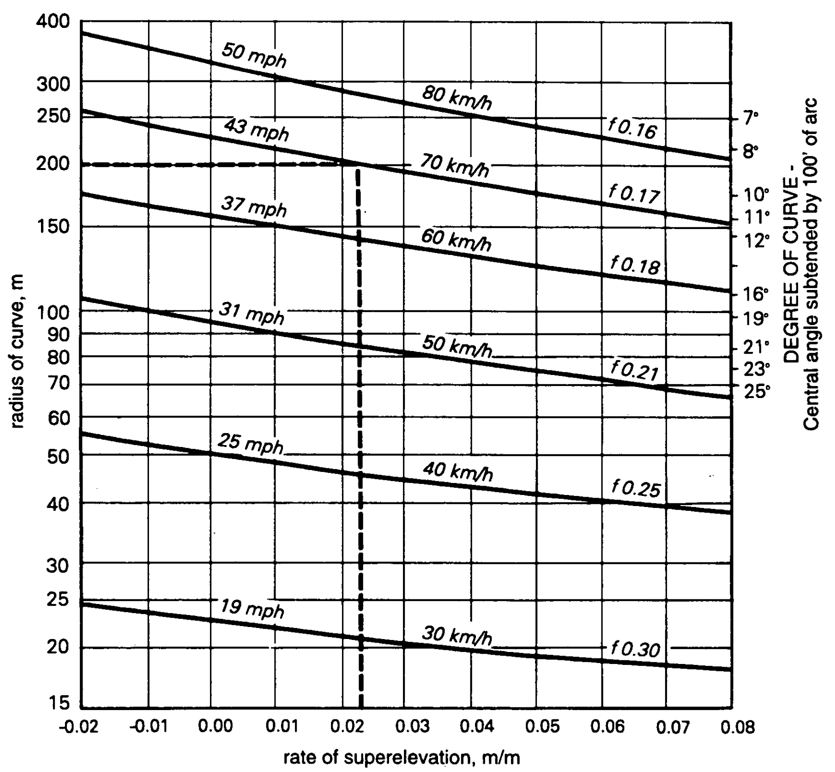

FIGURE 6 Relationship of speed, radius, and superelevations at urban intersections.

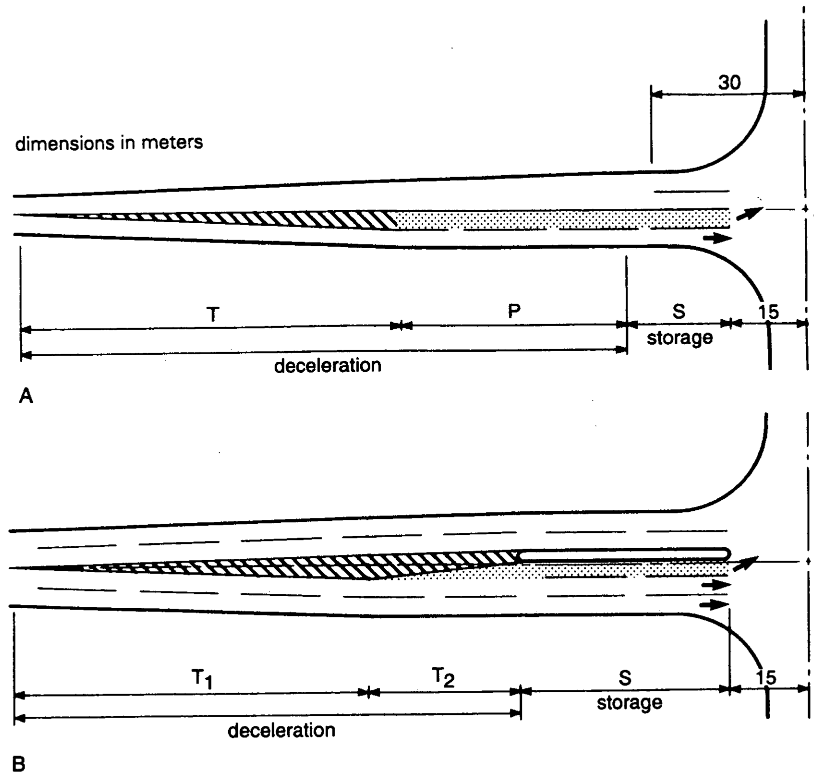

FIGURE 7 (A) Introduced flush left-turn lane and (B) left-turn lane, introduced raised median.

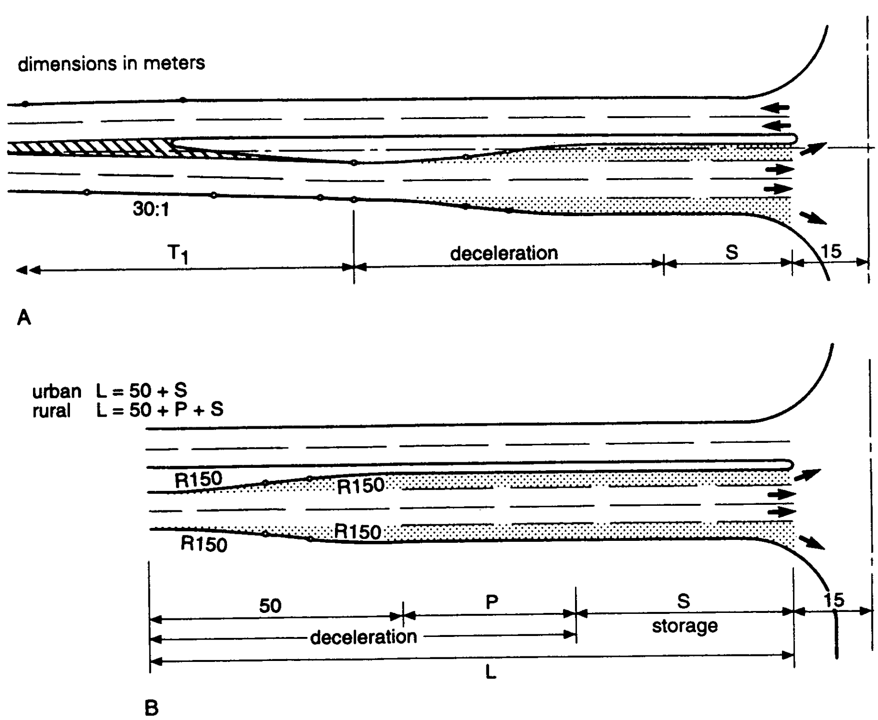

FIGURE 8 (A) Turning lane design, introduced median, and (B) continuous raised median.

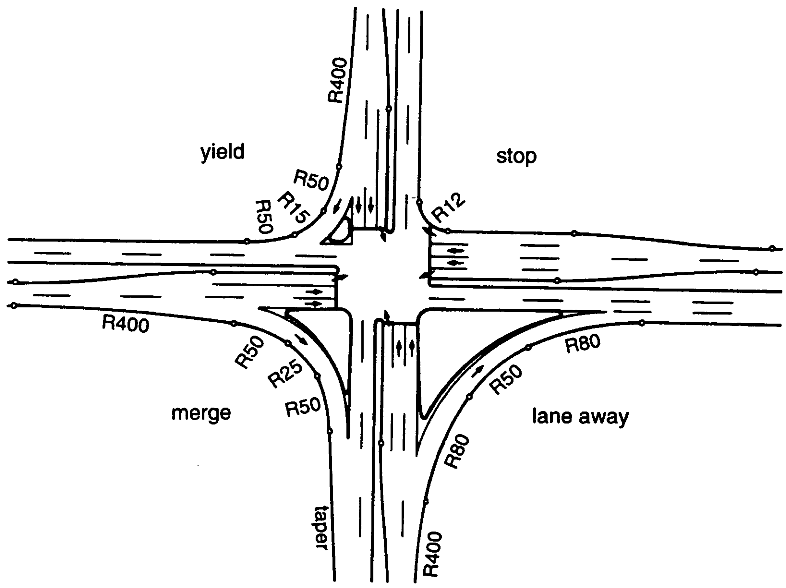

FIGURE 9 Typical right-turn lane channelization.

other direction is also offset from the centerline, which provides for safer operation. In some urban situations where space is restricted, the left-turn bays may not be offset but simply lined up with each other. This is an acceptable practice where speeds are lower and drivers are used to more constricted operations. However, wherever possible, the offset should be maintained because it provides for freer and safer flow of traffic. The layout allows for a deceleration distance made up of a taper (t) to shift the through traffic to the right and a parallel p distance or extension of the bay to safely complete the deceleration. After this, a space is left for storage.

Although Figure 7A is used in many rural situations, it does not provide any protection for the left-turning traffic. Figure 7B shows a more pronounced taper where the left turn is somewhat protected by the taper. In this case, all traffic is first shifted to the right and left-turn traffic has to shift back to the left, while the through continues on. Tapers for deceleration and storage lengths are provided in the design. The short raised median provides more guidance and protection for the left-turn vehicles. Some jurisdictions prefer this design because the raised portion of the median is offset from the main traffic flow and reduces the possibility of hitting the raised median. However, it does not completely protect the left-turning vehicle.

Figure 8A shows a full introduced median with both left- and right-turn lanes. Smooth tapered transitions have been provided for efficient traffic flow. This design gives more positive direction to vehicles, resulting in protection for left and right turns and smoother flow.

Figure 8B is basically the same as Figure 8A except that the median is continuous.

Four typical right-turn island layouts are shown in Figure 9.

- The top right corner has a simple radius and a stop condition.
- Top left shows a yield condition with a minimum three centered curve, which minimizes the property required while providing a turning path convenient for trucks. The 15-m (50-ft) radius assures that the entry angle will provide good sight distance, and if there is no traffic coming, vehicles will be able to commence accelerating on the curve with 50-m (150-ft) radius.
- The bottom left shows a tapered exit followed by an entrance merge.
- The bottom right has a tapered exit and a lane away (exclusive entering lane) at the entrance.

Both of these layouts provide for progressively higher right-turn volumes.

DRAINAGE

One of the most important features of intersection design is to ensure that proper drainage has been provided. This is especially true of channelized intersections on grades and curves. The designer must balance the horizontal and vertical alignment while making sure that no excess water gathers on the pavement surface, which could cause hydroplaning.

This requires careful design of pavement edge profiles by integrating the left- and right-turn islands with the horizontal and vertical curvature and grades. In doing this, the following points should be checked.

- Minimum grades on curb and gutter sections should be 0.5 percent.
- Additional catch basins should be placed in low areas to eliminate ponding.
- Cross-fall on each pavement surface should be checked through the transition areas from one superelevation to another to make sure that flat sections are kept to a minimum.

Minimum cross-fall of 2 percent is desirable to keep water from accumulating.

- The grades and cross-falls of both intersecting roads along with their right-turn lanes should be smoothly transitioned into each, allowing for all the preceding factors. This will often require that pavement edges be splined to effect a smooth profile. (Calculated grades will often give an uneven profile of the pavement edge. These can be smoothed with the use of a long plastic spline that is held down by weights. The spline passes above and below, close to calculated points, thus providing an even curved line. The elevations are then scaled off the large-scale profile.)
- When the cross section of the intersection is checked in both directions, it must provide a smooth path. There should be no surprises such as uneven operation caused by bumps or erratic changes in cross-fall.

Figures 10 to 14 are pictures of some existing intersections that illustrate the basic elements discussed above.

Figure 10 shows an intersection that has been placed just before the beginning of a horizontal curve. The superelevation

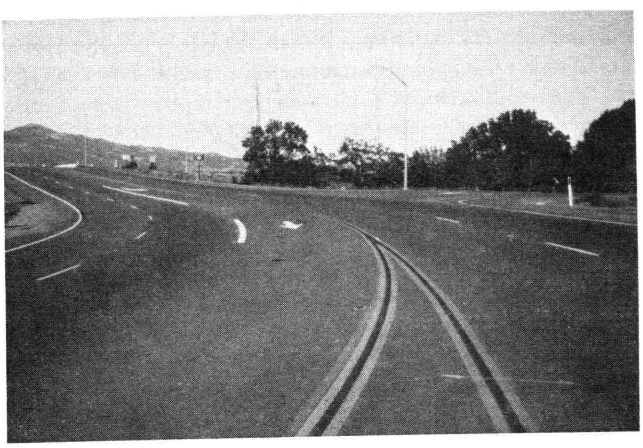

FIGURE 10 **Intersection at beginning of horizontal curve.**

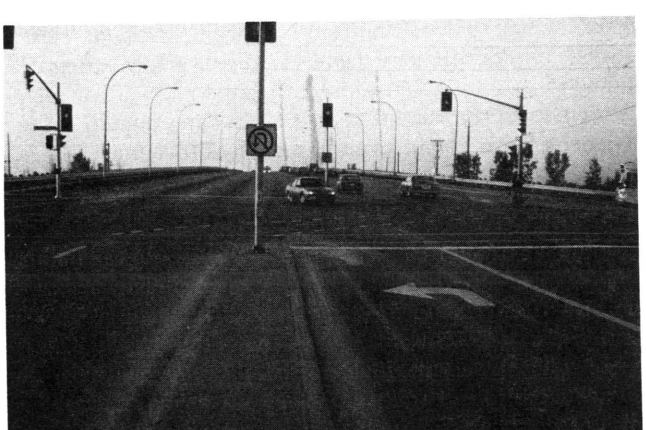

FIGURE 11 **Mainline grade carried through the intersection.**

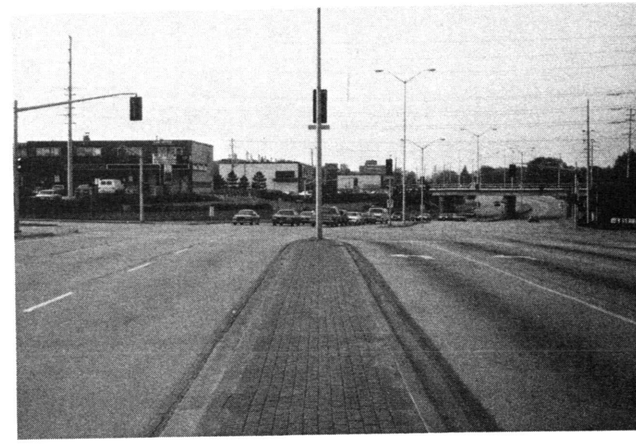

FIGURE 12 **Major arterials intersecting on grades, looking northbound.**

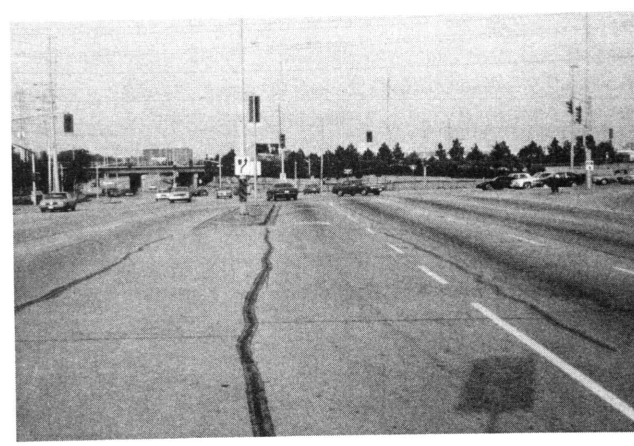

FIGURE 13 **Major arterials intersecting on grades, looking eastbound.**

FIGURE 14 **Royal Avenue and 6th Street—roller coaster.**

runoff has been taken through the intersection, and the cross street easily matches it. The flush left-turn lane bay is essential, because the intersection is placed just beyond a crest curve. Any vehicles waiting to make a left turn could create a hazardous condition for through traffic if the bay were not there.

Figure 11 provides an example of where the grade of the main road has been carried through the intersection. The grade is approximately 4 percent. The design provides a continuous grade through the intersection for both the major arterial and the cross street. The cross street is tilted to meet the grade of the main road. This location is in the snow belt, and the only movement that may have some trouble is the left turn against the grade in icy conditions. Because there are no abrupt changes in the grades lines, the whole intersection is smoothly developed and operates very well. Drainage patterns are also very good.

Figures 12 and 13 provide an example of two arterial streets intersecting on different grades and partially on horizontal curves. This intersection design was part of the need to grade-separate a main rail line, which crosses both streets very close to the intersections. The final layout had to allow for the closeness of the two grade separations while integrating all of the design elements (coordination of horizontal and vertical alignment, consideration of superelevation cross-fall through the intersection to allow for all directions of travel, minimum curb and gutter grades, and extra catch basins at low points to eliminate ponding and possible hydroplaning). Besides meeting these requirements, the fully channelized high-capacity intersection provides safe, convenient, and efficient operation.

Figure 14 has a roller coaster design, which could have been avoided with a little more care in the vertical design. The cross street's crown has been partially maintained, which has caused a dip on the through street as shown in the photograph. It would have required some special treatment on the lower side of the cross arterial to maintain the cross-fall, but it could have been achieved. Presently any driver approaching this intersection at more than 20 mph experiences discomfort. This type of operation is unsatisfactory for alert drivers, but for others it is a hazard. This intersection does not allow for human factors.

SUMMARY

The main factors that must be coordinated in intersection design were highlighted. Not only must the horizontal layout be carefully thought out, but the coordination of the vertical and horizontal alignment should be given more emphasis. Poor integration of these two elements often results in an intersection that is uncomfortable and less safe to use. A number of features have been discussed that could be used to improve the design. With the proper coordination, the intersection will give the user a safe, comfortable, easy-to-follow layout that allows for the limitations of the people using the facility while supplying an adequate level of service in an economical manner.

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