PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 13, NO. 5 ▽ JULY, 1932

ON THE MOUNT VERNON MEMORIAL HIGHWAY

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 13, No. 5 July, 1932

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to the described conditions.

In This Issue

THE BUREAU OF PUBLIC ROADS - - - - Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS - - - - - - - - - Mark Sheldon Building, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, P. O. Box 3900, Portland, Oreg.

DISTRICT No. 2. California, Arizona Nevada, and Hawaii.
Mark Sheldon Building, 461 Market St., San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
237 Custom House, Nineteenth and Stout Sts., Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
410 Hamm Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
Eighth Floor, Saunders-Kennedy Building, Omaha, Nebr.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
1912 Fort Worth National Bank Building, Fort Worth, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida Mississippi, South Carolina, and Tennessee.
Shepherd Building, P. O. Box J, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N. Y.

DISTRICT No. 10. Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D. C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
403 Fred J. Kiesel Building, Ogden, Utah.

Owing to the necessarily limited edition of this publication it will be impossible to distribute it free to any persons or institutions other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. Others desiring to obtain PUBLIC ROADS can do so by sending $1 per year (foreign subscription $1.50) to the Superintendent of Documents, United States Government Printing Office, Washington, D. C.

THE DESIGN OF STREET AND HIGHWAY INTERSECTIONS

By L. S. TUTTLE and E. H. HOLMES, Assistant Highway Economists, United States Bureau of Public Roads [a]

TWO general methods of solving the problems and difficulties created by the increase in volume and speed of traffic have been developed. One method of control regulates traffic movement by such artificial means as driving rules, city ordinances, traffic officers, or signal devices, while the other seeks to minimize the necessity of artificial restrictive measures through the physical design of streets and highways for the free flow of traffic.

This paper deals with two classes of intersections, those where traffic volume necessitates regulation and those where faulty design requires it. It is proposed to show how in certain instances intersections may be developed which will obviate all control devices and rely solely upon the physical construction of the various details to induce drivers to take the proper course voluntarily, to give preference to the major traffic without too severely penalizing the minor traffic, and, when some control device is absolutely necessary, to facilitate its operation by the proper physical design.

INCREASED EFFICIENCY FOR EXISTING INTERSECTIONS THROUGH MINOR CHANGES IN PHYSICAL LAYOUT

Curb radii.—A detail warranting most careful consideration in intersection design is the radius of the curves rounding off the curbs of the intersecting streets. Cutting back the curbs at existing intersections to facilitate the right turn movement is a simple and effective device for increasing intersection efficiency, particularly where the percentage of right turns is large.

A proper curb radius is one which can be followed by the vehicle having the largest normal inside turning radius. The largest radius which will be required for any but an exceptional passenger car is under 25 feet, but various types of trucks and busses have larger inside turning radii. It should not be necessary to provide for an occasional vehicle having a 40-foot turning radius, but it is absolutely necessary for efficient intersection operation that the radius be sufficient to allow the normal vehicle to follow the curb in turning and, for this reason, a curb radius of 30 feet is recommended as a minimum for highway intersections and is incorporated in all the designs presented.

For street intersections this rule applies only when the vehicle making the turn approaches in the outside lane of the roadway. Such would not be the case if parking were permitted along the intersecting streets and, while a 30-foot radius would be entirely satisfactory from the traffic viewpoint in this case, it may unnecessarily restrict sidewalk area. In this instance the proper turning radius depends not only on the vehicular requirements, but also on the sidewalk width and parking restrictions. If parking is restricted for a distance back of the intersection to allow another lane of traffic to collect while waiting for a signal, then the radius should be the same as for an open highway intersection, but in the case of the intersection of minor streets where there is no control and consequently no accumulated stoppage, parking should not be restricted so severely and so a design for curb rounding as shown in Figure 1 should be developed.

The above discussion concerns only the minimum turning radius of vehicles and results in a turn which restricts the speed to approximately 12 miles per hour. Obviously, in the case of an outlying intersection where land is available, it would be desirable to increase this turning radius to some figure which would permit higher speeds. This step becomes important at heavily traveled intersections. If the speed which would be maintained provided there were no turning traffic is 20 miles per hour and the radius of the curb of the intersection is such that only 12 miles per hour can be maintained in the turning, turning traffic will unnecessarily retard through traffic, materially reducing the capacity of the intersection. Therefore, it is advisable to design the turning radius to accommodate the same speed which would be maintained by traffic moving straight through the intersection, except where a heavy pedestrian movement will control the turning speed.

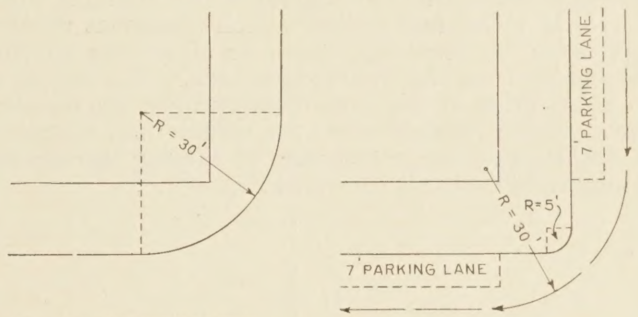


FIGURE 1.—DESIGN OF SHORT-RADIUS CURB

The speed which will be maintained around a curve will vary with the individual driver, but usually will not exceed that at which passengers begin to feel discomfort. This discomfort results from the effort to maintain an erect position in overcoming the centrifugal force resulting from the deflection from a straight course.

In order to determine the uncomfortable rate of deflection a series of test runs were made around curves of various radii in a coupé and also in a sedan, both in the lower price range. When it became necessary for the occupants to exert a distinct effort to remain erect, a speedometer reading was taken. While this method was rough, the observed speeds plotted against the radii gave a remarkably smooth curve, the two cars showing close agreement. Theorectically the curve should be a parabola since the centrifugal force varies as the square of the speed. A parabola was accordingly fitted to the data by the method of least squares, resulting in the following formula:

$$R = 0.22\ V^2$$

where R is the radius of curvature in feet and V is the speed in miles per hour. The comfortable rate of deflection as computed from this formula is 9.7 feet per second per second, and the tendency to skid is 0.3 the weight of the vehicle, which would be generally accepted

[a] Digested from a thesis prepared for the masters' degree at Albert Russel Erskine Bureau for Street Traffic Research, Harvard University.

as a safe condition. Computed comfortable speeds for various radii of curvature are given in Table 1.

It is obvious that higher speeds may be maintained with safety, and, if the curve is followed for only a short distance, without particular discomfort.

TABLE 1.—*Comfortable driving speeds for various radii of curvature*

Radius	Speed	Radius	Speed	Radius	Speed
Feet	*Miles per hour*	*Feet*	*Miles per hour*	*Feet*	*Miles per hour*
20	10	200	30	600	52
30	12	250	34	700	56
50	15	300	37	800	60
100	21	400	43		
150	26	500	48		

Splayed intersections.—Closely related to the improvement of curb radii is the practice of splaying or widening the roadways at the intersection. This device has been used in many places. Successful examples are found in Cook County, Ill. and in Reno County, Kans. The Illinois design provides an additional lane on either side of the pavement for a distance of 300 feet from the intersection. The Kansas design eliminates the intersection altogether for turning traffic by providing turning roads of 200 foot radius. Such treatment reduces congestion by removing much or all of the turning movement from the intersection area. The design of an intersection of this type depends upon the locality, the available right of way, the volume and character of traffic, and the percentage of turning movement. A suggested design is shown in Figure 2.

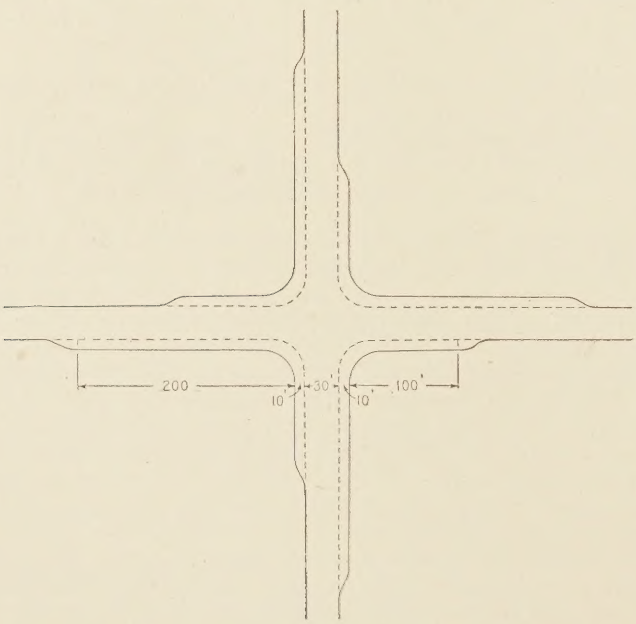


FIGURE 2.—INTERSECTION OF TWO 30-FOOT ROADWAYS SPLAYED FOR TURNING

At heavily traveled intersections where control methods result in considerable stoppage, splaying may prove advantageous to through traffic as well as to turning traffic, by permitting the accumulation of vehicles in a greater number of lanes, with a resultant shortening of the waiting lines. Before splaying an intersection for this purpose, care must be taken that the greater number of lanes may be accommodated beyond the intersection to such a point that the vehicles may resume their travel in the normal number of lanes. Each additional lane of width increases the pedestrian hazard, and necessitates a longer clearance period in the control device.

Islands.—To facilitate movement and to prevent confusion, islands may be installed within the intersection or in the entering streets. This is especially helpful when splaying or wide streets result in an intersection of extensive area.

Medial strips are useful where it is desirable to separate opposing traffic movements and at the intersection of wide routes where proper alignment on either side of the cross streets is difficult. The width should be at least 4 feet and should be varied to such an extent that the area remaining on either side can be divided into 10-foot traffic lanes, with the possibility of one 7 or 8 foot parking lane. The construction may be concrete or a curb-inclosed grassed or planted area. In any case, the curb height should be from 8 to 10 inches and the end confronting traffic amply protected at night by a flashing or reflecting beacon.

Directional islands are normally located in the throats of the streets composing the intersection and their size and shape must be very carefully considered in order that they will assist rather than hinder the flow of traffic through the intersection. They are normally placed in a dead area and are shaped according to the desired flow of traffic. The islands should extend into the throats of the entering streets for such a distance that there can be no mistake as to the route to be followed and, in case the islands are to be used for pedestrian safety zones, they must extend to a point beyond the crosswalk and be amply flood-lighted.

The natural tendency for a driver is to continue in a straight line unless compelled to change his route because of external conditions. Therefore, it is imperative that these islands, intended to align traffic properly, be so designed that the obvious route for a driver to follow as he passes the island is the route which will bring about the most effective operation of the intersection.

Directional islands may often be located nearer the center of the intersection to delimit a neutral area which otherwise would be a point of conflict for several lanes of traffic. The sides of islands of this sort which vehicles are expected to follow in turning must have a radius which fulfills the requirements previously stated under curb radii.

Many times directional islands are located at the center of the intersection to serve merely as a point about which traffic turning left must proceed. In this case, it is not necessary to have a minimum radius as specified above, for the vehicle does not follow the island for any appreciable distance. The island here merely serves to indicate to the driver the route which will least interfere with the opposing traffic. Its location must be such that any vehicle turning about it, presumably to the left, will be able to do so at a convenient turning radius and will not be required to swing out either before or after passing it with consequent fouling of other lines of traffic. It will be noted that the ordinary flashing beacons so often seen at the center of intersections fall under this classification and their location should be determined in the above manner. Applications of this theory are shown in the designs which accompany this article.

ROTARY TRAFFIC

Rotary traffic is here defined as the movement of vehicles around a traffic circle or square in one direction only. Such traffic circles and squares are usually formed by the convergence of several streets. Where the rotary system is in operation, vehicles are required to execute a right turn upon entering the circle, proceed around the circle to the right, interweaving with the traffic already upon the circular roadway and leave at the desired exit by means of a right turn. The circle should be so designed that no vehicle can pass directly through the intersection. In effect this plan creates a circular 1-way street which can be entered or left only by means of a right turn, no left turns being permitted. The rotary traffic plan intends a non-stop flow of traffic although in special cases it has been found necessary to control traffic by officers or lights for the convenience of pedestrians.

The rotary movement of traffic is graphically pictured in Figure 3, a typical design for the right-angled intersection of two 4-lane streets or highways, the paths of the vehicles being indicated by means of arrows. It will be observed that there are four points of conflict, one such point arising about halfway between any two entering streets. The basic theory of the system presupposes that actual conflict will be reduced to a minimum since entering vehicles are forced by the form of the intersection to interweave with the traffic already upon the circular roadway by proceeding in the same direction. The two traffic streams converge and mingle and there is no direct conflict of direction. The flatter the angle of convergence the easier and more efficient is the interweaving process. This angle of convergence bears an inverse relationship to the diameter of the central island, the angle decreasing as the diameter is increased. However, there are factors which limit the size of the central island, such as the amount of land available and the greater inconvenience to the traffic as the length of travel about the circle is increased.

The central island.—The function of the central island is to produce a true rotary movement. For best results, conflicting streams of traffic should converge at an oblique angle and there should be sufficient length of roadway between entering streets for a complete and easy interweaving of vehicles. The shape and size of the central island or obstruction around which traffic is required to pass, therefore, has a marked influence on the efficiency with which traffic is handled. Ordinarily the circular form of central island is desirable as best fulfilling the above conditions, but for intersections of radical design special forms of central island will be required. At a right-angled intersection where the traffic is much heavier on one street than on the other it is usually desirable to give traffic on the major road preference by using an elliptical form of central island, the long axis of the ellipse coinciding with the axis of the major route. By this method the traffic on the major route is given the advantage of easy curves at the intersection and will be able to pass through with greater speed and less delay than traffic crossing the major route. Cross traffic will be forced to slow down considerably and will filter through the main traffic or turn into the main traffic stream when opportunity offers with a minimum of delay to the major traffic.

The size of the central island is a function of the convenient turning radius of vehicles and the length between the entering streets required for the interweaving of vehicles. Where traffic volume is large, this distance should be at least 100 feet for efficient operation although satisfactory results have been obtained where the interweaving distance is considerably less. It has been observed, however, that where less than 100 feet is provided, the speed of movement is considerably reduced as the traffic increases in volume.

The size of the central island from the point of view of the speed which may be maintained through the circle may be determined from Table 1. As mentioned before, this table is conservative and the speeds will vary greatly with the individual driver's idea as to what constitutes a comfortable turning speed; but it does serve as an indication of the possibilities of a design of this sort.

The radius of the central island is not the only factor which controls the speed of vehicles through the rotary intersection. It would appear from Table 1 that a central island with a radius of 400 feet would permit vehicles to pass through at a speed of approximately 40 miles per hour. Such would not be the case in practice. Vehicles would necessarily be retarded by the interweaving of conflicting streams of traffic. Speed studies on several rotary intersections indicate that average speed of vehicles in passing through the intersection is between 15 and 20 miles per hour.

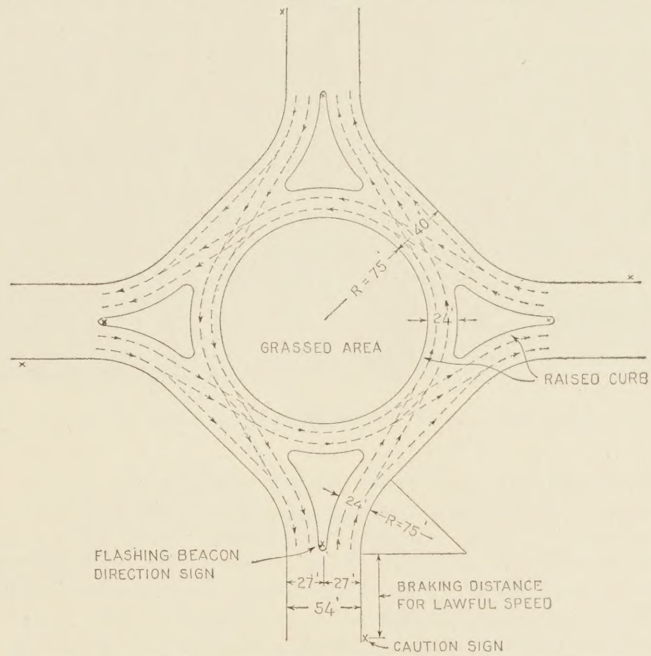


Figure 3.—Recommended Design for Rotary Intersection with Central Island of Minimum Diameter

The traffic studies at Lee Circle, New Orleans, show that during the maximum hour 2,543 vehicles passed through the circle and that the average speed during that time was between 16 and 19 miles per hour. Several observations at the rotary traffic intersection of Old Colony Avenue and Columbia Road, Boston, indicate that the average speed through this circle is between 15 and 20 miles per hour. While the radius of the central island at Lee Circle is 140 feet and the radius at Old Colony Avenue and Columbia Road is only 88 feet, the average speeds of vehicles passing through the intersections are remarkably similar.

Observations at these two intersections and others indicate that an average speed of 15 to 20 miles per hour is safe and that interweaving of traffic can be accomplished at this speed satisfactorily. It is believed that speeds much in excess of 20 miles per hour are dangerous except where the intersection has been designed along the elliptical form to pass traffic upon a major route with a minimum of delay, and where cross traffic is light and turning movement negligible.

Observations of actual intersections indicate that central islands should not be designed with radii of less than 75 feet. At the customary right-angled intersection of two 40-foot roadways, a central island with a radius of 75 feet will allow vehicles to pass around the island comfortably at a speed of about 20 miles per hour and will also give a satisfactory distance between the entering streets for the interweaving of traffic.

Width of rotary driveway.—In an effort to determine a logical theory of design for the width of the rotary driveway, the following formula has been evolved as a basis from which to work. A symmetrical case is assumed, as shown in Figure 4 and all traffic is assumed to pass directly through the circle, making no right or left turns. It is also assumed that traffic streams occupy the same width upon the circular roadway as upon the entering streets. This is believed to be the case in practice. Observations show that there is little or no tendency for vehicles to cut out and pass each other while upon the rotary driveway and it has also been shown that there is little increase in the capacity of a lane of traffic, measured in vehicles per hour, as the speed of vehicles increases above 15 miles per hour. In other words, while a stream of traffic approaching a rotary intersection might be slowed from an average speed of 30 miles per hour to an average speed of 15 miles per hour, the capacity of such a lane would not be materially decreased and there would be no tendency for the traffic stream to become broader.

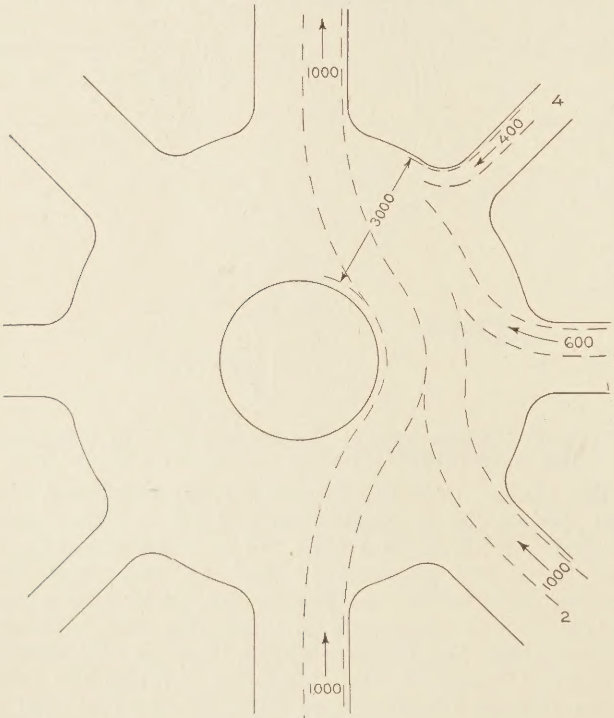


FIGURE 4.—DIAGRAM ILLUSTRATING REQUIRED WIDTH OF ROTARY DRIVEWAY

At any point where the traffic on the circle is of maximum width, as between two successive entering streets, it may be readily proved that this maximum width is the sum of the entering traffic upon one-half of the circle. For example, if we consider one-half of the entering streets in the accompanying diagram, streets Nos. 1, 2, 3, and 4, the width of the traffic stream on the circle just past street No. 4 will be 1,000+1,000+600+400=3,000 cars per hour (here the term "width of traffic stream" is understood to mean the graphic width of the band representing traffic density). If we let t designate traffic density upon the entering streets and T the traffic density upon the circle, the density of the stream at a maximum point upon the circle may be expressed as follows:

$$T=\frac{t_1+t_2+t_3+\text{--------}t_n}{2}$$

As the ultimate capacity of any street is in general determined by the number of traffic lanes upon that street, it seems desirable to express the width of the circular roadway in terms of the total number of traffic lanes on the streets entering the circle. If both entering and leaving lanes of traffic be included, the total must be divided by 4 instead of 2 to hold the same relation, as there are as many lanes entering as leaving the circle. The width of the circular roadway may then be expressed in terms of the total number of traffic lanes as follows:

$$\text{Number of traffic lanes of circular driveway}=\frac{\text{Sum of all traffic lanes of entering streets}}{4}$$

Any such formula must necessarily be modified in practice. In any case, it seems desirable to have at least two traffic lanes upon the circular driveway, one for cars passing through and one for cars making right turns. It is also doubtful if more than six lanes are desirable. Large open spaces tend to confuse drivers and the traffic pattern tends to lose an orderly channelized form. Widths as great as six traffic lanes require lane markers, which are objectionable upon the rotary driveway.

Curb radii.—Curb radii should in all cases correspond as nearly as possible to the radius of the central island. It has been observed that where curb radii are small, traffic tends to make the turn upon entering the circle as broad as is convenient, with the result that vehicles are carried away from the outer edge of the circular drive, and a large percentage of unused pavement results. In Figure 8, F is shown a trafficp attern of the Old Colony Avenue-Columbia Road Circle in Boston. This pattern clearly shows the effect of short curb radii. In this case, approximately 20 per cent of the total area of the circular driveway was never used by traffic.

At this point it may also be pointed out that reverse curves made by curb radii and the outer edge of the circular drive are ignored by traffic. It is much better to follow this traffic tendency in design and to eliminate such reverse curves by making the outer edge of the drive in effect a square or a polygon, as shown in Figure 3.

Directional islands.—Directional islands here refer to obstructions in the throats of the streets entering a traffic circle, the principal purpose of which is to channelize the entering traffic and to direct it into the rotary traffic stream at an oblique angle. The shape of the island should be such that the entering traffic is properly guided in its movement and that no vehicle can break out of line to take an undesired course into the rotor. This effect is best attained by the use of triangular islands, which are naturally formed by the traffic pattern, the base of the island being an arc concentric with the central island and the apex extending well up into the entering street. The photograph of Scott Circle, Washington, D. C. (fig. 5), shows very clearly the dead space at the entrances of the converging streets which traffic does not use and which should determine the shape and position of the islands.

FIGURE 5.—VIEW OF SCOTT CIRCLE, WASHINGTON, D. C., SHOWING AREAS UNUSED BY TRAFFIC AT ENTRANCES OF CONVERGING STREETS

In designing the sides of the islands it is important to bear in mind the basic principle that in so far as is possible the routes followed should be the natural routes of the traffic. The sides should, therefore, be arcs concentric with the curbs of the entering streets and so terminated that traffic entering the circle is released parallel to a tangent to the central island and traffic leaving the circle is not deflected from a straight line course, paralleling a tangent to the central island.

The width of pavement necessary between the base of any one of the directional islands and the central island should not be greater than that required to provide for the expected volume of traffic at that point. In the case of a right-angled intersection of two 4-lane streets or highways carrying an equal volume of traffic, the necessary width is two traffic lanes. In this case, where traffic negotiates a curve of comparatively small radius, it is recommended that 12-foot lanes be provided.

For the sake of appearance and permanency, the directional islands should be constructed of concrete or masonry curbing, inclosing a graveled or sodded area. Where the location of the rotary intersection is such that pedestrian traffic must be provided for, the directional islands will also function as pedestrian safety islands and should be so constructed. The surface of the island should be given a rough finish to insure safe footing and the end of the island farthest away from the intersection should be provided with a concrete buttress or post to protect pedestrians from reckless motorists. The buttress will also serve to support a directional sign.

Signs.—In addition to the directional islands, traffic should be guided in its movement by appropriate signs. Such signs should serve two purposes: First, as a warning to approaching vehicles of the rotor which they are about to enter and the necessity of proceeding with due caution; and, second, as a means of directing traffic movement on the rotor. In existing circles this purpose is usually accomplished by a series of warning signs upon the entering streets and 1-way arrows at appropriate points upon the circle. A logical system of signing is indicated in Figure 3.

Minimum and maximum designs.—In order to illustrate the application of the theories developed in the preceding discussion, two typical designs have been prepared, one suggested as the minimum desirable installation, while the other is intended as an example of the maximum size beyond which no improvement in operation may be gained.

As the rotary installation requires considerably more area than the ordinary intersection, the cost of the extra land will limit the size of the circle at many locations. The design decided upon will be the result of balancing the cost of land against the size necessary for efficient operation.

The design shown in Figure 3 is suggested as the minimum desirable circle for the intersection of two 4-lane highways or streets and should be applied at a location where land values are relatively high and traffic speeds are moderate.

The basic requirement which should determine the minimum size is the distance necessary for easy interweaving of the vehicles and the angles at which converging lanes approach each other. As previously noted, the interweaving distance should not be less than 100 feet for good operation and the angle of convergence should not exceed 30°. In the present design, these requirements are satisfied by a central island 150 feet in diameter as the distance between any two consecutive directional islands is 100 feet and the angle between any two conflicting lanes of traffic is less than 30°.

A central island 150 feet in diameter gives a turning radius of 75 feet and satisfies the minimum conditions for convenient operation, permitting a speed of about 20 miles per hour around the circle.

It will be noted that the curb radii are also 75 feet to correspond with the radius of the central island and that the outer curbs of the circular roadway are straight sections joining the curbs of the entering streets. This facilitates the right turning movement, for the same speed may be maintained when turning right as when proceeding through the circle. There is no tendency to swing out into the traffic upon the circle and all the pavement area is utilized.

The islands in the throats of the entering streets occupy the area which would normally not be used by traffic and are so shaped that they channelize the traffic movement, but in no way interfere with the natural routes. The sides of the islands are circular arcs, 24 feet from and concentric with the curbs of the entering streets, while the base in each case is an arc concentric with the central island and 24 feet from it. This allows for two 12-foot lanes on all sides of the island, the lane width recommended for curves of comparatively small radius. The sides of the islands are so shaped that traffic is released on a tangent to the circle and appropriate warning and directions are provided. As shown in the diagram, the roadway is designed to carry two lanes of traffic on all parts of the circle with provision for four lanes between entering streets.

The diagram of the possible traffic paths would indicate 16 possible conflict points. A condition such as this would probably never exist, even in the heaviest traffic. For illustration, consider the case of a driver going straight through the circle. When there were two lanes moving on the circle, his tendency would be to remain in the outer lane and to head directly for the exit street on passing the central island. If, however, he wished to make a left turn, following around the rotor for 270°, he would in all probability enter the outer lane of traffic and at the first opportunity move into the inner lane next to the rotor, remaining there until he approached the street on which he intended to leave the circle. When an opportunity offered, he would mingle with the vehicles in the outer lane and leave on a tangent as did the first driver.

If the drivers acted as outlined above, which is a reasonable assumption, they would cut only the two lanes of traffic upon the circle and this reduces the number of conflict points to a possible maximum of eight, or one for each lane of traffic. There will ordinarily be but a single line of traffic around the rotor and probably one on each entering street, thus reducing the number of conflict points to four.

Since land values and costs fluctuate widely, there has been no attempt to estimate the cost of constructing the traffic circle illustrated in Figure 3. However, the following comparison of the rotary design with an ordinary intersection is made, 100-foot rights of way being assumed for each of the highways:

Item	Rotary	Ordinary intersection	Excess
	Square yards	*Square yards*	*Square yards*
Grading	6,400	3,600	2,800
Paving	3,716	3,600	116
Island area	2,697	None.	2,697

Approximately 1,800 square yards of land will be required in addition to that included in 100-foot rights of way.

In many cases, where land is less expensive and the acquisition of extra land at the intersection is not an important consideration, the size of the circle may be increased to good advantage. In the design suggested as a minimum, the entering lines of traffic intersect those leaving at the next street at an angle of approximately 30°. As the diameter of the rotor and the curb radii of the entering streets are increased, this angle becomes smaller until at some point the entering and leaving lanes become tangent to the rotary traffic lanes, as shown in Figure 6.

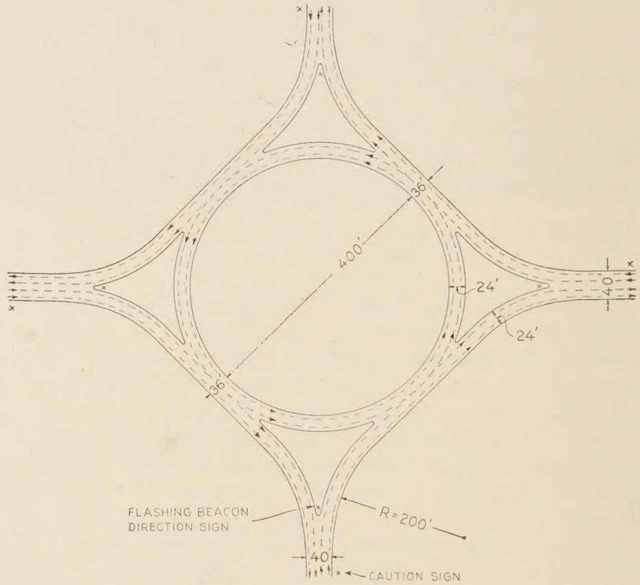


FIGURE 6.—RECOMMENDED DESIGN FOR A ROTARY INTERSECTION WITH CENTRAL ISLAND OF MAXIMUM DIAMETER

It is obvious that any further increase in the diameter of the circle will not result in a corresponding improvement in operation. The entering lanes of one street merely become tangent to the rotary movement before the exit lanes of the next successive street leave it and, in addition, it becomes necessary to introduce the objectionable reverse curve in the outer curb.

The physical features of this circle are designed in accordance with the general principles followed in the design of the minimum circle. The central island and the curbs of the entering streets are of equal radius and the straight outer edge of the circular roadway eliminates the reverse curve in turning right. The islands are designed according to the traffic pattern and since the distance between islands is much greater than is the case of the smaller circle, the roadway width may be less and still permit easy interweaving.

From the standpoint of efficient operation, this circle is the largest that should be used. There is no conflict between entering and leaving lanes and with reasonably skillful driving there should be no conflict of traffic lanes upon the circle. The only reduction of speed is occasioned by vehicles interweaving and jockeying for position. Table 1 indicates that speeds of 30 miles per hour may be maintained on the circular roadway with comfort. A circle of this sort would be rarely installed, but it may be advantageously used at the intersection of two heavily traveled rural highways or at such locations as parkways, civic centers, and the like.

The land required in excess of the 100-foot right of way is approximately 14,500 square yards, and the quantities are as follows:

Item	Circle	Ordinary intersection	Excess
	Square yards	*Square yards*	*Square yards*
Grading	27,800	7,000	20,800
Paving	9,800	7,000	2,800
Island area	18,000	None.	18,000
Curbing	[1] 5,740	[1] 3,120	[1] 2,620

[1] Linear feet

Adaptability of rotary traffic.—In conclusion, it may be well to point out the advantages of the rotary traffic system and to suggest the limiting conditions which will determine the expediency of its application at a particular location. The greatest apparent advantage of rotary traffic is that in theory it presupposes a continuous movement of traffic, direct conflict of vehicles and the troublesome left turn being eliminated by the device of compelling all traffic to proceed in one direction around a circular drive. The system is capable, therefore, of handling a large volume of traffic with little delay.

Another very distinct advantage is the reduction in accident loss. The shape of the true rotary intersection is such that traffic is compelled to slow down and the paths of vehicles do not cross at right angles, but rather converge and interweave. Any accident which occurs, therefore, is the result of a small differential of speed, a following car colliding with a slower vehicle proceeding in the same direction, or side-swiping a vehicle during the interweaving process. Head-on collision, or a right-angled conflict of vehicles, is virtually impossible.

That safety is improved by rotary traffic is evidenced by Table 2, which gives the experience in Los Angeles, Calif., before and after the installation of a traffic circle.

In spite of these obvious advantages there are several disadvantages which seriously restrict the application of rotary traffic in the ideal symmetrical form. The cost of the excess land required is a significant factor where land values are high. It would be economically unsound, for example, to install even the minimum suggested design at intersections in the business district of a city. The cost of excess land at such a location would be so great that it would probably be more economical to construct a grade separation.

A second factor is that of topography. The rotary system is designed for operation on level circles and any attempt to install a rotary intersection on a grade would result in obvious complications. As far as is known, there are no installations where the circle itself is on a grade.

TABLE 2.—*Number of accidents and property damage before and after the installation of a traffic circle in Los Angeles, Calif.*

1922	Intersection at Wilshire Boulevard and Western Avenue: Accidents	Intersection at Wilshire Boulevard and Western Avenue: Property damage	Neighboring right-angled intersection at Wilshire Boulevard and Vermont Avenue: Accidents	Neighboring right-angled intersection at Wilshire Boulevard and Vermont Avenue: Property damage
4 months, before installation of traffic circle	50	$1,491	30	$833
6 months, after installation of traffic circle	32	353	62	1,640

A most important consideration is the character of the traffic. The system operates to greatest advantage when traffic is uniform in character, as a variety in type of traffic seriously reduces its efficiency. It was intended primarily to facilitate motor-vehicle traffic of roughly uniform operating qualities. When, in addition, pedestrian and street car traffic must be provided for, it is necessary to modify the system to a considerable extent.

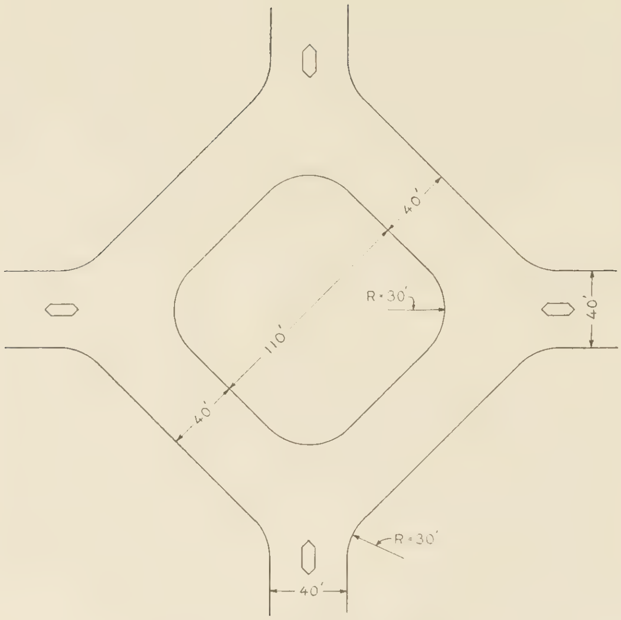
In the usual rotary intersection, vehicular flow is uninterrupted and the pedestrian is at a decided disadvantage. The situation, however, is similar to that at any uncontrolled intersection and unless there is a very large volume of traffic, no particular provision need be made for pedestrians. The auxiliary directional islands serve as convenient refuges and it is suggested that pedestrian crosswalks be laid out to utilize the safety areas thus provided. By using the islands in this manner, the pedestrian crosses no more than two or three lanes of traffic at one time, and encounters vehicles moving in one direction only.

When vehicular traffic is very heavy and when, in addition, there is a large volume of pedestrian traffic, it will be necessary to provide pedestrian subways or to interrupt the vehicular flow occasionally for the convenience of pedestrians. This is easily accomplished by the installation of traffic signals as at an ordinary intersection.

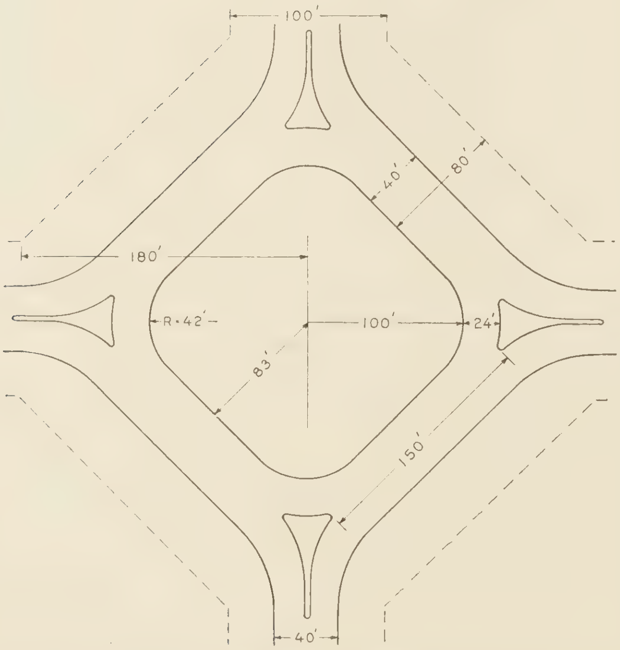
Street cars present a more difficult problem. In a great many instances where the rotary system has been applied to regulate traffic on an existing circle or square, tracks are so located that street cars conflict with the rotary movement of vehicles, the street cars generally proceeding directly across the circle. In periods of light traffic this conflict is not serious, but as the traffic volume increases it becomes necessary to interrupt movement upon the rotary roadway for the passage of street cars.

Square or polygon-shaped central islands.—The use of square or polygon-shaped central islands in the design of rotary intersections reduces the efficiency of the system and any advantages which may be attributed to this type of design are enhanced in the circular design. This particularly is true where the minimum size of rotor is contemplated for a given intersection.

Figure 7 illustrates two types of rotary intersection in which a square central island is used, the island being so designed that the sides of the square are at an angle of 45° to the center lines of the streets forming the intersection. The intersection in each case is a simple right-angled one and the purpose of the designers has evidently been to evolve a rotor requiring a minimum amount of land compatible with efficient operation.



BRITISH ROUNDABOUT DESIGN



COOK COUNTY DESIGN

Figure 7.—Rotary Intersection Designs with Square Central Island

The British design appears in A Report on the Layout of Crossroads, Junctions, and Corners, submitted by the British Ministry of Transport to all road authorities in England. This report was published in full in the The American City for November, 1929, Volume XLI, No. 5, pages 151–154. The design which appears here was recommended for use at the crossing of two roads of equal traffic importance. The Cook County design is included in the report of the Cook County, Ill., Grade Separation Advisory Committee, August 5, 1929.

The greatest apparent advantage of this type of design is that it permits better arrangement of the building lots about the intersection than does the circular form. However, if the outer curbs of the intersection are designed as straight lines, as suggested in Figure 3, rather than as arcs concentric with the circular island, this apparent advantage disappears. There remains only the possible advantage to be gained in a saving of land required by the square design.

Table 3 gives a comparison of the dimensions of the two square designs and the recommended circular design, showing the various areas of pavement and islands required:

Table 3.—*Dimensions of central island and land areas required for British and Cook County designs, as compared with recommended circular design of Figure 3*

Design	Dimensions of central island	Area pavement		Area islands		Area excess land taken	
		Square yards	Per cent[1]	Square yards	Per cent[1]	Square yards	Per cent[2]
British	110 feet square	4, 157	112	1, 281	47. 4	860	47
Cook County	166 feet square	4, 224	113	2, 982	110. 5	2, 300	126
Recommended	150 feet diameter circle	3, 716	100	2, 697	100. 0	1, 820	100

[1] Percentage of recommended design.
[2] Excess area required to be taken based on 100-foot right of way in each case.

In spite of the slight advantage in the amount of land required in the case of the British design, there appear to be several serious objections to the square design from the point of view of traffic efficiency. These objections may be made clear by a detailed discussion of the designs in Figure 7.

The first objection is the necessity of using a very short radius in rounding off the corners of the square island. In the British design, while the square is 110 feet on a side and gives an admirable distance between entering streets for interweaving, the curves rounding off the square have a radius of only 30 feet. This radius is but slightly larger than the minimum turning radius of our longer-wheelbase automobiles. It is obvious that in negotiating this rotor traffic will be compelled to travel very slowly to remain in the channels provided for it or it will maintain a normal rate of speed and avoid the designed channels. At a speed of 15 or 20 miles an hour, the vehicles occupying the inner lane of traffic next to the central island will be thrown toward the outer lane on rounding the corners, with resulting conflicts and possible accidents. The traffic proceeding about the square will tend to take a circular course and the traffic pattern will undoubtedly show the square inscribed in a rough circle. The 30-foot curb radii of the entering streets will bring about a similar effect along the outside of the rotor when vehicles make a right turn. These two tendencies reduce the effective width of the roadway and concentrate traffic in the two center lanes.

The Chicago plan has some advantages over the English design. The curb radii are 75 feet, and cars turning to the right with the intention of leaving by means of the next street can negotiate the turn at about 20 miles per hour without swinging wide into the inner lane. However, the design is not consistent in that the radius of the curves rounding off the square rotor is only 42 feet. While a right turn can be made at a speed of 20 miles per hour, a car proceeding directly through the intersection must slow down considerably in making the 42-foot radius curves. If speed is not so reduced, the motorist will be forced to swing out into the next traffic lane and the same disadvantages hold as for the English design.

EXISTING TRAFFIC CIRCLES DISCUSSED

In an attempt to gather information concerning the design and operation of existing traffic circles, a questionnaire was sent to all cities with a population of 100,000 or more and to other cities in which it was known that traffic circles were in operation. A summary of the data assembled through the courtesy of the various city engineers and members of city planning commissions appears in Table 4. This table, while containing all the information received, is admittedly incomplete, but will reveal particularly the wide variance in practice in the design of circles. In view of this fact, several plans are presented, each of which has one or more particularly good features which, if incorporated in a single design, would result in an intersection almost coincident with that presented in the previous chapter.

It will be seen in the table that the speed of vehicles passing through the intersection was given in only two cases. Despite the wide difference in both the diameter of the rotor and the volume of traffic, the speed maintained is practically the same. It is believed that this speed will be relatively constant for all circles, but any additional information both as to volume and speed which may be maintained upon existing circles would be very valuable to one considering the installation of such a design.

Monument Circle.—Monument Circle [1] in Indianapolis, Ind. (fig. 8, A), represents good practice in existing traffic circles. It was originally planned in 1821 by Ralston, an assistant to Major L'Enfant, as the center of a city 1 mile square with four broad avenues radiating from it. At the present time, the circle passes 1,500 to 2,000 vehicles per hour without interruption and without regulation by traffic officers or signal-control lights. It is also the terminal of all city bus lines.

Features of note are the large radius of the central island and the design of the islands in the entering streets. These islands were installed in response to traffic demands and for pedestrian safety. It is worthy of note that while the areas are merely outlined with stanchions and traffic buttons, the operation is efficient.

The circular driveway width, which is entirely adequate in this case, is the same as that given by the formula previously suggested, that is, one-quarter of the width of the entering streets. The operation of the circle would undoubtedly be improved by increasing the curb radii of the entering streets, but there is serious question if increased efficiency would compensate for the expense of such a proceeding in the heart of the city.

Niagara Square.—Niagara Square, Buffalo, N. Y. (fig. 8, B), is a good example of the rotary system applied to a large square. The corners of the central island have been cut back to such an extent that it is practically a circle and large turning radii are provided for traffic circling the island. It will also be noted that the curbs of the entering streets are cut back to provide a turning radius sufficient to allow entering vehicles to execute the right turn without interfering with the traffic already upon the square.

As there are seven entering streets, the interweaving distance in several places is less than has been recommended; but because the heavy traffic flow is largely confined to Niagara Street and Delaware Avenue, the operation of traffic through the square is not seriously affected. Here the width of the circular roadway is less than the maximum given by the formula and this width is still further reduced by vehicles parked around the outer curb, illustrating that the formula gives a very generous roadway width and that traffic can be handled efficiently with less width.

A traffic count made on July 7, 1929, showed that 3,548 vehicles entered the square during the maximum hour and passed through without delay or confusion.[2] The advantages of the design are the large radii of the central island and the curbs of the entering streets.

Circles in Portland, Oreg.—Two traffic circles of Portland, Oreg., present examples of good design. Figure 8, C is the intersection of two main traffic streets in a residential district. Both carry a large volume of traffic which passes through the circle without interruption.

An interesting feature of this design is the exceptionally large radii of the curbs of the entering streets. A radius of 200 feet gives a continuous curve for traffic turning right from one entering street into the next and results in the outer curb of the circle being convex with respect to the central island. Where land is not exceptionally expensive, this practice offers some advantage over the straight outer curb design. Very little roadway width is wasted and vehicles are encouraged to follow a natural route. The radius of the central island is 95 feet, resulting in a satisfactory interweaving distance.

Figure 8, D illustrates a treatment where a number of streets converge at a point. The radius of the central island is too small to give a satisfactory interweaving distance provided all the streets were carrying a heavy traffic load, but it is effective in this case because the traffic is concentrated on Ladd Avenue and the other streets are of comparatively minor importance.

TABLE 4.—*Existing traffic circles in cities of 100,000 or more population in the United States*

Circle	Location	Diameter of circle	Total width of entering streets	Width of circular roadway	Number of entering streets	Maximum vehicles per hour	Speed in miles per hour
		Feet	*Feet*	*Feet*			
Lee	New Orleans, La.	280	202	40	4	3,400	16–19
Claiborne	do	210	268	31	7		
Druid Hill Park	Baltimore, Md.	115	236	85	7		
Niagara	Buffalo, N. Y.	305	374	75	7	3,500	
Monument	Indianapolis, Ind	333	200	50	4	2,000	
Du Pont	Washington, D. C.	386	464	40	10	2,176	
Sheridan	do	190	164	40	3		
Thomas	do	208	440	50	8	3,300	
Scott	do	120	450	60	6	2,350	
Iowa	do	380	324	36	8	2,500	
Washington	do	350	360	40	8		
Grant	do	300	300	40	8		
Sherman	do	320	300	50	8		
Lincoln Memorial	do	640	290	60	6		
Chevy Chase	do	240	350	70	8		
Laurelhurst	Portland, Oreg.	190	192	8	4		
Central Park	do	240	264	36	8		
Colorado and Orange.	Pasadena, Calif.	60	194	70	4		
Columbia Road and Old Colony Avenue.	Boston, Mass.	175	177	60	4	3,000	15–20
Kaign Avenue	Near Camden, N.J.	320	310	50	6	3,200	
Whitehorse Pike	do	[1] 110	145	45	5	2,465	
Brooklawn East	Near Brooklawn, N. J.	200	167	36	4		
Brooklawn, West	do	155	135	33	3		
Ridge Road Bridge approach.	Rochester, N. Y.	216	300	60	6		
Lindell (proposed)	St. Louis, Mo.	130	320	70	5		

[1] Minimum.

[1] Information furnished by Mr. H. B. Steeg, secretary-engineer, city planning commission.

[2] Report of the Committee on Street Traffic Economics, Bulletin 104 of the American Railway Association, p. 28.

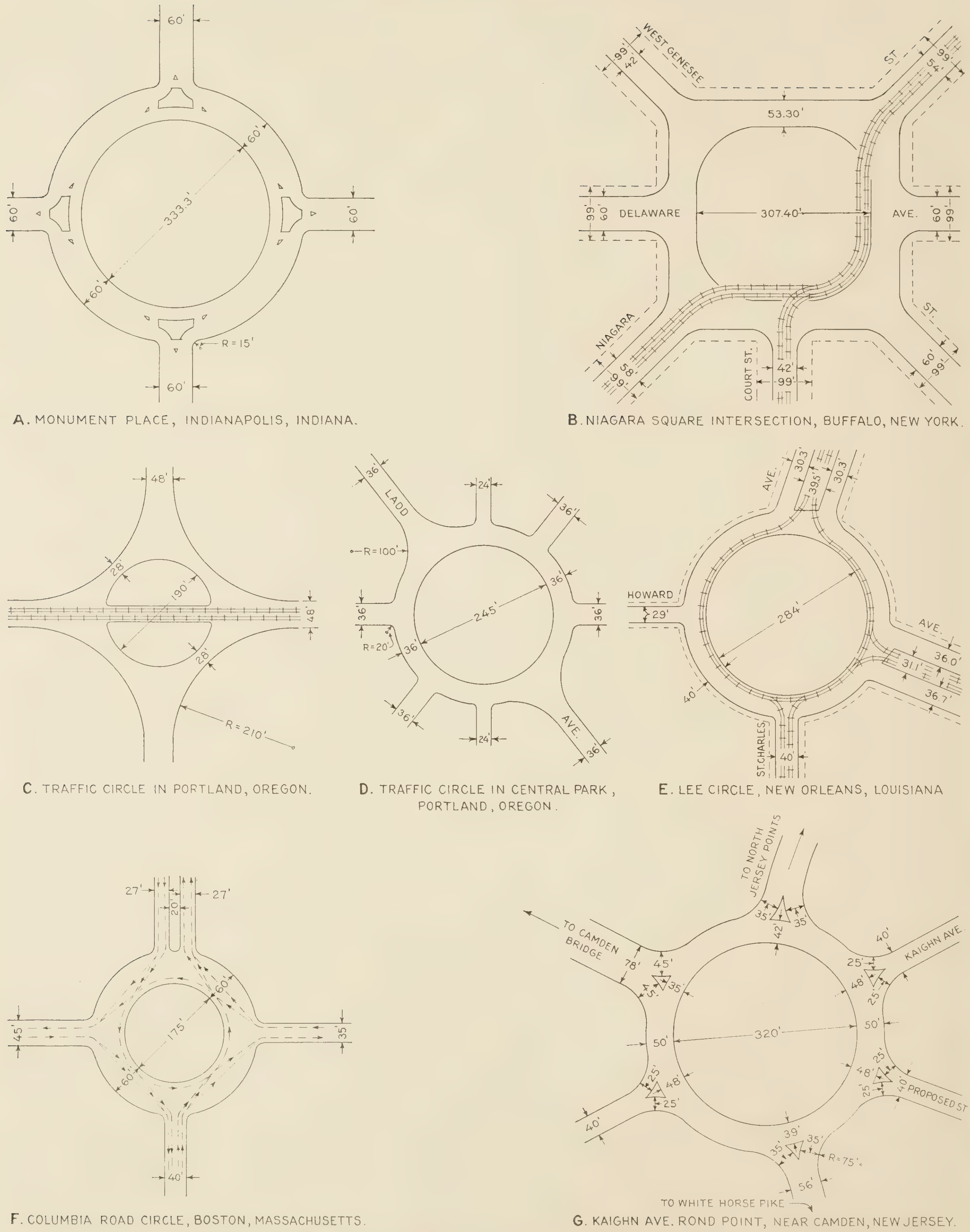


Figure 8.—Examples of Existing Traffic Circles

In both these designs excellent results are obtained with a roadway width less than the theoretical maximum, three lanes of traffic being provided in the first case and four in the second. Directional islands might well be added in the design, being particularly adapted in the first case where the open space in the entering streets created by the large curb radii is likely to prove confusing to entering traffic and hazardous to pedestrians.

Lee Circle.—Figure 8, E is a drawing of Lee Circle in New Orleans, La., which has a diameter of 280 feet. The short curb radii necessitate a reverse curve movement through the circle. This condition gives rise to a large area of unused pavement and makes improbable the desirable flat angle of intersection. However, the large diameter affords a greater interweaving distance, a desirable feature.

Traffic counts taken for the entire circle show a total of 2,543 vehicles entering the circle during one hour. Partial counts during the peak period indicated that nearly 3,400 vehicles passed through the circle during the rush hour. Speed studies showed that the speed varied from 16 to 19 miles per hour.

The roadway width in Lee Circle is 40 feet which, with a parking lane, permits three lanes of traffic. The total number of lanes on the entering streets, subtracting parking lanes, is 13. Thus the width is slightly under the maximum given by the formula suggested. The fact that there was at all times a complete freedom of movement in spite of the disadvantage of the short curb radii indicates that the formula gives a reasonable maximum width of roadway.

Columbia Road Circle.—This circle, near Boston, Mass., is represented in Figure 8, F. It is very near the minimum recommended design, having a central island 175 feet in diameter. It is located at the intersection of Old Colony Boulevard and Columbia Road and at certain times of day is required to accommodate a large number of vehicles with a large percentage of turning movements.

The effective operation of Columbia Road Circle, even under its peak loads, is a proof of the efficiency of this type of design. Observations indicate that well over 3,000 vehicles pass through the intersection during a peak hour at speeds ranging from 15 to over 20 miles per hour. During these observations congestion was not appreciable, no actual stoppage was ever seen, and little slowing down below the speed required for comfort in turning was noticed, even in periods of heavy traffic.

This circle further indicates the unused area created by the circular outside edge of the roadway. Traffic patterns on the pavement show that over 20 per cent of the pavement is never traveled over by vehicles passing through the circle.

Kaign Avenue Rond Point.—This circle, shown in Figure 8, G, was constructed by the New Jersey State Highway Commission. It has for a rotor a perfect circle, the large radius being necessary to provide for a proper interweaving distance.

It will be noticed that close attention has been paid to detail and that all details, in themselves correct, are properly combined to form an efficient intersection design. It is this attention to detail that premits the effective operation of this circle under the conditions of heavy traffic, a maximum of about 3,000 vehicles per hour being passed with little delay.

In the preceding designs no effort was made to provide for unbalanced traffic flow. The designs shown in Figure 9 are intended to illustrate the flexibility of the system, to suggest a modification applicable to the intersection where it is advisable to give preference to the traffic upon one or the other of the intersecting streets, and to suggest a rotary treatment for the common forked intersection.

It will be noted that each of the designs applies the basic principles on curb radii, island location, and interweaving distance previously developed. Figure 9, C shows how even a common parkway may be developed on rotary principle, which results in a design similar to that applied by Mr. Fritz Malcher in Radburn, N. J.[3]

SPECIAL DESIGNS WITHOUT ROTARY PRINCIPLE

The rotary principle is a specialized type of treatment which is particularly well adapted when a large volume of traffic must be handled at a comparatively low rate of speed. At intersections where there is only an intermittent flow of cross traffic, the vehicles upon the main highway are unduly penalized by the shape of the rotor. While the rotary system is not well adapted to such a situation, some form of treatment is desirable to permit the high speed boulevard traffic to flow without interruption and at the same time to protect the traffic crossing the main route and that turning into it from the minor route. The following designs have accordingly been presented to illustrate how this purpose may be accomplished by means of a system of well-placed channelizing islands.

The design in Figure 10, A, is well adapted to a T intersection where the traffic entering the heavily traveled street is very light. This type of intersection was developed by the Westchester County Park Commission and has proved very efficient at various intersections on the Saw Mill River Parkway. In this design the main roadway is 40 feet in width and, as shown, the opposing traffic is separated by islands at the intersection and the half roadway width increased to 30 feet. The widening effect is accomplished by means of reverse curves so flat (8° in this case) that there is no cause for reduction of speed on the main route.

The purpose of the islands is not to produce a rotary movement, but rather to provide a safety zone for vehicles waiting to enter or leave the main traffic by means of a left turn. For right turns, either entering or leaving the side street, 40-foot curves are provided and the increase from 20 to 30 feet in the half roadway width permits the turning vehicle to proceed alongside the main stream of traffic until it can accommodate itself to the speed of this traffic. In the case of left turns the importance of the islands is shown to best advantage. In turning left into the through street, the driver waits in the entering street until there is a sufficient interval in the traffic stream to allow him to cross to the space between the islands. If necessary, he may wait again in this protected area until the lane next to the island is open, when he enters and remains close to the island as he accelerates to the speed of the main traffic. During this acceleration period, there is still 20 feet to the right of the vehicle as it follows the island and there is ample room for all vehicles to pass even though both lanes are flowing full.

Similarly, in making a left turn from the main street into the side street, the driver remains close to the other island as he decelerates, thus leaving room for two lanes to pass on his right. Having slowed down suffi-

[3] Abolishing Street Traffic Intersections Without Grade Separation by Fritz Malcher ,American City ,September and October ,1929.

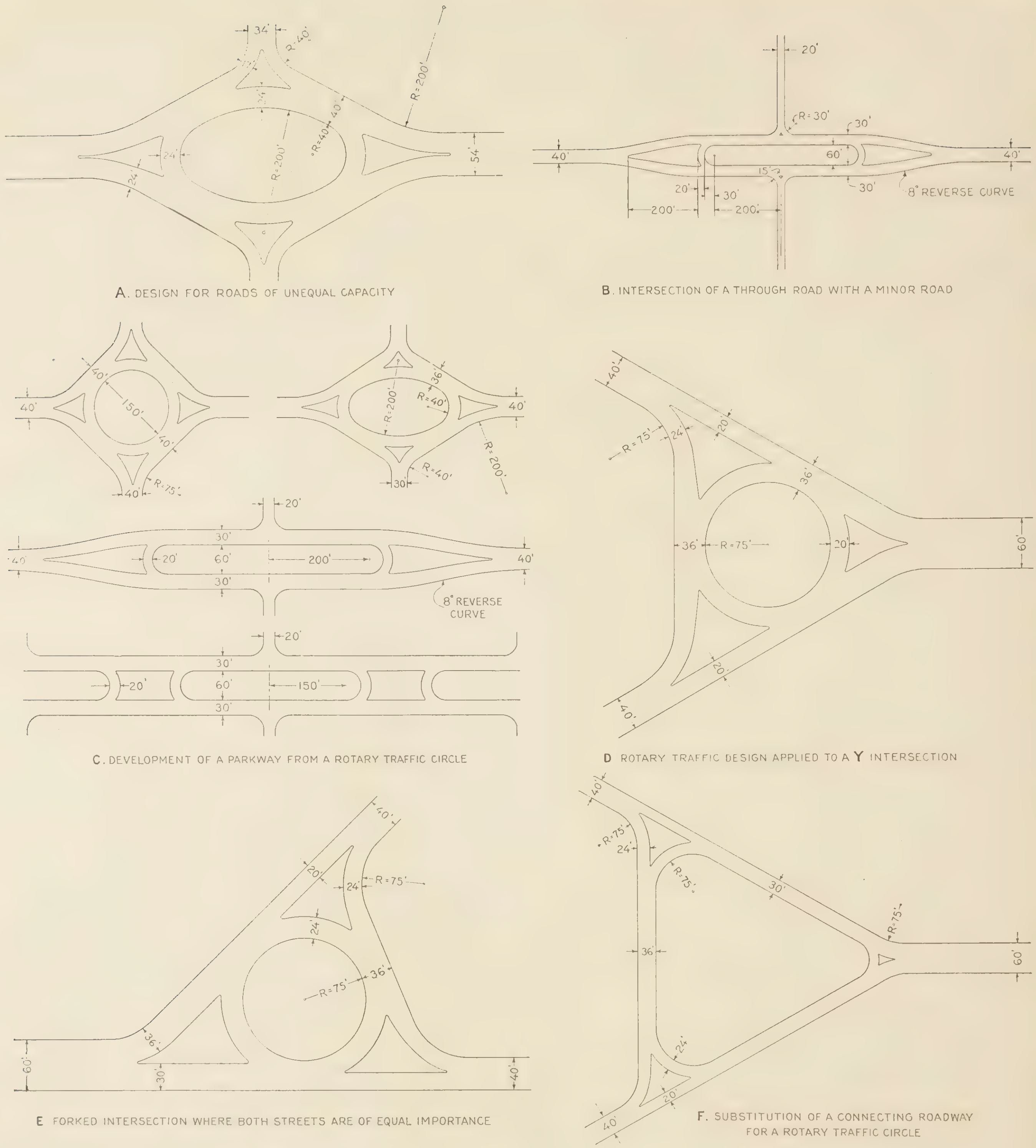


FIGURE 9.—SPECIAL ADAPTATIONS OF THE ROTARY PRINCIPLE

ciently, he turns into the protected area and as soon as the opportunity arises, crosses the other half of the highway and proceeds on the side street.

A design of this sort is less rigid in its various requirements than is a rotary traffic circle. Since no one will turn completely around an island, there is no necessity for making it the usual 60 feet in width. It is sufficient to place it so that it will be just inside the path followed by a vehicle in making a normal left turn as indicated by the traffic movements. Thus, the width is a factor only of the space required to provide an adequate safety zone. In this case 14 feet is used, a width which has been found satisfactory. Since a vehicle waiting in the protected area will stop at some point in its normal turning path, it will be in a diagonal position to the roadway at an angle of approximately 45°, so that 14 feet is ample to protect the largest car. The width of the narrow end of the island and its length are immaterial, the sides of the island generally being concentric with the sides of the road and the limiting condition at the narrow end being the width necessary to protect properly a significant warning sign.

No extra land is required over the normal right of way. An estimate of the quantities follows:

Item	Special design	Ordinary intersection	Excess
	Square yards	*Square yards*	*Square yards*
Grading	3,670	2,570	1,100
Paving	3,470	2,570	900
Island area	200	0	200
Curbing	[1] 435	0	[1] 435

[1] Linear feet.

The design shown in Figure 10, B, is very much the same as that discussed for stub-end intersections. This design, it may be observed, is applicable to the intersection resulting when a lightly-traveled street enters a heavily-traveled main highway on a curve and approximately tangent to the curve, a case very often encountered.

The physical features of this intersection follow exactly the same principles as those developed for the T intersection. In this case, the desired extra width is obtained by flattening the curve of the inside edge, and providing curves of greater degree on the outer edge. To eliminate a reverse curve on entering the main road from the secondary road and to prevent a vehicle from encroaching on the traffic lanes of the main road before it has acquired sufficient speed, the outer edge of the secondary road should be brought in on a tangent to the widened curve from a point some distance back of the intersection as shown in the diagram.

The effectiveness of the operation of this intersection depends entirely upon the proper location of the islands which, in turn, depends upon the radius of curvature and the angle of intersection. The details of the location of these islands may be seen in the diagram.

With the usual rights of way now acquired for rural highways, this design does not require much excess land. Assuming 100 and 60 foot rights of way, respectively, and that the present roadways are centered on the center lines of the rights of way, 2,500 square feet of excess land will be required, consisting of a small triangle in the throat of the intersection. When the design is to be constructed in conjunction with a relocation of the highways under consideration or in conjunction with new construction, the center lines of the highways may be so placed with respect to the rights of way that no extra land is required.

The design in Figure 10, C, another adaptation of the Westchester system, is similar to that presented in Figure 10, B except that the minor street is the one requiring the turn instead of the major street. The basic principle is the same; the turning traffic is protected from the through traffic and can not inconvenience it. Extra highway width on either side of the islands permits the slower turning traffic to mingle freely with the fast through traffic and an ample protected area between the islands is provided for waiting if necessary before turning.

The feature to be noted is the difference in the location of the safety islands. As in the previous design, they are so located that traffic turning about them will be directed into the proper route, but because of the difference in angles and the straight instead of curving through highway, the distance between the islands is much less. This indicates the necessity of a study of the particular intersection before placing the islands, since their proper location is the determining factor in the successful operation of this type of intersection treatment.

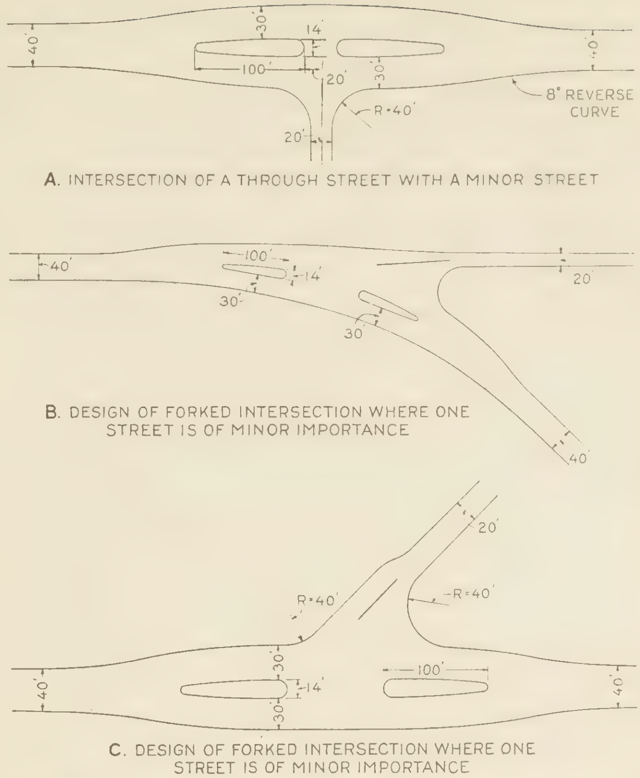


Figure 10.—Special Designs Without Rotary Principle

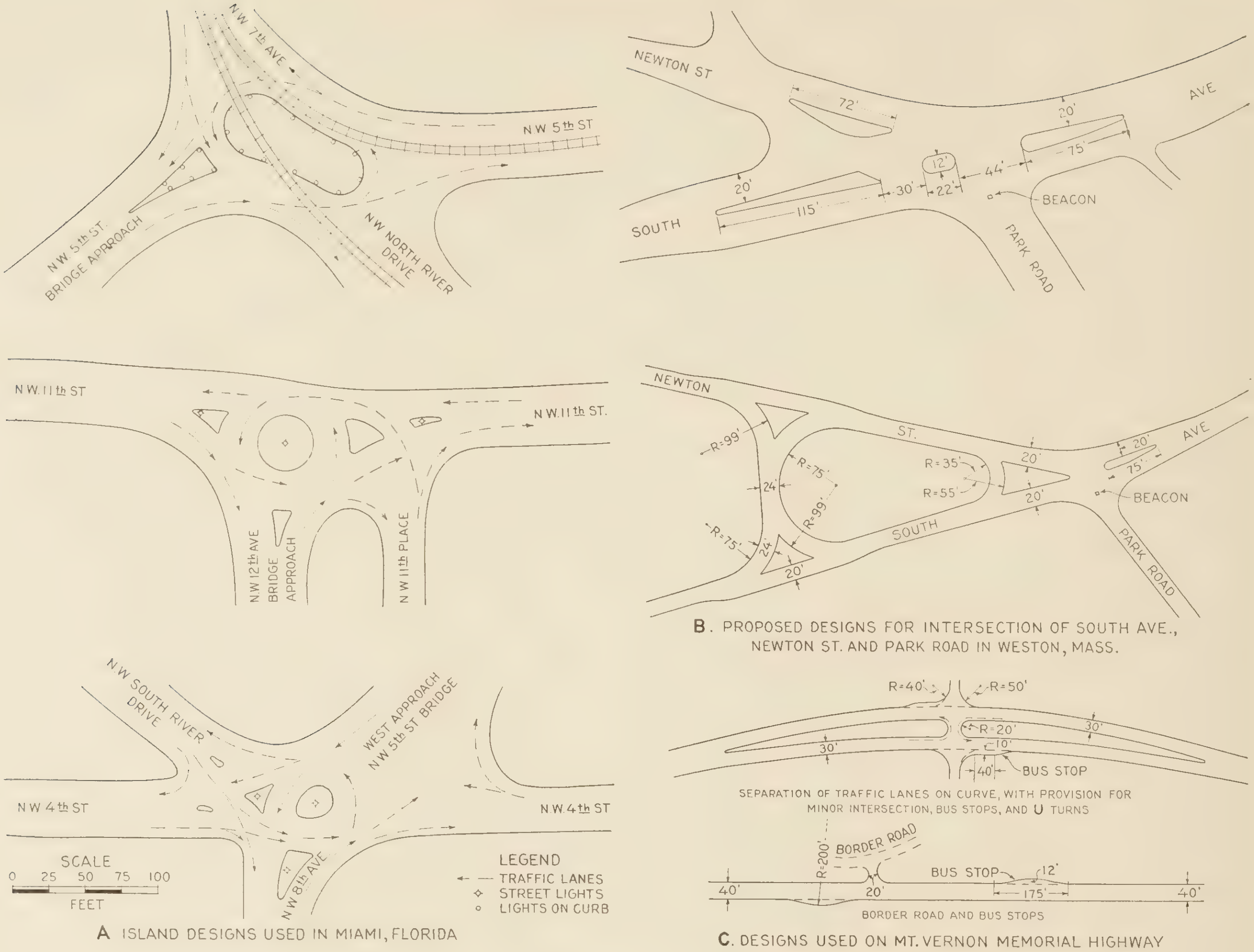
The extra land required is negligible and, as the additional pavement is dependent on the angle of intersection, no specific estimate is presented. In any case, the quantities will not be much in excess of those for the stub-end, right-angled intersection. (Fig. 10, A.)

EXISTING SPECIAL DESIGNS

The designs presented in the preceding paragraphs were not intended to cover all possibilities, but rather to bring out the principles involved and to show their application to a few common types of intersection. The designs illustrated in Figure 11 show how, in some cases, these principles have been actually applied and, in others, the proposed application. Each design represents a carefully considered solution of the particular problem and is illustrative of a practice which might well be applied at countless intersections.

The three designs shown in Figure 11 A are in Miami, Fla., and represent a good application of the principle that the driver should be directed into the proper route by making that route the natural one. The first of these (N.W. Fifth Street) might be termed a modified rotary system, in which case the central island would be a rotor, about which the streams of traffic flow, vehicles entering or leaving as the line progresses. In a sense this is what actually happens, but because of the general layout of the intersection and the turning movements to be expected, it is probable that most of the traffic will turn about the island rather than follow it closely for any considerable distance, as in a true rotary movement. For this reason, therefore, this design is classed as a special design and all the islands are termed directional islands.

The traffic entering the intersection from any street is confronted by the oval island, about which it must turn. The island is so placed that any vehicle following its natural course through the intersection inter-



A. ISLAND DESIGNS USED IN MIAMI, FLORIDA

B. PROPOSED DESIGNS FOR INTERSECTION OF SOUTH AVE., NEWTON ST. AND PARK ROAD IN WESTON, MASS.

C. DESIGNS USED ON MT. VERNON MEMORIAL HIGHWAY

FIGURE 11.—EXISTING SPECIAL DESIGNS

sects other lines of traffic at an oblique angle, which makes interweaving or intermingling easy.

The second design (N.W. Eleventh Street) represents the solution of a rather complicated intersection, the open areas of which, without directional islands, would cause confusion. The largest of these islands is a circle 40 feet in diameter. As in the preceding case, this might be termed a rotary traffic island, but its small size and the fact that again few vehicles follow close to the edge for any considerable distance leads to its classification as a directional island.

Its location is the most important feature of this design, for upon this depends the routing of all traffic passing through the circle. The other islands serve to make vehicles approach the circular island at the proper angle. The two smaller islands at the east of the central island provide safety for traffic turning left from NW Eleventh Place, and prevent any vehicles from cutting to the left of the circle as they emerge from NW Eleventh Street.

The third design (NW. Fourth Street) is composed of strictly directional islands, there being no semblance of rotary movement. The islands are so shaped and located that the route which any vehicle should follow is obvious and is the one which will cause the minimum of confusion in the intersection area.

In all these cases the islands are of permanent construction, all being curbed and planted with grass, shrubs, or palms which add measurably to their appearance. It is of interest to note that they were not installed as permanent fixtures until the size and shape had been determined by trial, using temporary islands. In this way it was possible to insure efficient operation.

The following excerpt from a letter from Mr. J. E. Jewett, office engineer, is of interest:

> There is little question but what such traffic islands reduce accidents very materially. Rotary traffic is usually slow traffic in terms of miles per hour, but is rapid traffic in terms of vehicles per hour. As traffic congestions develop, we expect to install more such traffic separators.
>
> We have learned that we can seldom lay out a system of islands in the office that will work. It is nearly always necessary to make changes in the field. Our policy is to put up movable forms for the islands, making changes here and there until we are convinced that we have solved the problems. These forms are left in place as long as 30 days before the permanent curbs are built.

Figure 11, B represents two designs prepared for the intersection of South Avenue and Newton Street in Weston, Mass. The upper plan shows an adaptation of the design presented as the Westchester type to the special conditions encountered here. The islands are so shaped and located that they direct traffic into the routes consistent with the most efficient operation of the intersection. No traffic lines are materially deviated from their natural courses and ample area between islands provides for the safety of the turning traffic.

A more elaborate solution, which would be justified only in case of a marked increase of traffic on both routes, such that the consequent delay is considerable, is seen in the lower plan. This design, similar to Figure 9, E provides a rotary movement, and necessarily functions well only at relatively low speeds.

It should be noted that the second design might be considered an extension of the first, the throat of the intersection being practically the same in both cases. Allowance in a design for future development is an important feature.

PROGRESSIVE DEVELOPMENT OF AN INTERSECTION

In view of the tremendous cost of acquisition of land at a date when traffic demands require an intersection treatment, it is an increasing practice to obtain control of sufficient land abutting intersections to allow progressive improvement.

Various means of reserving this land for future use are exemplified by the methods used in city planning control of new developments. The simplest and most effective method is by outright purchase at the time of initial construction, based on the theory that it costs little more to obtain a wide strip of land than a narrow one, but that to take additional land after the original route is laid out is invariably expensive.

An alternative is to purchase immediately only the land necessary for the first development of the intersection; and, by means of zoning regulations, to insure against private developments in the right of way to be needed in the future. Such regulations must necessarily conform to court decisions on the subject of zoning in the jurisdictions concerned. A reasonable restriction would allow the owner to make whatever use of his property he desired, so long as he complied with the general zoning requirements, but would stipulate that any buildings or other improvements would be removed from the area in question, without compensation to the owner, at the time anticipated for the improvement of the intersection. This would permit the erection of inexpensive buildings having a length of life less than the period between the first and the second improvements, as well as the use of the land for agricultural or other purposes. It would, on the other hand, prevent the building of permanent structures which would preclude the possibility of a grade separation or a traffic circle.

Where zoning acts do not permit this procedure, it may be possible to incorporate in the deed covering the original purchase a provision similar to the restriction outlined above, applying to land which will be required for future intersection development.

In case all the land required for full development of the intersection is purchased at the time of initial construction, the land not needed immediately may be leased for the construction of temporary buildings or such other use as may be profitable. In this way all or part of the carrying charges on the additional land may be defrayed during the period when it is not needed for the intersection.

If this plan were followed a State highway department or other agency would find itself with a considerable amount of land on its hands for which it had no particular use at the time but which must be kept in a presentable condition. In order best to use the available area, the following methods for a progressive development of an intersection are presented.

The intersections fall naturally into two classes according to location, first, those in country or parkway locations and, second, those in districts which will be built up with industrial or commercial structures.

In the first instance, a proper design would be one requiring a generally square plot of land with the intersecting roads forming its diagonals. To provide for any desired future construction, this square should be about 425 feet on a side, its corners being located on the center lines of the right of way about 300 feet from the intersection of the center lines. Assuming that this amount of land is taken at the intersection of two newly designed routes, it is of interest to follow the possibilities of the layout of the intersection through increasing traffic stages, as indicated in Figure 12.

The first design shows the crossing of two 20-foot roadways. The intersecting edges are rounded at a 30-foot radius, but otherwise nothing need be done. As the traffic becomes heavier or more flexibility of movement is desired, it may be desirable to increase the roadway widths to 40 feet or two lanes in each direction, but it may still be unnecessary to provide any special intersection treatment. If turning traffic becomes a factor and left turns as well as right turns complicate the traffic, turning roads may be beneficial. Roads such as these are now installed as a component

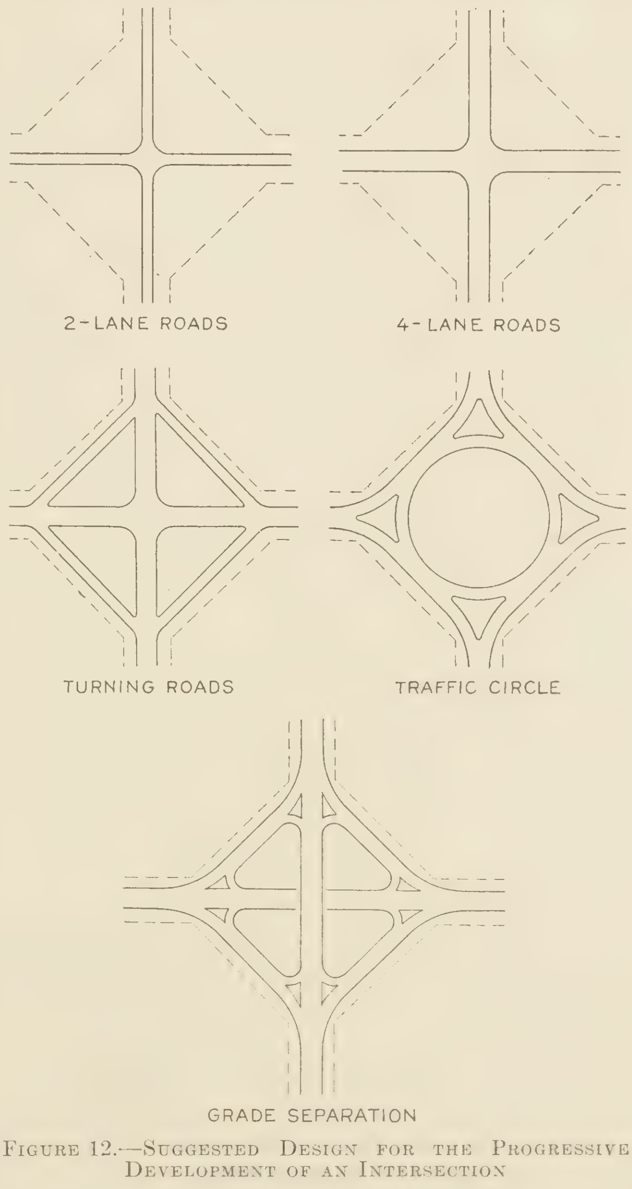


Figure 12.—Suggested Design for the Progressive Development of an Intersection

part of many intersections, but usually are laid out in a circular arc, of perhaps 200-foot radius. The reason for selection of the straight turning roads is apparent, however, on inspection of the solution for the next stage, a rotary traffic circle.

When traffic becomes so heavy that traffic signals would be necessary to regulate the right-angled crossing, a rotary design is very effective and, in this case, inexpensive. The turning roads already constructed will form a part of the circular roadway and a central island of 150-feet radius may be laid out in the area inclosed by the turning roads. The radius of the throats of the entering streets will be increased, for though in the previous case only turning traffic used the diagonal roads, now all traffic swings right on entering the intersection and follows around the rotor. It may be seen that there is ample area to provide a traffic circle which will fulfill every specification developed in the section on rotary traffic.

In the case when the traffic demands become so great that the rotary traffic circle will cause an economic loss due to the required reduction of speed of vehicles passing through it, a grade separation may be justified. When this installation is completed, it will be found that the diagonal roadways which were first classified as turning roads and then as an integral part of the circular roadway of the traffic circle have now become access roads for a grade separation and the two intersecting streets again pass straight through the intersection, but at different elevations.

Figure 13 shows a clover-leaf grade separation at the intersection of U. S. Route 1 and the Mount Vernon Memorial Highway.

The foregoing discussion outlines a possible intersection development from the simplest to the most elaborate, each stage of which fits as nearly as possible with the next and eliminates almost altogether the too prevalent factor in highway work, depreciation through obsolescence. Proper foresight will eliminate much unnecessary expense in solutions which are worthless after a short period. It is by no means compulsory that each step be followed in order, but it is extremely unlikely that the traffic demands at any intersection will warrant a transition from the initial to the final solution in one step and if a progressive, flexible development in provided for, much expense and inconvenience may be saved.

The second case, that in which the intersection is in a district expected to be closely built up, does not so readily adapt itself to a progressive development. It is for an intersection such as this that the Cook County Grade Separation Committee recommended a set-back line 60 feet on either side of the center line for a distance of 660 feet back of the intersection. As in the preceding case it is not necessary to proceed at once from the simple intersection to the final solution, but rather to follow a series of steps which, though not developing one from the other as did those in the outlying intersection, have a definite relationship with one another.

Again, there are the two narrow intersecting roadways and an equal or greater amount of excess land not in the form of a square, but instead shaped like a huge cross, the center lines of which are the center lines of the intersecting roadways. In this case, also, the second step may well be the widening of the two roadways to four lanes each, merely rounding the intersecting edges with 30-foot curves. As turning traffic needs to be better accommodated or as the necessary stoppage by control devices interferes with the freedom of right turns, a splaying design becomes appropriate.

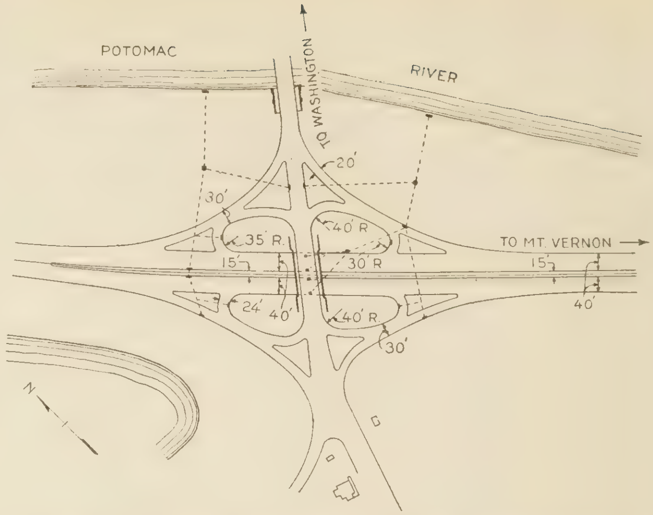


Figure 13.—Grade Separation at the Intersection of U. S. Route 1 with the Mount Vernon Memorial Highway

Here is an admirable opportunity for installing the separated lane splaying feature, since land is available both on the sides and for a sufficient distance back of the intersection. As the traffic becomes even heavier, a second line may be filled in between the through pavement and the turning lane to increase the storage capacity and in this way increase the efficiency of the intersection somewhat. Following this comes the final step, a complete separation, effected by carrying the middle four lanes of one roadway under the other.

In this development one feature does not become an integral part of the succeeding feature. The only possibility is that the turning lanes introduced by the splaying may serve as turning roadways for the separation. It is quite possible, however, during the construction of a project such as the grade separation structure and approach ramps that the existing pavement would be seriously injured and in this event the outer paving would also be relaid.

Thus, even though successive designs may not lead to the construction economies resulting from the parkway development, a proper program of construction related to the traffic needs will result in an intersection effective at all times.

Both the preceding cases are concerned with the intersection to two approximately equally traveled highways. Another case which very often arises is that of a major, heavily traveled, highway crossing several other highways carrying different volumes of traffic. This case, too, is well worth considering from the point of view of progressive developments. One or more of the intersecting highways may have traffic sufficient to warrant a grade separation or rotary traffic circle immediately while others, though not now critical, may in time carry such a volume of traffic that their intersections necessitate some special treatment and still others obviously may never have enough travel to warrant an elaborate intersection design. It will be found that in every case where the volume of traffic to be expected some years hence can be estimated, some progressive plan can be well adapted to the intersection. Various designs have been presented for the intersection of roadways having different volumes of traffic and all of these designs have been built up from the same fundamental principles; so it is only a method of applying the pertinent designs and providing a means of evolving one from the other as traffic increases.

ROAD PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the department and as the department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1925. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1926. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1930. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 532D . . The Expansion and Contraction of Concrete and Concrete Roads. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 660D . . Highway Cost Keeping. 10 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

No. 93MC . . Direct Production Costs of Broken Stone. 25 cents.

No. 109MC . . Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters. 10 cents.

MISCELLANEOUS PUBLICATION

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They can not be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio. (1927.)

Report of a Survey of Transportation on the State Highways of Vermont. (1927.)

Report of a Survey of Transportation on the State Highways of New Hampshire. (1927.)

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio. (1928.)

Report of a Survey of Transportation on the State Highways of Pennsylvania. (1928.)

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States. (1930.)

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS was printed in PUBLIC ROADS, vol. 13, No. 3, May, 1932. Copies of this list may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

▼ ▼ ▼

United States Department of Agriculture
Bureau of Public Roads

Current Status of Federal Aid Road Construction

As of June 30, 1932

State	Completed mileage	Under construction: Estimated total cost	Under construction: Federal aid allotted	Under construction: Percentage completed	Under construction: Mileage Initial	Under construction: Mileage Stage *	Under construction: Mileage Total	Approved for construction: Estimated total cost	Approved for construction: Federal aid allotted	Approved for construction: Mileage Initial	Approved for construction: Mileage Stage *	Approved for construction: Mileage Total	Balance of Federal-aid funds available for new projects	State
Alabama	2,393.9	$ 1,812,011.04	$ 884,109.47	95	74.1		74.1	$	$				$ 5,469,694.24	Alabama
Arizona	1,220.1	2,782,928.26	2,014,700.15	64	104.9	61.7	166.6	4,594.57	3,459.24		0.3	0.3	742,533.48	Arizona
Arkansas	1,960.2	2,452,768.24	1,127,328.92	82	64.7	45.1	109.8	404,816.95	201,796.90	17.4		17.4	2,162,507.23	Arkansas
California	2,328.6	10,475,483.57	4,985,605.01	54	211.3	52.0	263.3	1,475,029.90	645,642.39	44.4	7.0	51.4	32,946.23	California
Colorado	1,603.2	4,355,182.99	2,276,199.42	75	171.4	50.8	222.2	73,822.81	41,458.38	7.5		7.5	2,057,603.69	Colorado
Connecticut	281.7	4,362,762.05	1,613,060.26	74	30.2		30.2	563,726.40	263,977.96	7.7		7.7	390,452.51	Connecticut
Delaware	345.7	870,529.25	435,264.62	59	41.2		41.2	86,524.00	43,262.00	4.7		4.7	167,140.82	Delaware
Florida	638.0	3,563,837.58	1,659,559.53	85	102.1		102.1	655,532.89	327,766.42	17.3		17.3	2,541,174.33	Florida
Georgia	3,068.4	6,410,060.34	2,999,196.48	61	160.3	166.8	327.1	174,461.46	87,230.72	6.5	1.2	7.7	1,345,949.03	Georgia
Idaho	1,460.3	2,573,893.23	1,517,125.45	77	123.5	93.7	217.2	1,302,449.66	781,761.33	30.8	228.7	259.5	345,018.54	Idaho
Illinois	2,649.2	25,384,659.55	11,764,654.34	76	751.9	36.8	788.7	3,495,560.26	1,569,434.05	125.4	5.2	130.6	1,310,641.51	Illinois
Indiana	1,822.0	10,326,406.44	5,114,814.33	63	352.4	20.5	372.9	1,609,394.59	792,712.22	73.7		73.7	381,104.02	Indiana
Iowa	3,350.2	3,512,604.68	1,639,295.18	30	178.3	40.4	218.7	2,294,536.74	1,072,924.03	106.9	25.4	132.3	87,585.99	Iowa
Kansas	3,643.0	5,160,560.54	2,521,332.53	64	293.4	68.2	361.6	2,324,281.14	1,126,345.63	72.3	304.6	376.9	567,001.31	Kansas
Kentucky	1,911.0	2,439,460.44	1,079,480.86	74	144.2	4.0	148.2	1,399,504.67	525,166.87	17.3	107.8	125.1	1,182,786.01	Kentucky
Louisiana	1,566.8	7,471,657.46	3,511,759.18	46	87.0	10.6	97.6	1,103,383.51	538,516.32	29.8	13.3	43.1	321,408.48	Louisiana
Maine	720.4	3,348,521.01	1,423,360.93	52	82.9		82.9	887,397,91	431,757.49	34.3		34.3	137,272.92	Maine
Maryland	778.9	701,917.80	255,754.94	81	23.4	.6	24.0	1,633,360.88	691,459.64	60.4	5.6	66.0	8,964.30	Maryland
Massachusetts	817.3	7,129,265.67	2,897,641.92	68	71.3	.2	71.5						602,611.77	Massachusetts
Michigan	2,071.5	9,062,647.19	4,162,775.75	70	395.4	31.9	427.3	655,889.46	325,630.00	21.4	20.1	41.5	2,452,326.98	Michigan
Minnesota	3,956.1	11,284,587.17	3,749,501.38	33	204.9	296.8	501.7	842,326.55	229,800.00	15.7	20.2	35.9		Minnesota
Mississippi	1,809.0	3,910,633.74	1,915,689.81	85	171.2	68.8	240.0	116,017.23	58,008.61	16.1		16.1	5,152,976.98	Mississippi
Missouri	2,922.0	7,031,555.37	3,036,644.01	41	191.0	88.3	279.3	689,291.30	329,813.03	25.1	11.9	37.0	567,602.87	Missouri
Montana	2,724.3	4,576,181.82	2,572,131.43	75	397.7	31.5	429.2	67,501.64	36,033.68	5.7	4.2	9.9	3,465,267.40	Montana
Nebraska	4,255.2	3,329,003.58	1,650,271.38	73	151.9	26.1	178.0	1,817,311.97	845,048.85	28.1	111.6	139.7	1,849,946.51	Nebraska
Nevada	1,281.2	1,576,562.30	1,289,906.62	81	21.2	163.0	184.2	859,152.00	693,501.34	26.8	33.3	60.1	86,974.21	Nevada
New Hampshire	421.0	339,864.67	140,869.77	85	9.5	2.5	12.0						553,268.42	New Hampshire
New Jersey	616.5	4,716,807.19	1,770,638.23	56	34.3	.5	34.8	1,023,047.07	496,650.88	.9		.9	698,945.91	New Jersey
New Mexico	2,250.1	1,469,046.56	1,028,823.23	92	61.9	17.8	79.7	998,601.99	618,039.80	41.1	42.3	83.4	897,851.56	New Mexico
New York	3,273.4	14,125,400.00	6,352,125.00	50	334.3		334.3	6,402,600.00	2,462,500.00	135.9		135.9	2,250,042.54	New York
North Carolina	2,226.4	1,152,326.37	567,278.11	77	67.6	5.0	72.6	300,312.76	150,156.36	7.1	4.0	11.1	3,728,867.35	North Carolina
North Dakota	5,062.7	3,316,919.40	1,680,534.96	45	383.7	283.5	667.2	1,931,160.99	973,516.22	183.5	478.4	661.9	821,723.31	North Dakota
Ohio	2,858.4	6,314,566.20	2,097,263.73	79	101.7	26.4	128.1	6,292,605.00	2,240,240.53	153.0	46.4	199.4	1,682,314.29	Ohio
Oklahoma	2,295.2	3,478,222.78	1,625,741.63	84	157.3	45.0	202.3	1,713,059.54	877,359.08	112.5	17.6	130.1	1,276,063.13	Oklahoma
Oregon	1,522.8	4,145,699.29	2,305,513.64	85	128.0	47.1	175.1	1,590,510.22	864,268.36	46.9	74.8	121.7	875,392.92	Oregon
Pennsylvania	3,012.6	5,021,298.77	2,322,443.57	35	181.7		181.7	6,392,381.18	2,851,912.07	196.7		196.7	775,956.02	Pennsylvania
Rhode Island	255.6	926,504.32	459,140.00	60	16.7	2.2	18.9						325,565.85	Rhode Island
South Carolina	2,013.6	3,131,546.27	1,409,414.06	94	73.2	59.7	132.9	101,152.78	50,000.00	5.2		5.2	744,636.09	South Carolina
South Dakota	4,039.4	3,318,617.13	1,909,863.38	70	266.1	183.8	449.9	233,615.05	157,987.24	30.8	12.0	42.8	1,085,351.79	South Dakota
Tennessee	1,682.4	1,427,533.89	697,948.21	57	48.7	6.4	55.1	733,446.20	356,461.69	17.1	21.8	38.9	3,157,110.04	Tennessee
Texas	7,802.7	13,843,539.36	6,348,479.78	69	605.0	223.6	828.6	3,980,124.61	1,802,196.04	232.1	185.1	417.2	3,333,824.82	Texas
Utah	1,203.5	1,109,608.87	797,552.81	67	84.9	27.7	112.6	847,650.66	635,771.92	37.6	108.5	146.1	520,628.78	Utah
Vermont	339.1	1,408,800.97	630,501.86	19	45.6		45.6	7,618.95	3,809.47					Vermont
Virginia	1,922.9	1,915,279.75	957,639.81	69	113.5	6.2	119.7	754,053.46	298,883.54	22.9	21.5	44.4	1,817,277.70	Virginia
Washington	1,197.9	2,915,547.20	1,432,094.35	62	106.2	14.5	120.7	519,265.07	213,800.00	11.5	5.3	16.8	1,007,069.51	Washington
West Virginia	893.3	1,783,964.32	768,721.07	71	44.5	10.5	55.0	283,803.60	132,744.79	6.2		6.2	998,160.51	West Virginia
Wisconsin	2,593.8	7,833,923.20	3,203,398.32	41	204.8	75.4	280.2	1,110,874.93	432,400.00	29.6	23.5	53.1	283,938.52	Wisconsin
Wyoming	1,894.3	3,630,824.26	2,232,041.40	72	192.4	230.9	423.3	205,019.30	134,595.13	26.2	20.1	46.3	120,711.31	Wyoming
Hawaii	76.3	811,202.36	395,047.85	65	22.0		22.0	740,008.72	598,548.44	18.8	3.6	22.4	1,335,908.87	Hawaii
Totals	101,032.1	234,042,724.44	109,230,238.67	64	7,885.4	2,626.5	10,511.9	60,696,780.57	28,014,349.16	2,110.9	1,965.3	4,076.2	61,720,100.60	Totals

	Estimated total cost	Federal aid allotted
Construction completed	148,147,000	69,982,000
Balance uncompleted	85,896,000	39,248,000

(*) The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

U. S. Government Printing Office: 1932