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Traffic Control: Devices and Delineation

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Foreword

The seven papers that comprise this Record are concerned with the problem of using traffic control devices to guide drivers and the role of medians in providing traffic separation and delineation. The information in these papers will be, in many instances, of immediate use to highway department administrators, designers, traffic engineers and operations personnel. Five of the papers are by state highway department authors and reflect research undertaken with the aid of their departments.

The first paper presents the results of a California study of over 100 miles of raised reflective highway lane line markers. The purpose of the delineation was to provide more effective reflectorization during inclement weather. Durability factors are also presented. The second paper illustrates a novel concept in intersection design for major highways and proposes the use of progressive traffic signals to eliminate grade separations.

The third paper offers information on studies made in Louisiana concerning Interstate-highway-type post-mounted reflective delineators. Although surveys indicated widespread driver acceptance of the delineators, measurement of vehicle speed and placement revealed no significant differences between delineated and non-delineated sections.

Three of the papers are concerned with medians. One discusses the 422 medians constructed in Illinois over 35 years and evolves a philosophy concerning their provision and design details such as width and median barriers. Another, using median studies on Chicago freeway sites, indicates the possibility of obtaining substantial improvement in safety on divided highways through appropriate median plantings. The final paper on median barrier effectiveness is based on California studies that indicate that while barriers eliminate cross-median accidents, and decrease fatal accidents, property damage and injury accidents seem to increase.

The last paper in this Record reports on the findings of a Michigan study of interchange ramp color delineation. Results indicate general driving benefits from the color schemes employed and that there is a reduction in erratic driving maneuvers near exits.

Contents

Raised Reflective Markers for Highway Lane Lines

JOHN L. BEATON, Materials and Research Engineer, and
HERBERT A. ROONEY, Senior Chemical Testing Engineer,
California Division of Highways

•IT is California practice to use a broken (9 ft painted, 15 ft unpainted) white stripe to delineate traffic lines. The painted portion is beaded for night visibility.

It has long been observed by motorists that during periods of inclement weather and moderate-to-heavy rainfall at night that water tends to accumulate on the pavement to a depth sufficient to cover and obscure the beaded painted centerline traffic stripe. Under such conditions, light from a motor vehicle is not reflected back to the driver and he is unable to see the painted stripe. In this situation the driver often finds it difficult to remain in his traffic lane.

HISTORY

Beginning in 1954, the Materials and Research Department began experimentation to solve this problem with the installation of reflectorized white "buttons" or markers, made of epoxy or polyester resins, 4-in. diameter and ¾ in. high, the convex shape corresponding to the outer segment of a sphere (Figs. 1 and 2). These buttons were cemented to the highway surface with an epoxy adhesive, one each in the center of the 15-ft gap in the broken painted stripe. In theory these elevated markers "shed the

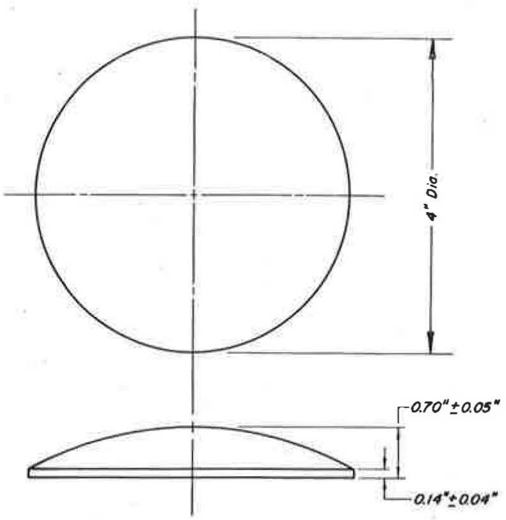


Figure 1. Button-type reflective pavement marker.

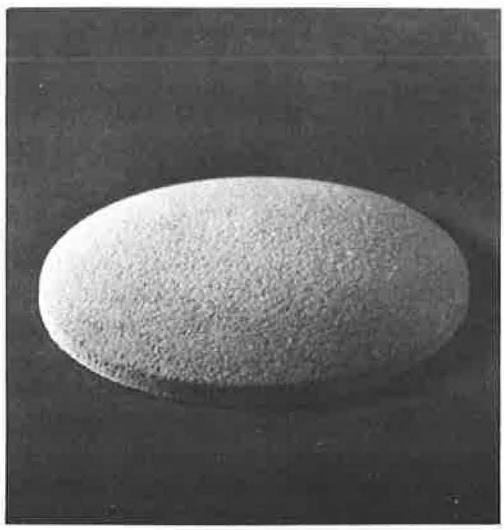


Figure 2. Glass-beaded white button.

Paper sponsored by Committee on Traffic Control Devices.

water" and are not readily submerged. Such markers are considered as auxiliary devices to provide adequate delineation during periods of wet weather at night. The normal painted stripe is considered thoroughly adequate in clear weather.

Performance since 1954 indicates that these markers should have a service life of at least 20 years on portland cement concrete highways. In order to attain this durability the proper epoxy adhesive must be used and the concrete must be thoroughly cleaned by sandblasting to remove laitance, dirt, oil and grease in the area where the marker contacts the pavement surface. Useful life of the marker mounted upon asphaltic concrete pavements is dependent upon the quality of the asphaltic concrete and its cohesive strength in hot climatic areas.

Beginning in 1955 a test section was installed in which "wedge" type markers (Figs. 3 and 4) were used as a complete replacement for a painted stripe on a portland cement concrete divided freeway. In this test section the distance between wedges varied, the extreme spacing being one wedge every 24 feet. All later installations had four markers, each 3 ft apart in the 9-ft sections where the normal stripe usually occurs. Some of these installations used the beaded wedges and others the beaded buttons. Two-way wedges, as shown in Figures 5, 6, and 7—except that they were beaded, have been used on 2-lane roads or as a no-passing line on nondivided freeways. In the latter case they would be yellow in color and two wedges would be cemented adjacent to one another. Figures 8 and 9 show clear weather nighttime delineation provided by the button and one-way wedge markers, respectively. Figures 10 and 11 illustrate nighttime visibility of these markers during a moderate rainstorm. In another photograph taken during the rain adjacent to the test area where a painted stripe was placed, the painted stripe was invisible.

The California Division of Highways has installed over 100 miles of the "wedge" and "button" shaped raised reflective white markers since 1959 in various sections of the State on both portland cement and asphaltic concrete pavements. In some installations the markers were used as a replacement for the painted stripe and in others they were installed as a supplement to the stripe, usually two in the gap and placed 6 ft apart. When used as a supplement to the painted stripe the intention was to provide nighttime delineation during periods of inclement weather. Other types of "wedges" and "buttons" which were tried and evaluated in service (both photographically and visually) for effective delineation under the specific conditions discussed are shown in Figures 12 through 15.

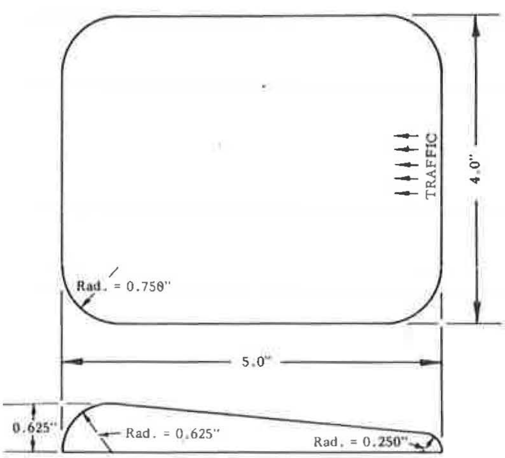


Figure 3. Wedge-type, one-way traffic, reflective pavement marker.

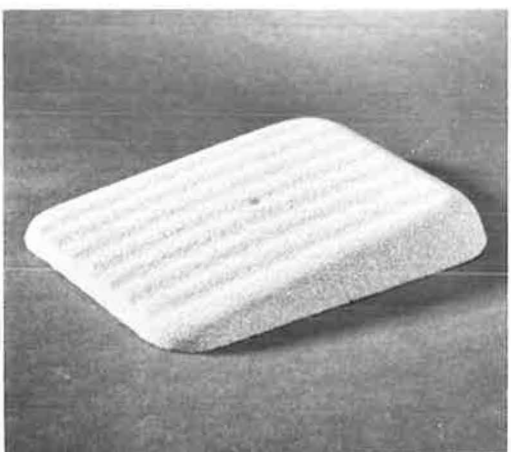


Figure 4. One-way glass-beaded white wedge.

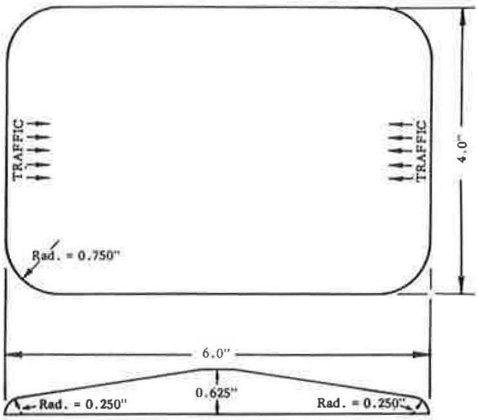


Figure 5. Wedge-type, two-way traffic, reflective pavement marker.

RECENT DEVELOPMENTS

In order to select a marker which is visible in both clear and rainy weather day and night, California has recently used a partially beaded marker. This is of necessity a compromise in order to have the virtues of the fully beaded and non-beaded types present in one marker. Being a compromise it is not as effective as the fully beaded or nonbeaded types under conditions where the fully beaded or nonbeaded types are the best. Specifications for all types of the raised white polyester reflective pavement markers currently used are California Specifications 64-F-41b, October 1964, and 64-F-42b, October 1964.

Figure 6. Two-way wedges, white non-beaded, on the roadway of the Webster Street Tube.

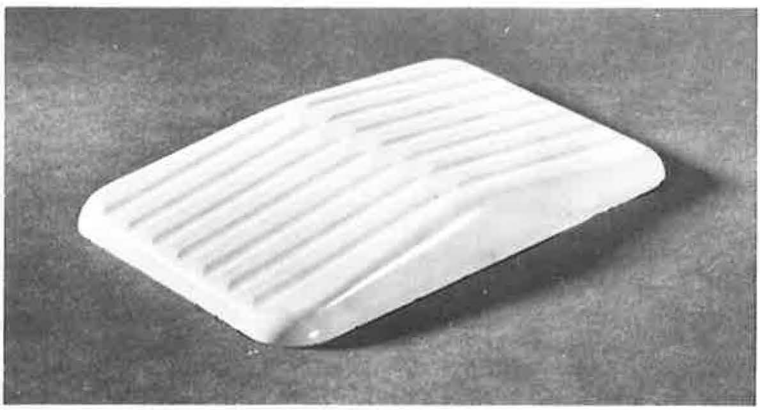


Figure 7. Two-way plain white non-beaded wedge.

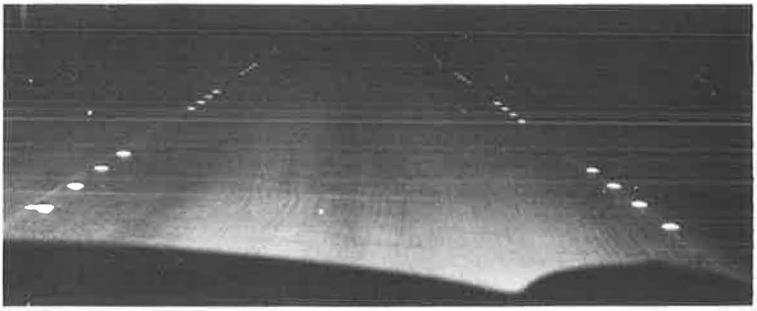


Figure 8. Buttons on the pavement at nighttime, clear weather.

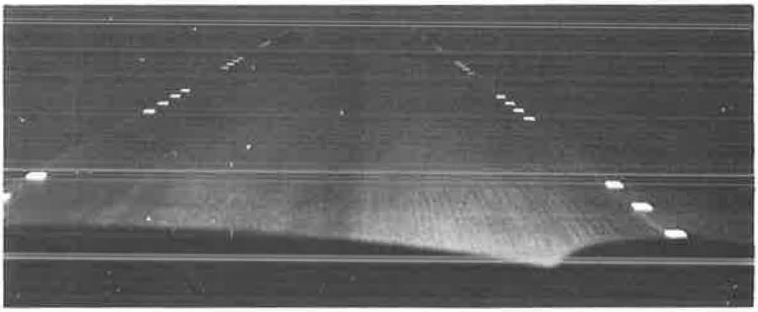


Figure 9. One-way wedges on the pavement at nighttime, clear weather.

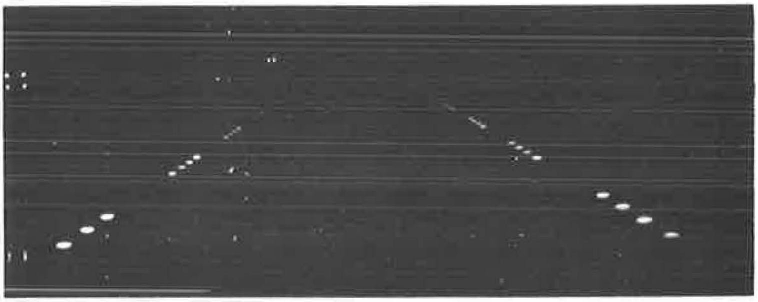


Figure 10. Buttons on the pavement at nighttime, moderate rain.

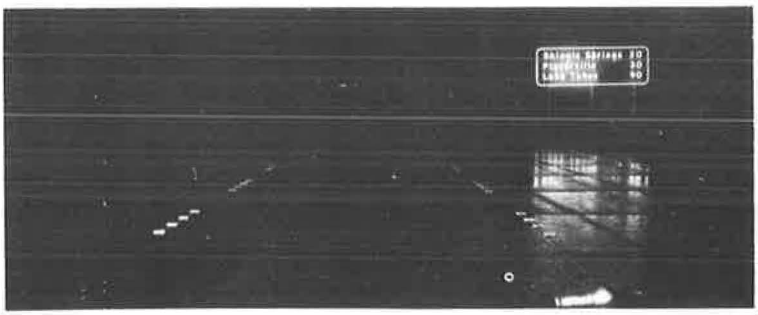


Figure 11. One-way wedges at nighttime, moderate rain.

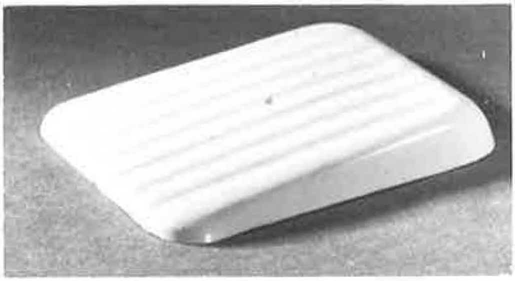


Figure 12. One-way plain white non-beaded wedge.

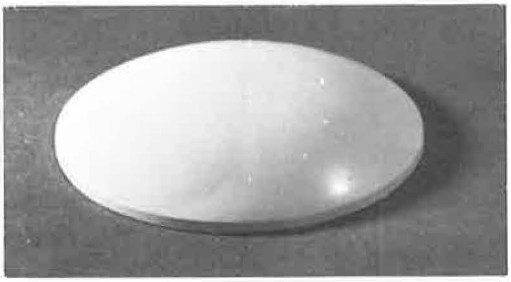


Figure 13. Plain white non-beaded button.

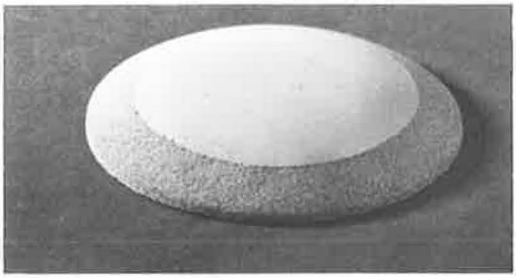


Figure 14. Plain white top button with glass-beaded white rim.

Figure 15. Glass-beaded white top with plain white non-beaded rim.

In April 1964, the Materials and Research Department installed 200 of an entirely new type raised marker on a divided freeway in Sacramento. The marker is wedge shaped and its reflectivity is based on the same principle as reflex reflectors used on guide posts. The reflecting surface is a reflex reflector encased in an acrylic plastic. The interior of the marker is filled with an epoxy resin to provide rigidity. So far this type marker provides brilliant delineation in clear and rainy weather at night but is almost invisible in the daytime. Durability over an extended period of years and its effectiveness in foggy weather is yet to be determined.

This marker (Fig. 16) has been manufactured in three types to reflect either white, amber or red light. A nighttime view of an installation of these markers is shown in Figure 17.

In order to select the proper type of a raised pavement marker for use in lane line delineation it is first necessary to determine which of the following conditions the markers are intended to serve:

1. Direction of traffic, one-way or two-way.
2. Replacement of the painted stripe.
3. Supplementation of the painted stripe.
4. Nighttime delineation only in inclement weather.
5. Delineation only under dry conditions, e.g., in a tunnel.
6. Day and night delineation under all weather conditions.

While not a part of this study, the fact that raised markers serve as a rumble warning strip to drivers changing lanes should be considered as a plus safety factor in any evaluation.

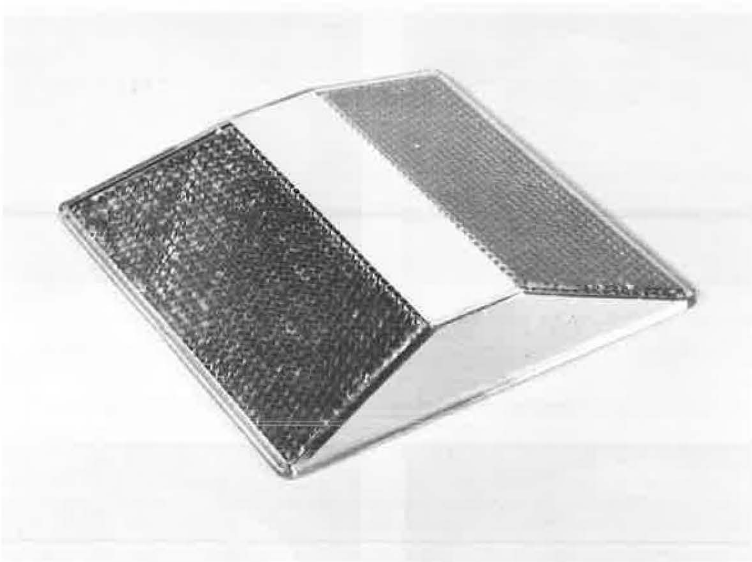


Figure 16. Reflex reflector pavement marker.

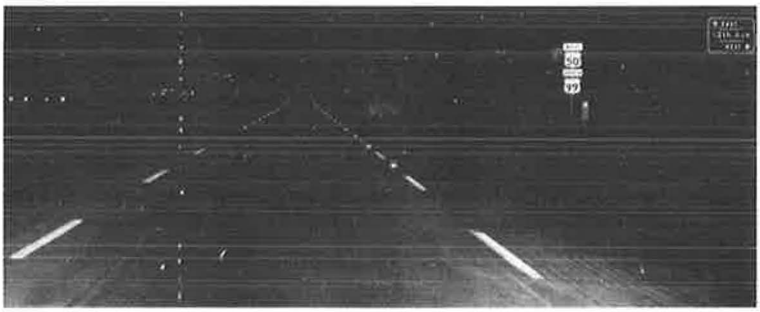


Figure 17. Reflex reflectors at night.

FINDINGS

Table 1 summarizes the uses of the various markers.

Extensive studies made of these experimental installations reveal the following pertinent facts concerning the suitability of the white plastic markers under various conditions.

1. The fully reflectorized markers (beaded) are ineffective for daylight delineation in clear and rainy weather, particularly on portland cement concrete. The glass beads scatter the sunlight causing the markers to have a grayish cast which blends in with the portland cement concrete.
2. The fully beaded button marker is more effective in rainy weather at night than is the wedge marker (Figs. 3 and 11).
3. On asphaltic concrete pavements, the wedge marker is more durable than the button type. Impact of traffic is less likely to cause failure in cohesion of the asphaltic concrete under the marker.
4. The glass beads used in the reflective button or wedge markers should contain the high index of refraction variety (1.90 minimum).

TABLE 1

Type*	Condition						
	Replace	Supplement	Inclement Night Only	Tunnel or Cont. Lights	Day and Night All Weather	One Way	Two Way
1A				X		X	
1B		X	X			X	
1C	X				X	X	
2A				X			X
2B		X	X				X
2C	X				X		X
3A				X		X	X
3B		X	X			X	X
3C	X				X	X	X

*1A = One-way wedge, non-beaded; 1B = One-way wedge, beaded;
1C = One-way wedge, half beaded; 2A = Two-way wedge, non-beaded;
2B = Two-way wedge, beaded; 2C = Two-way wedge, half beaded;
3A = Button, non-beaded; 3B = Button, beaded;
3C = Button, half beaded.

5. Under overhead lighting or in the daytime the nonbeaded markers are more effective than the beaded type in both clear and rainy weather.

Intersection Design: Switch Point

W. R. BELLIS
Director, Division of Research and Evaluation, New Jersey State Highway Department

•AN intersection of two crossroads in which vehicles do not stop or deviate from their normal speed is possible without the use of bridges. This has been named "switch point" design. It involves the use of alternate roads which are located in such a manner that by alternating from one to the other at specified times there will be no conflicts between streams of traffic. Because of the radical departure from standard

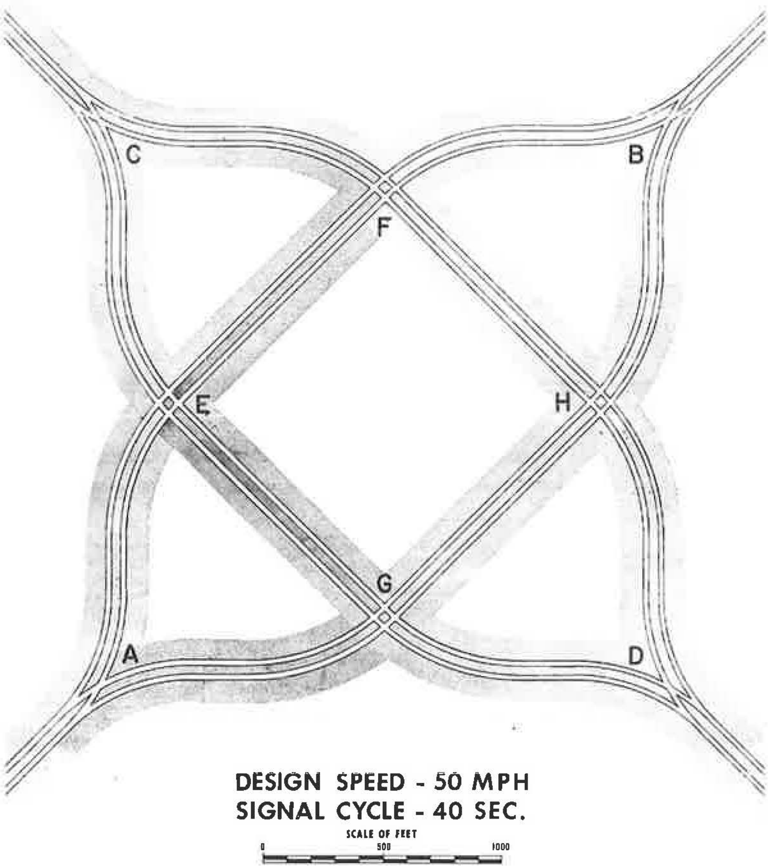
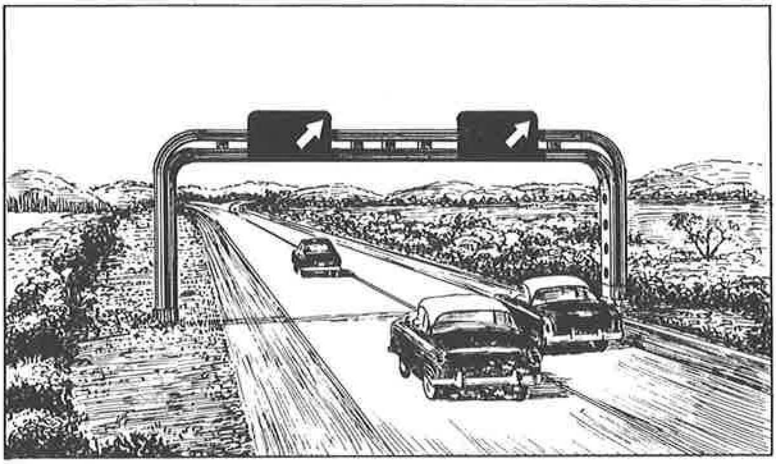
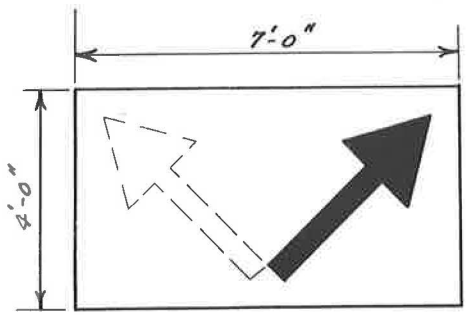


Figure 1.

Paper sponsored by Committee on Operational Effects of Geometrics.



SWITCH POINT SIGN



SWITCH POINT SIGN DETAIL

Figure 2.

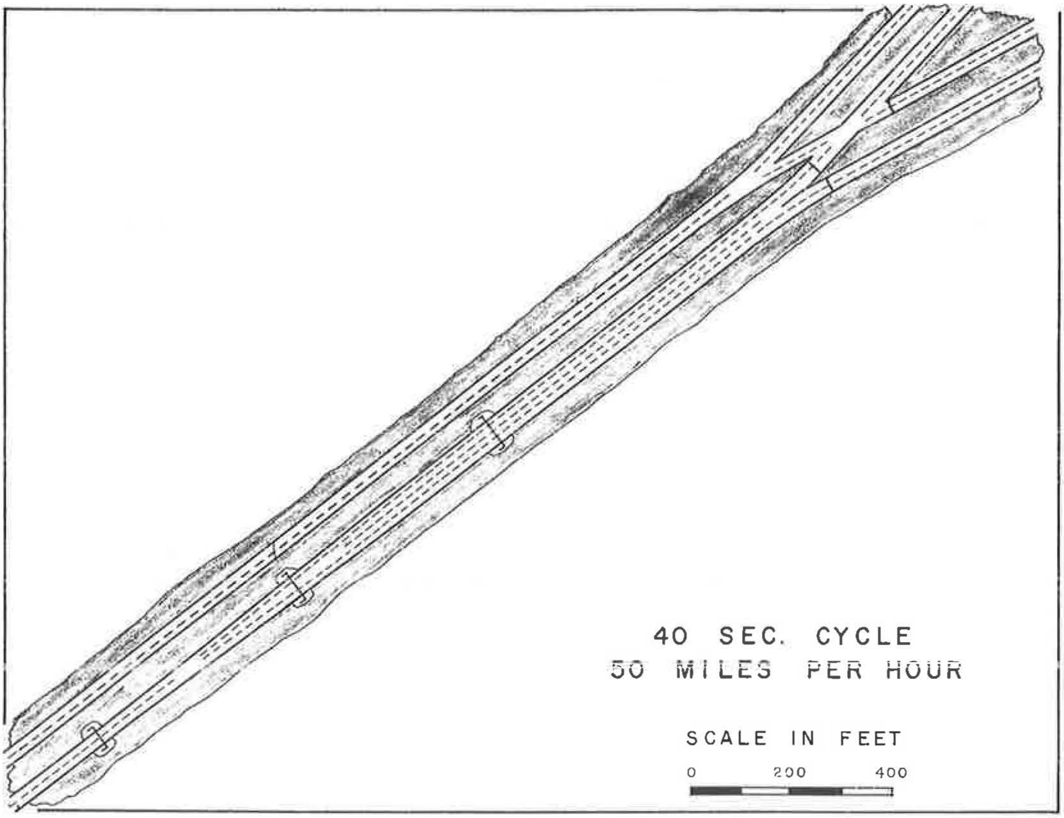


Figure 3.

types of design, administrators and designers have hesitated to consider its application.

BASIC DESIGN

Figure 1 shows the design for the right-angle intersection of two 4-lane divided highways. Between A and B there is an alternate choice of roadway to use. When traveling in the direction from A to B, a driver could go by way of E and F or he could go by way of G and H. Likewise, in traveling from C to D there are two equally desirable ways to go. At A, B, C and D drivers must make decisions to go either to the left or to the right as they approach the intersection. These points are the switch points and at each there is a signal device to tell drivers to go either to the left or to the right. This signal could be a sign bridged over each lane (Fig. 2) and show an arrow first pointing to the left, then to the right, then left and so on. This sign would be repeated at intervals along the road approaching the switch point and each would change in a progression equal to the normal speed of approach traffic. The approach roadway would be widened to double its normal width before reaching the switch point. This will provide for smooth maneuvering at the time of change of direction (Fig. 3).

For a speed of 50 mph and a cycle of 40 sec the distance from A to E, E to F and so on would be 1, 500 ft. This is the distance traveled in 20 sec (one-half cycle) at 75 ft/sec (50 mph). At each of the switch points A, B, C and D approaching drivers are told by the arrow signals to go to the right from zero time to 20 sec later (Fig. 4); then the next approaching drivers are told to go to the left from 20 sec to 40 sec which is the end of one cycle and the beginning of the next cycle. The next "slug" of traffic is

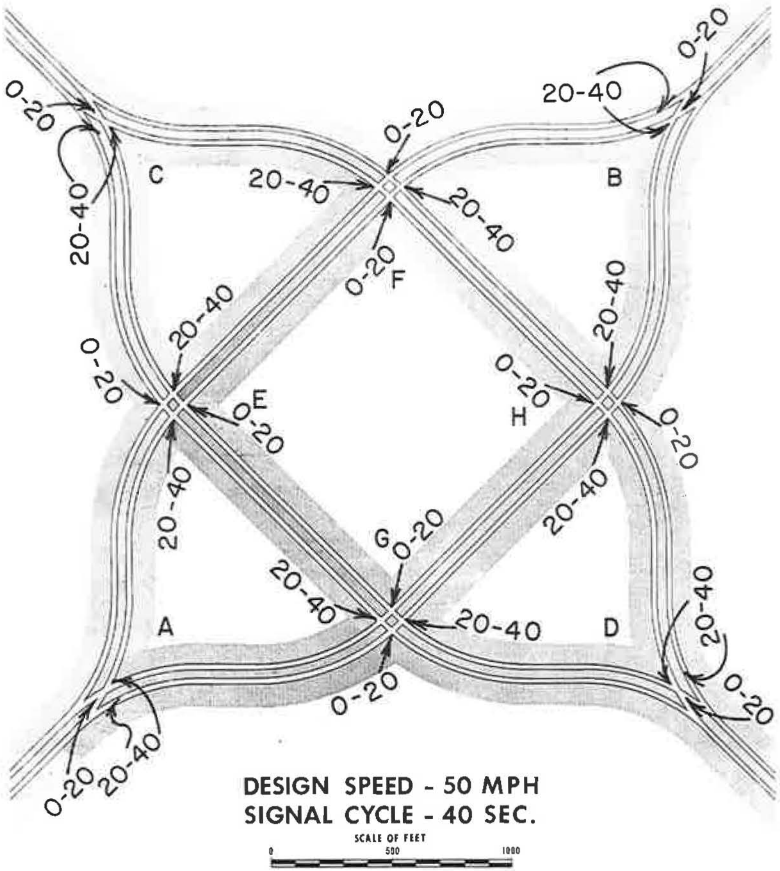


Figure 4.

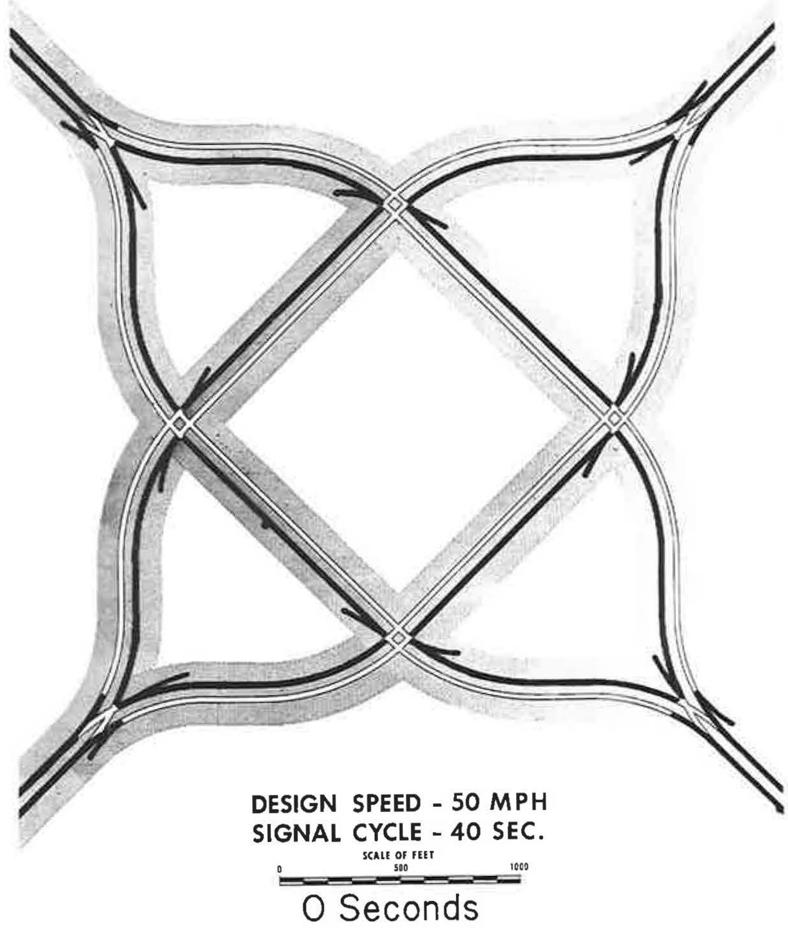
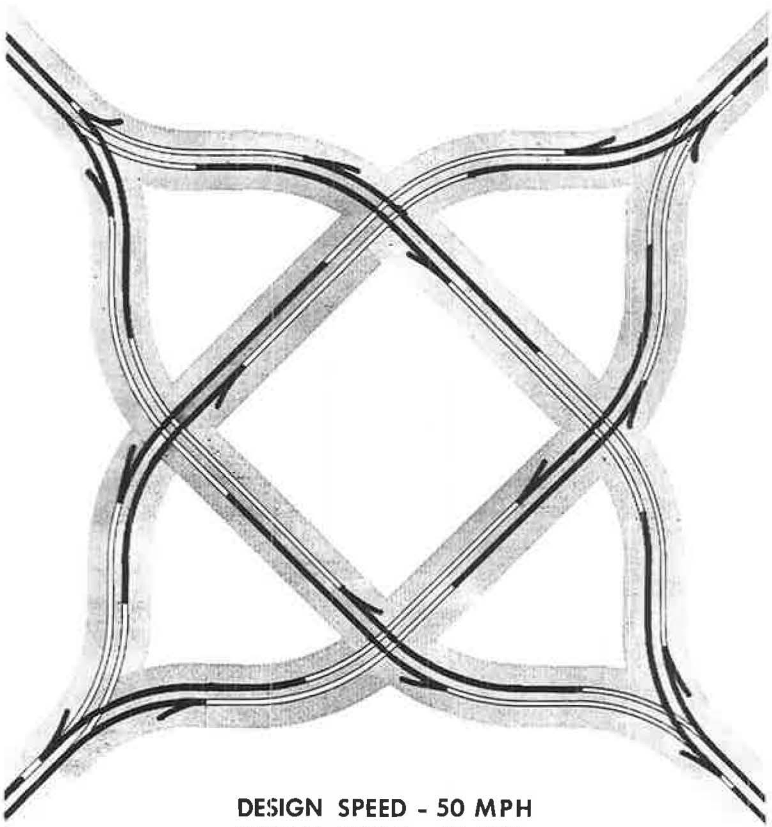


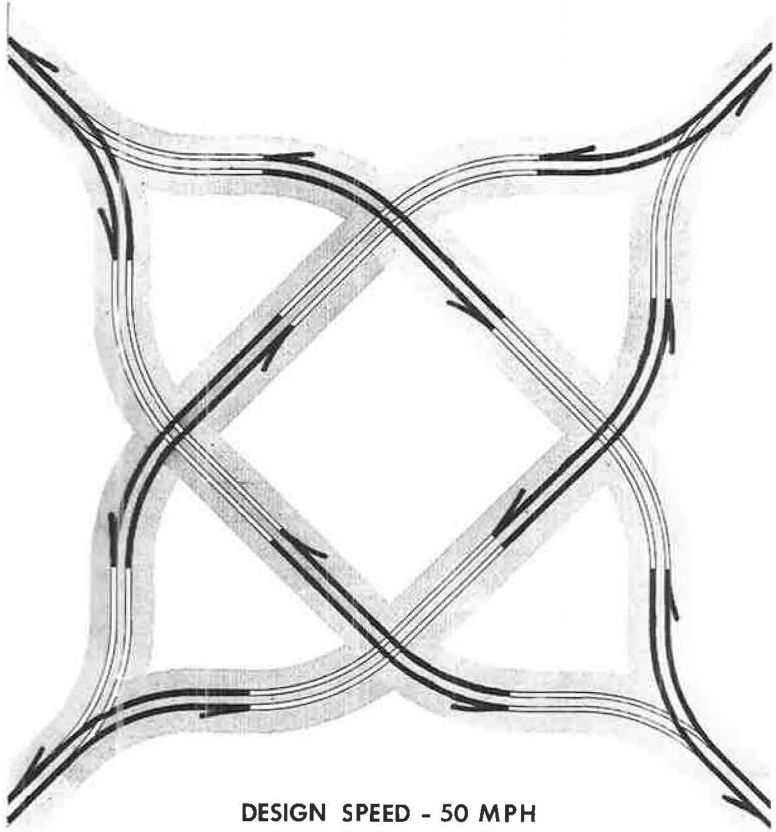
Figure 5.



DESIGN SPEED - 50 MPH
SIGNAL CYCLE - 40 SEC.
SCALE OF FEET
0 500 1000

5 Seconds

Figure 6.



DESIGN SPEED - 50 MPH
SIGNAL CYCLE - 40 SEC.
SCALE OF FEET
0 500 1000

10 Seconds

Figure 7.

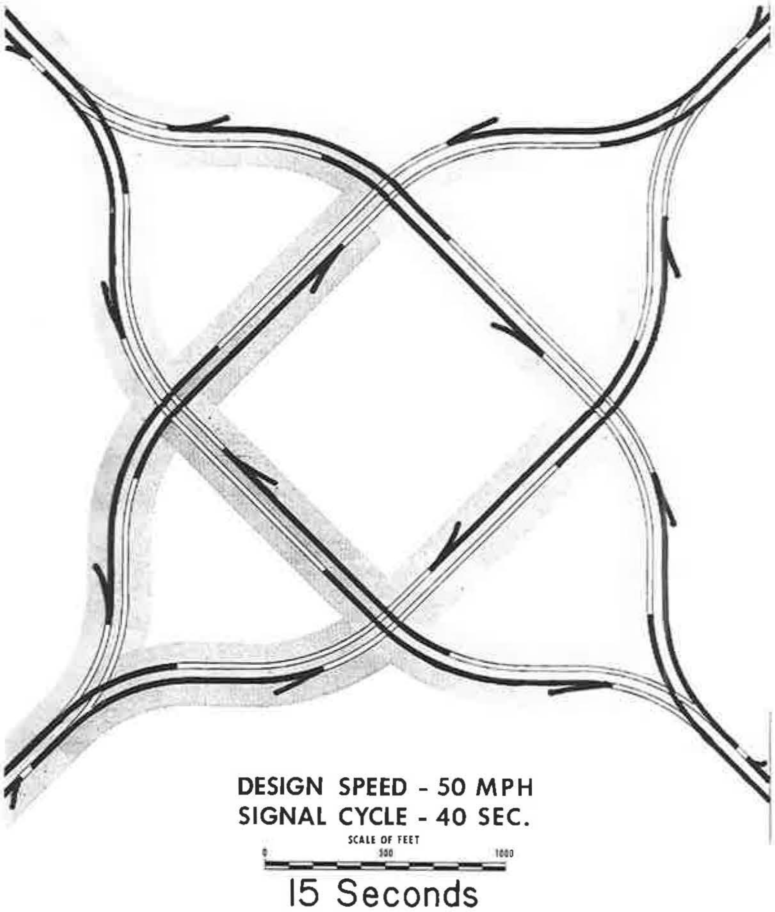


Figure 8.

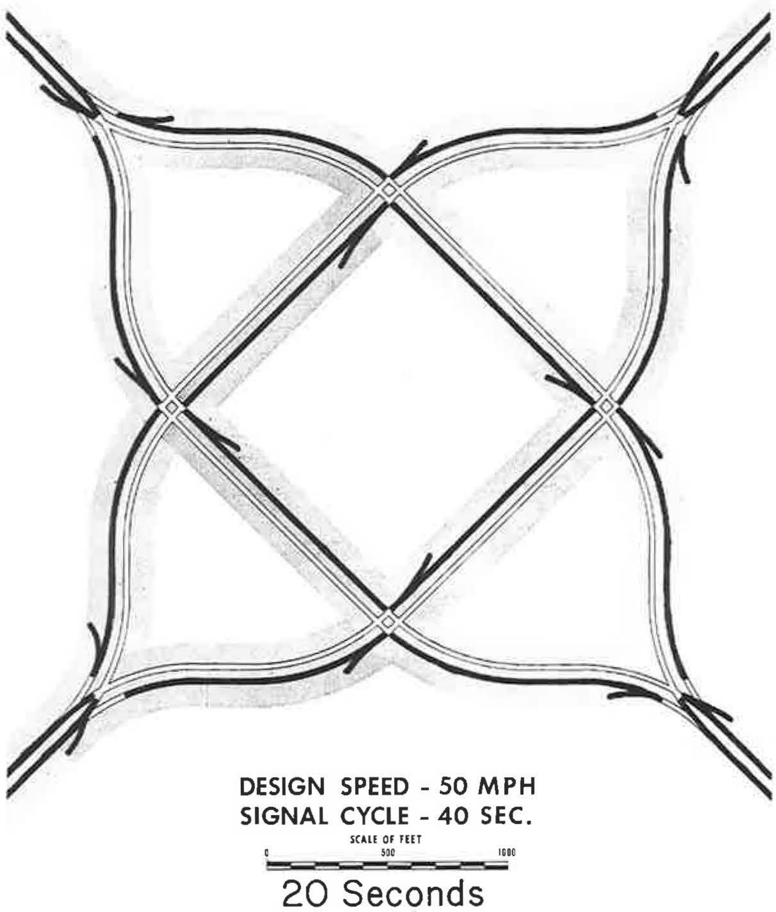
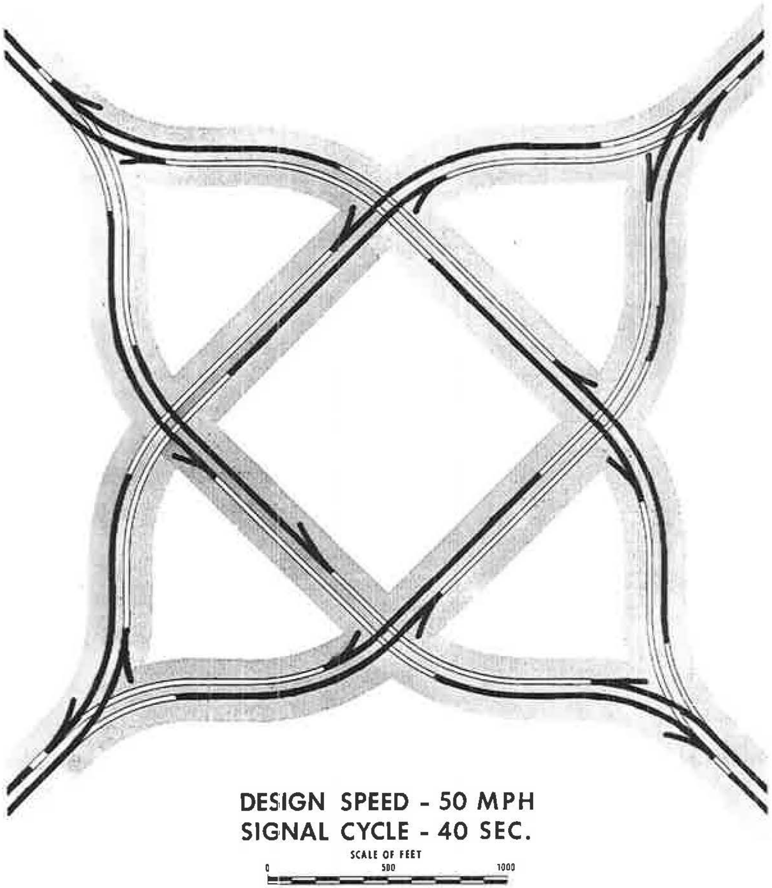
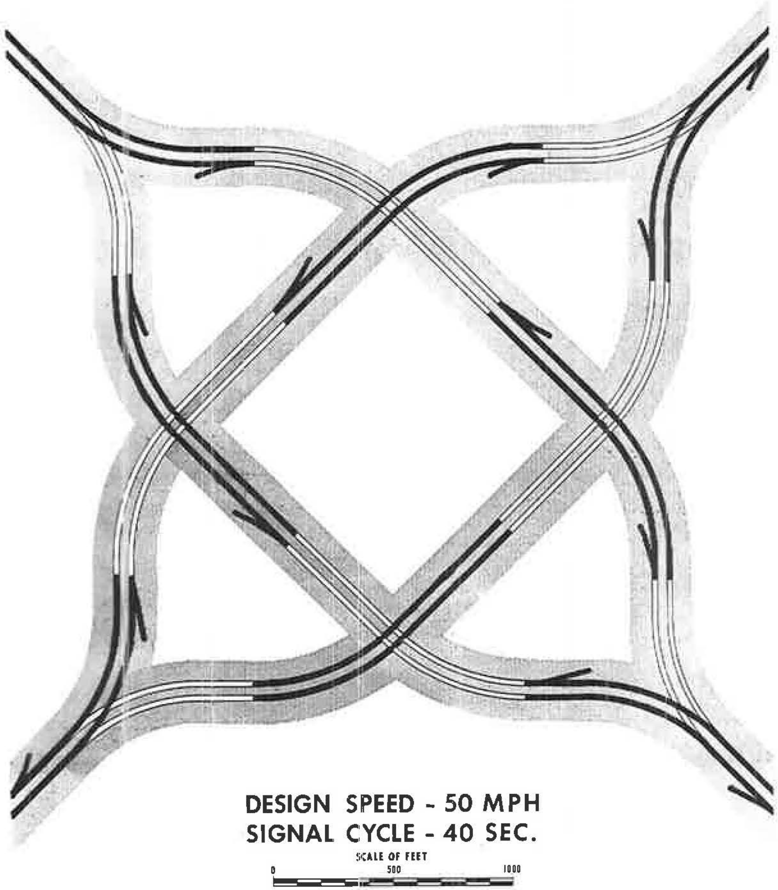


Figure 9.



25 Seconds

Figure 10.



30 Seconds

Figure 11.

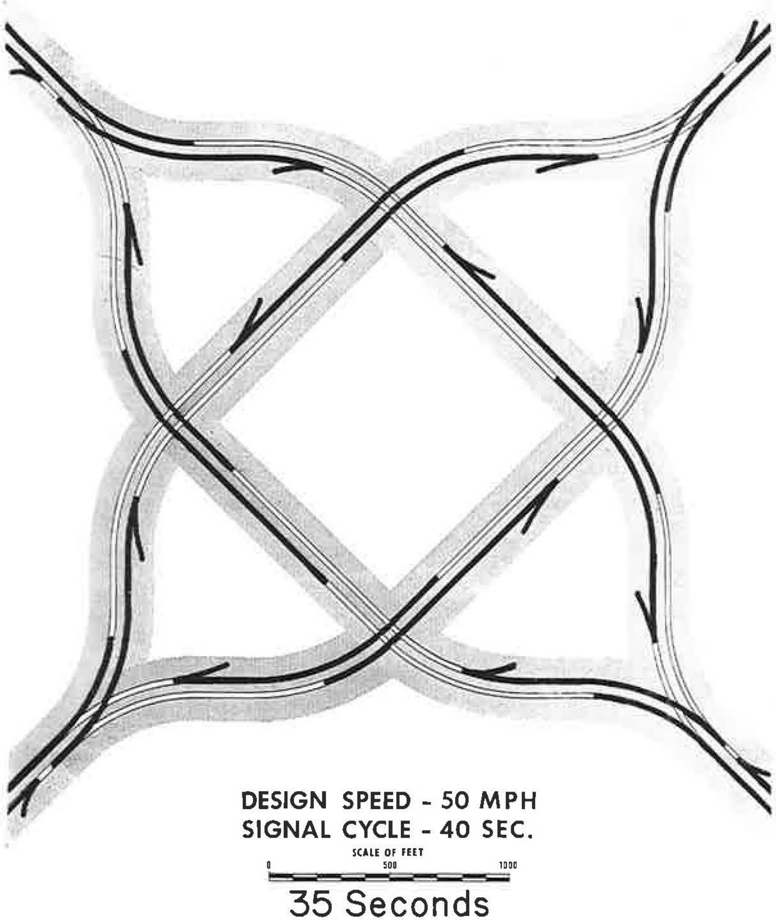
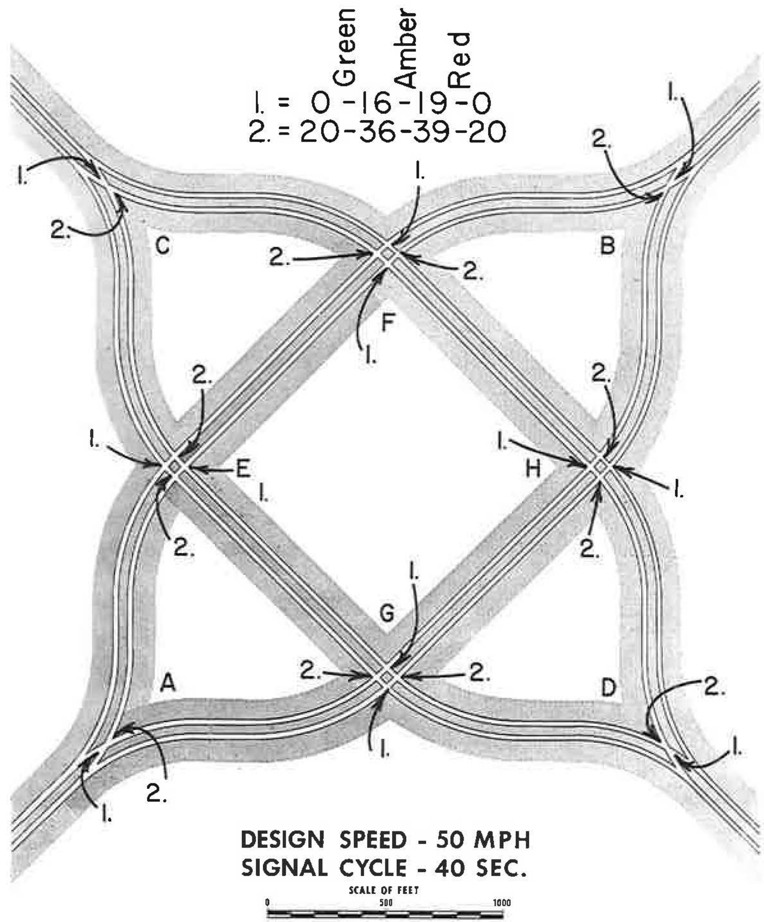


Figure 12.



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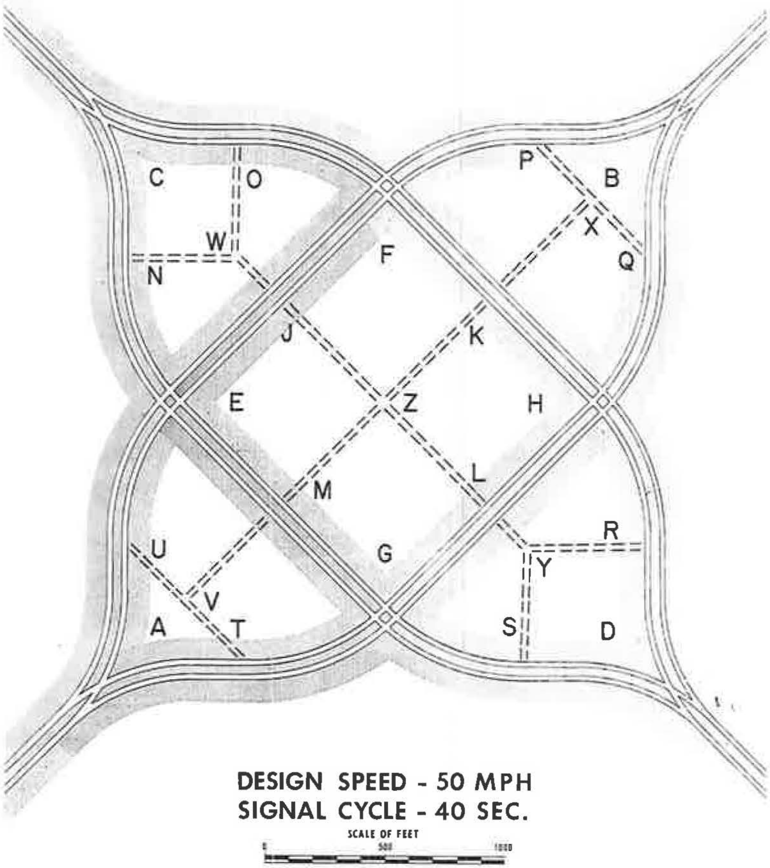

Figure 14.

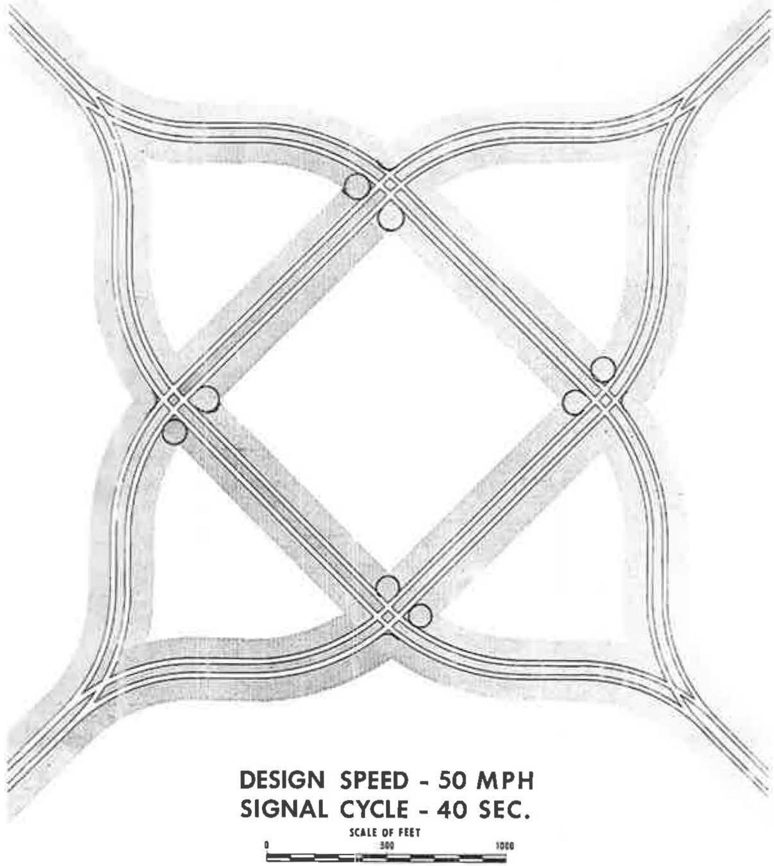

Figure 15.

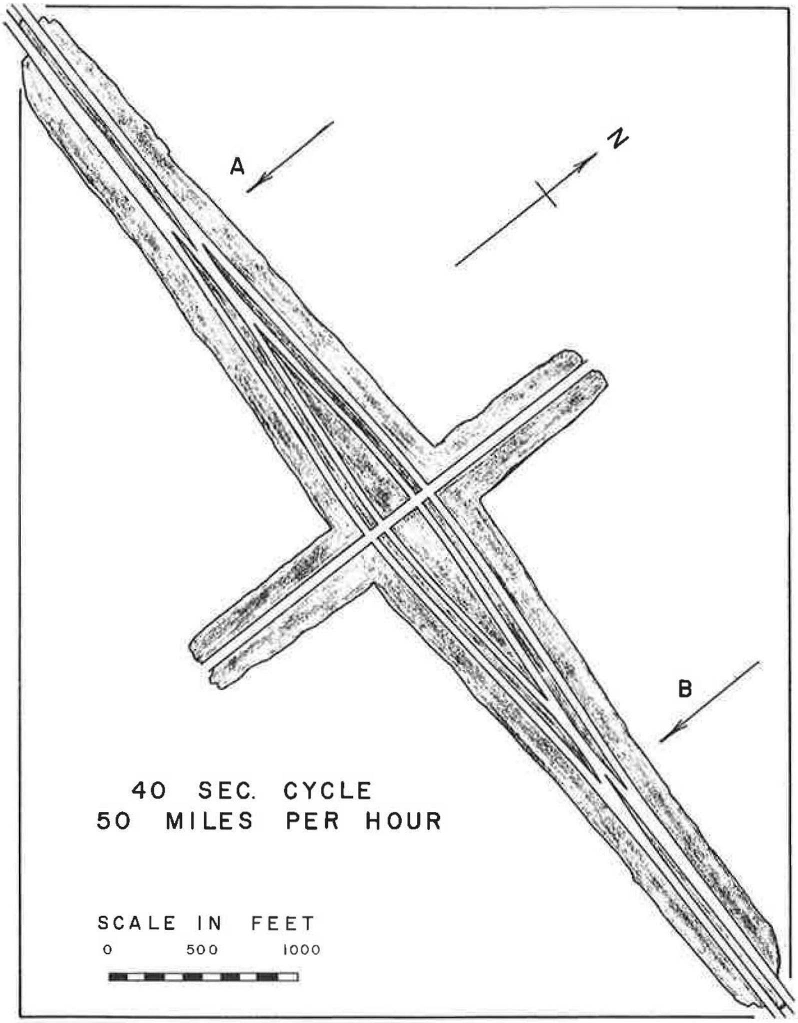

Figure 16.

directed to the right from 40 to 60 sec which is the same as 0 to 20 sec repeated. This alternation continues at these fixed intervals.

TRAFFIC CONTROL

The first car passing A after 0 time will go to the right and, traveling at 50 mph, will pass G right after 20 sec time, will pass H right after 40 sec (0 time), and then pass B right after 60 sec (20 sec). The last car going to the right at A will pass just before 20 sec, pass G just before 40 sec, pass H just before 20 sec and pass B just before 0 sec (or 40 sec). The next 20 sec of cars at A will go to the left with the first car passing E at 0 time and the last car at 20 sec. In this manner all straight through movements can be traced through the intersection. Turning movements will be discussed later. It can be seen that if the first car of any slug goes faster than 50 mph it must be slowed down or stopped, but if it goes slower it would still get through in the proper time band. The last car in the slug, if it goes faster than 50, will not be delayed, but if it goes slower would be in the wrong time band.

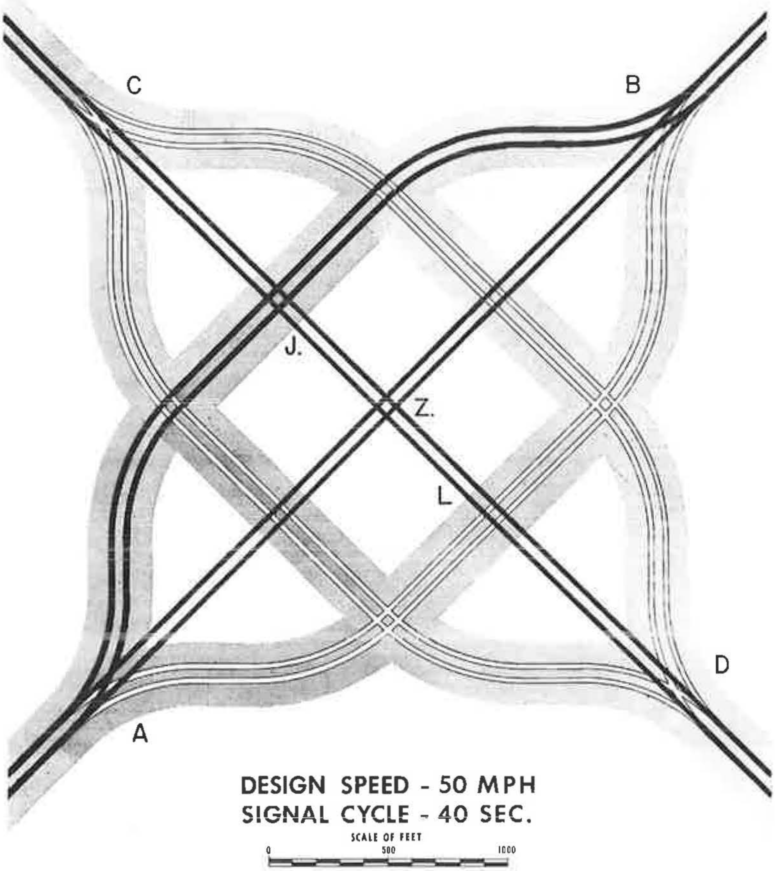

Figure 17.

Although a great majority of cars moving freely on any section of road maintain speeds with little variation, a few cars do travel faster and a few do travel slower. Drivers that are going too fast can be induced to slow down by proper signal systems. It is easy for them to realize that it is to their advantage to slow down to avoid stopping. The drivers that are going too slow at the end of the slug can be induced to go faster by the same signal system. If they cannot, or do not care to go faster, they must stop before crossing the path of other cars.

Figures 5 to 12 illustrate the progression of vehicles through the intersection in 5-sec intervals demonstrating that there are no conflicts.

SPEED CONTROL AIDS

Speedometers are not as precise as would be necessary for good operation, and it is not desirable that drivers continually look at their speedometers. Therefore, to provide a positive indication to aid those who might be going too fast or too slow, a timing device would be located at each signal.

The timing device could be a lighted sign 10 ft long and 2 ft high suspended horizontally on a mast arm. When the signal is red, the horizontal bar would be lighted with random razzle-dazzle red lights. At the beginning of the red period the bar would be entirely lighted. As time passed, the lights toward the middle of the road would go out progressively. When the prohibited time was half consumed, the bar would be lighted throughout one-half its length. As time passed, the bar would get

smaller and smaller until at the end of the restricted period all of the bar lights would be out and a green bar mounted vertically on the pole would behave similarly during the "go" period. In this manner approaching drivers could adjust their speeds favorably.

In addition to the special timing device, standard traffic signals would be used. The timing and offsets for the signals are shown in Figure 13. Note that there is a one second all red interval at each change of signal.

FREEWAY

The areas not needed for roadways such as the area E F H G, A E G, etc., remain in private ownership. They may become valuable parcels of lane. The roads (Fig. 1) could be freeways with no access permitted to adjacent property. This access could be provided by secondary roads such as shown by dashed lines in Figure 14. At points J through U, left turns off the highway onto the secondary roads could be made without interference. Left turns from the secondary roads to the major roadways could not be permitted, but since right turns could be permitted at all points E through U, all movements could be made without undue inconvenience.

Movements directly across the major roads at J, K, L and M could not be allowed. A movement Z to V would be made by way of Z to L to G to T and to V. The movement from V to Z would be made by way of U, E and J. Traffic signals would also be installed at locations J through U to make the alternation of traffic positive, but they would also serve as traffic pacers for the through traffic. It can be seen that left turns toward V, W, X and Y can be made during one-half cycle from 10 sec (Fig. 7) to 30 sec (Fig. 11) without conflict. The left turns to Z would be made for one-half cycle from 30 sec (Fig. 11) to 10 sec (Fig. 7). If at A a driver was sent to the right, he could get to W by way of T, U and J.

LEFT TURNS

Left turns can be routed indirectly by way of the secondary roads if available. If not available inside loops, as shown in Figure 15, could be provided. These inside loops should have a length that would require one-half cycle to complete at the reduced speed provided by this short radius. In this way the left turn vehicles would not stop although they would be slowed down to about 15 or 20 mph.

MINOR CROSS ROAD

Figure 16 illustrates a possible treatment for the intersection of a major and a minor road in which the major movements are uninterrupted but the minor road traffic is delayed. A minor road with 5,000 cars per AADT would be served very well with this design.

STAGE CONSTRUCTION

Figure 17 shows the possibilities of utilizing stage construction. Assuming that there are existing crossroads A Z B and C Z D the road A J B could be built creating a major-minor type design. This stage must operate on a 58-sec cycle, the speeds on A J B must be 52 mph and on A Z B must be 47 mph because of the shorter distance on A Z B. During the second stage the road A L B could be constructed and the old road A Z B should be cut off at A and at B. Now 50 mph can be maintained on both roads between A and B and the signals operated on a 60-sec cycle. The final stage would be to build the alternate roads between C and D, cut off the old road C Z D at C and at D and to operate the signals on a 40-sec cycle.

ADVANTAGE

This principle is suitable for freeways, as well as other highways. It is common practice along freeways to build a bridge at each road or street crossed even though they may not have provisions for interchange movements. Some of the roads crossed may have very small traffic volumes, but the bridges cost just as much as if it were an important crossroad.

The switch point intersection has a great advantage over bridged intersections in that the switch point capacity can be increased as traffic volumes increase year after year whereas this is not readily possible with bridges. The capacity of the switch point design can be increased by adding more lanes to the existing lanes. To increase the capacity of bridged interchanges by adding lanes most always requires the reconstruction of the bridges and possibly a redesign of the entire interchange.

On high volume roads the normal yearly increase in traffic may require the addition of one lane in each direction every year or two in order to maintain the same level of service. For example, a road carrying 150,000 cars per average day with a one-way design hour factor of 10 percent and a design capacity of 1,500 cars per hour per lane, should have no less than 5 lanes in each direction. Now if the traffic volume increases 20 percent in two years there should be no less than 6 lanes in each direction. This means the addition of two lanes in 2 years. If the road had 300,000 cars per average day and for the same conditions it would be necessary to add one lane in each direction at the end of one year.

Grade separated interchanges such as the clover leaf, diamond interchange, and directional interchange were developed and became popular in the period from 1930 to 1950 when high volume roads carried from 30,000 to 60,000 cars per average day. Now high volume roads carry more than 100,000 cars per average day the major problem is to maintain the desired level of service as traffic volumes increase year after year. The switch point design can be flexible and, therefore, provide for future growth economically.

A Study of Roadside Delineator Effectiveness On an Interstate Highway

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This research was initiated to determine if post-mounted reflective delineators placed along Interstate highways were effective and valuable enough as a traffic control device to warrant their installation and maintenance.

The primary investigation consisted of the measurement of vehicle speed and placement at a single point within each of 4 test sections, 2 tangents and 2 curves, located on a single segment of Interstate 10 in southwest Louisiana. These measurements were made with a radar speed meter and a Bureau of Public Roads placement tape for a minimum sample of 100 independent passenger-car vehicles for each combination of experimental conditions: daylight vs nighttime, nondelineated vs post-delineated vs edge-stripe delineation, eastbound vs westbound direction of travel, and tangent vs curve geometrics, a total of 24 combinations. In addition, supplementary speed and placement, nighttime driver interview and test-vehicle distance-lapse film studies were conducted to help verify primary investigations.

Analysis of the principal study data showed mean speeds to be some 2 mph lower under delineated conditions than under nondelineated conditions but this difference was not considered to be significant from a practical standpoint. Also there was no significant effect of delineation on vehicle placement. (In general it was shown that vehicles travel closer to the centerline at nighttime as compared to daytime and at speeds over 64 mph as compared with traveling at speeds less than 55 mph.) Driver interviews provided origin-and-destination data on vehicles using the test sections at night and yielded an almost unanimous approval of delineation by drivers.

Analysis of test-vehicle distance-lapse films provided placement profiles for individual vehicles or drivers and determined a new traffic characteristic, the Placement Profile Smoothness Index; however, the limited number of such studies obtained did not provide a positive basis for distinguishing the effectiveness of roadside delineation.

•THE manual on Uniform Traffic Control Devices (1) contains the specification for the placement of reflective delineators along Interstate highways. In general, it is required that the delineators be placed 2 ft off the edge of shoulders or 2 ft outside the face of barrier curbs at 200-ft longitudinal intervals on tangent sections. The delineator faces should also be 4 ft above the near pavement edge (Fig. 1a).

Paper sponsored by Committee on Traffic Control Devices.

Experience with these delineators on sections of I-20 has led the Louisiana Department of Highways to seriously question their value. A high incidence of vandalism and damage from vehicles made the maintenance costs much higher than usually claimed for this type of delineation. Also, when placed off the shoulder edge, the delineator posts become obstacles for mowing machines requiring additional time and expense for hand clipping around the post.

The Department of Highways therefore posed this question. Are these delineators effective and valuable enough as a traffic control device to warrant their installation and maintenance? To answer this question the Division of Engineering Research of Louisiana State University entered into a research contract with the Louisiana Department of Highways financed in part by Federal-aid funds through the cooperation of the U. S. Bureau of Public Roads.

BACKGROUND

Opinion Surveys

In the past two years there have been two questionnaires relative to delineator use on Interstate highways sent to the highway departments of the 50 states and the District of Columbia. The first was the AASHO questionnaire of November 1962 (2); the second was sent out by the Alabama State Highway Department in December 1963 (3).

Based on 44 replying departments, the AASHO study showed 68 percent favoring the use of these delineators on the entire Interstate System while the others felt that the use of delineators was desirable and necessary on horizontal curves, interchanges, or at special locations. Only 20.4 percent of the respondents favored the use of the standard 200-ft spacing of delineators; 34.1 percent preferred 264 ft, 1/20th mile spacing, 11.4 percent preferred 264 ft-400 ft, 27.3 percent preferred 400 ft, and 6.8 percent preferred over 400-ft spacing.

The Alabama survey had 46 replies with only one, Alaska, in this group reporting no Interstate highways. The results of this survey showed the following based on the indicated number of definite responses to each question.

1. Of 40, 82.5 percent indicated that delineators constitute a maintenance problem.
2. Of 41, 48.8 percent indicated that the general Manual spacing of delineators (200 ft) is too close (plus 9.7 percent say too close on tangents).
3. Of 31, 35.5 percent recommend 400 ft or greater spacing in general (plus 6.5 percent recommend 400 ft on tangent).
4. Of 41, 70.7 percent use edge striping on Interstate highways with 100 percent of edge striping done with solid line.
5. Motorist preference in 23 states showed 30.4 percent preferring edge striping, 8.7 percent preferring delineators, and 60.9 percent preferring the combination of edge strips and delineators.
6. Of 39, 69.2 percent believe the delineator's value is doubtful in lighted sections.
7. Of 43, 67.5 percent believe that AASHO should reconsider its policy on delineators.

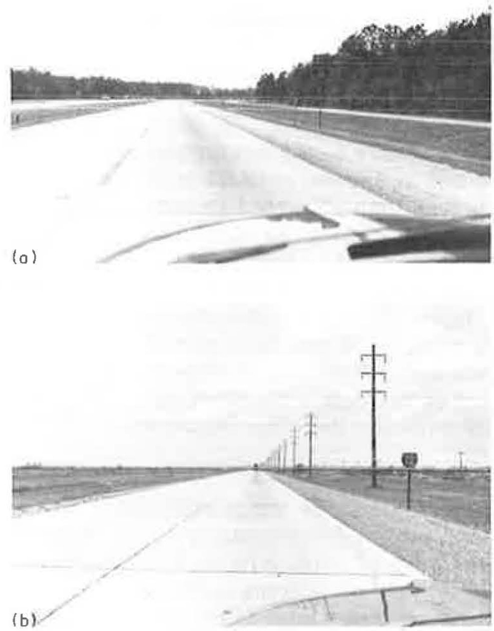

Figure 1. Delineation treatments used on I-10: (a) post-mounted reflective delineators, (b) edge striping.

Other Delineation Research

In considering this research, the literature was searched for similar studies in an attempt to determine what methodology would be most applicable to this study.

A study initiated in 1958 and reported by Taragin and Rudy (4) evaluated the effectiveness of highway illumination and roadside delineation in interchange areas of the Connecticut Turnpike. Under nine different combinations of illumination and delineation, the effects on accident rate, vehicle speeds, lateral placement, headways, lane use, and utilization of acceleration and deceleration lanes were measured. The Bureau of Public Roads Mobile Traffic Analyzer was used to record data for a total of some 183,000 vehicles. Analysis of these data showed no significant relationship of average speed or lateral placement to the nine study conditions. However, based on lane-use analysis, they concluded that the results pointed up the value of roadside delineation with or without illumination in the interchange area.

Another study conducted in Connecticut was reported by Williston (5) in 1960. This study also measured speed and placement of vehicles on three 2-lane highways and one 4-lane divided highway under nondelineated and edge-striped conditions. They found that edge striping increased nighttime speeds and tended to move vehicles farther from the centerline of the highway.

The Louisiana Department of Highways has conducted two studies of traffic operation characteristics on sections delineated by edge stripes. Equipment of the Bureau of Public Roads was used to measure speed and placement of vehicles through several test sections 2.5 to 4 miles long. In the 1956 research reported by Thomas (6), there were few significant results obtained from speed and placement data; there was a tendency for vehicles to be closer to the centerline with edge striping than without, especially at night. The main benefit of the edge stripes was found to be psychological, as 86 percent of all drivers interviewed in one study believed that the edge stripe helped them in driving. The 1957 research reported by Thomas and Taylor (7), on different highway sections tended to verify the placement results of the 1956 research and served as a basis for the adoption of edge striping on all 24-ft two-way highways and limited use on 4-lane divided highways.

Other studies have used accident analyses to show the benefit of delineation. Virginia studies reported by Mills (8) in 1958 showed the accident rate was reduced 57 percent on one route and 67 percent on another after special 6- × 48-in. delineators were installed. A paper by Musick (9) concerns accident studies made in Ohio on nine pairs of highway sections, 6 miles long on the average, throughout the state. One half of each pair was edge striped, and the other half was not edge striped. The main results were significant reductions of fatalities and injuries, night accidents, and accidents at intersections, alleys, and driveways.

The most recent delineator research was reported by the Arizona Highway Department (10). On seven representative 2-lane, two-way highway sections, 13 to 53 miles long, installation and maintenance costs were obtained for each delineation treatment (nondelineated vs steel post-mounted delineator plates, 2 × 6 in. placed 8 in. off the pavement edge and spaced 400 ft apart vs 4-in. white continuous shoulder stripe), traffic accident experience, vehicle speeds, and lateral placement of vehicles in a driving lane. The following results were obtained:

> 1. Night speeds increased when roadway delineation was installed. Increase of night speed was greater with shoulder stripe than with post delineators (5.9 mph vs 3.4 mph faster than the expected night speeds based on statewide trends).
> 2. Vehicle placement measured in feet from the centerline decreased under all shoulder conditions after dark. There is no significant difference between shoulder stripe and post-delineators with respect to vehicle placement day or night.
> 3. Neither shoulder striping nor post-mounted delineators had any deterrent effect on accident occurrence under the conditions of this study.

4. Installation and maintenance costs of the two systems are as follows:

System	Installation Cost/ Route Mile ($)	Annual Maintenance Cost/Route Mile ($)
Post-mounted delineators	146.11	18.55
Shoulder striping	117.97	124.40

On the basis of these cost data they concluded:

1. The annual maintenance cost of shoulder striping makes it too expensive to use except for short sections where special driver guidance is needed.
2. The use of post-mounted delineator plates is considered to be the most practical method of roadway delineation since it provides a satisfactory definition of the pavement edge at a reasonable maintenance cost.

SCOPE

The purpose of this research was to evaluate the effectiveness of roadside delineators on Interstate highways. Inasmuch as it was felt that the primary purpose of any type of roadside delineation was to enable drivers better to follow a road at night or under other adverse visibility conditions, it was hypothesized that the effectiveness of any such delineation would be reflected in improved traffic operation characteristics over those of nondelineated roadways. The two most sensitive characteristics that could be measured were considered to be vehicle speed and placement within a traffic lane, both of which are usually measured at a single "point" within a designated test section.

Based on the results of others' research, previously cited, it was anticipated that point studies might produce insignificant results. It was therefore further hypothesized that the effectiveness of a delineation treatment might be reflected in a smoother path of travel through a delineated section than one not delineated. To measure this characteristic a test vehicle equipped with time-lapse photography equipment was used on a limited study under all conditions of delineation.

Since most engineers agree that relatively sharp curves and interchange areas should be delineated, this research was limited to the study of tangent and relatively flat curve sections. A single 2-mile section of I-10 near Crowley, La., provided four test sections, two curves, two tangents, for the purpose of this research.

In addition to the standard Interstate post-mounted delineator, measurements were made under nondelineated and edge-striped conditions in all test sections. (See Fig. 1b.) Data were collected for both daylight and nighttime conditions.

The complete documentation of this research is contained in a recent report (12) of the Louisiana State University Division of Engineering Research.

EXPERIMENTAL PROCEDURES

Test Section Selection

Construction of I-10 through southern Louisiana is incomplete except for a few sections. One of these sections runs for 14.7 miles between Jennings and Crowley (Fig. 2). This section was opened to traffic in April 1963 two months prior to the start of this research. Average daily traffic measured on the eastern end of this section was 2,337 in May 1963 and 2,727 in May 1964. Though this relatively low volume would require longer periods of time to collect sufficient data for analysis, it was felt that a high percentage of the vehicles on the facility would be independent

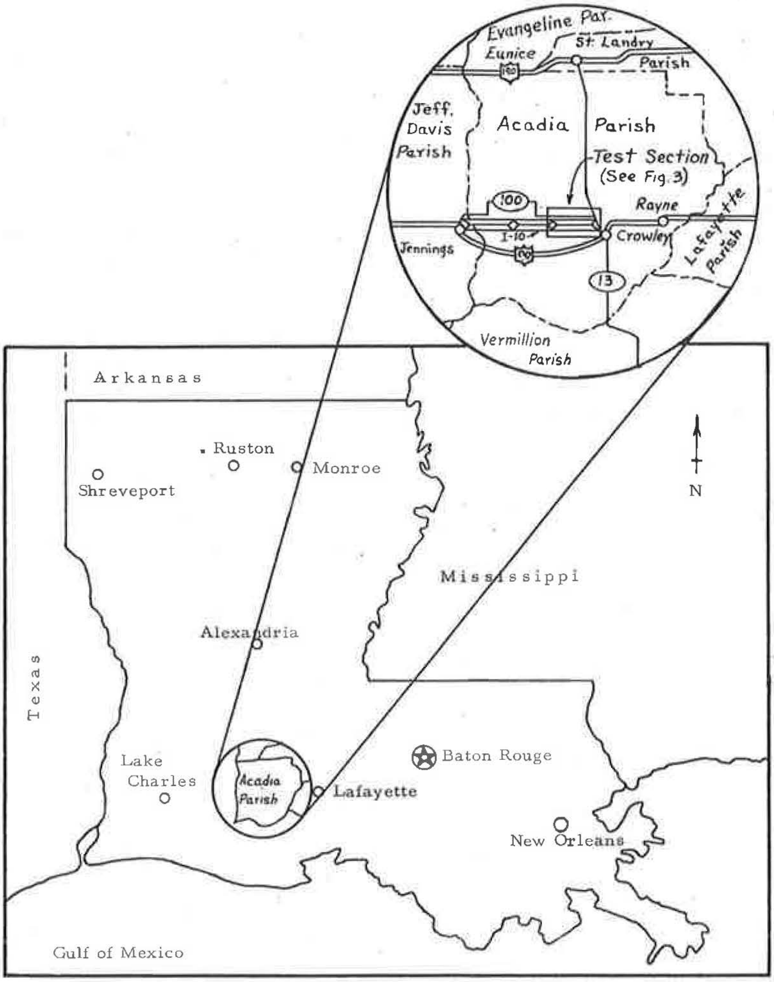

Figure 2. Location of project test sections.

of each other, and therefore their speed and placement characteristics should reflect the effect of roadway characteristics or delineation treatment.

The eastern end of this section of I-10 was used for this research because it had the longest tangent roadways, separated by a median at least 120 ft wide, and also contained a relatively flat curve at one end of this tangent (Fig. 3). It was felt that the wide median would minimize the effect of opposing headlights on vehicle speeds and placement. Another advantage of this location was the availability of continuous service roads on either side of I-10 providing a less conspicuous location for study personnel and equipment.

Speed and Placement Studies

Experimental Variables. —In setting up an experiment to measure speed and placement values, the following variables were considered important.

1. Delineation treatment—standard lane lines (Section 2B-5, 1) present for all 3 of the following treatments: (a) nondelineation (of roadside or edge of pavement), (b) post delineators, and (c) edge-stripe delineation.
2. Roadway alignment: (a) tangent, and (b) curve.

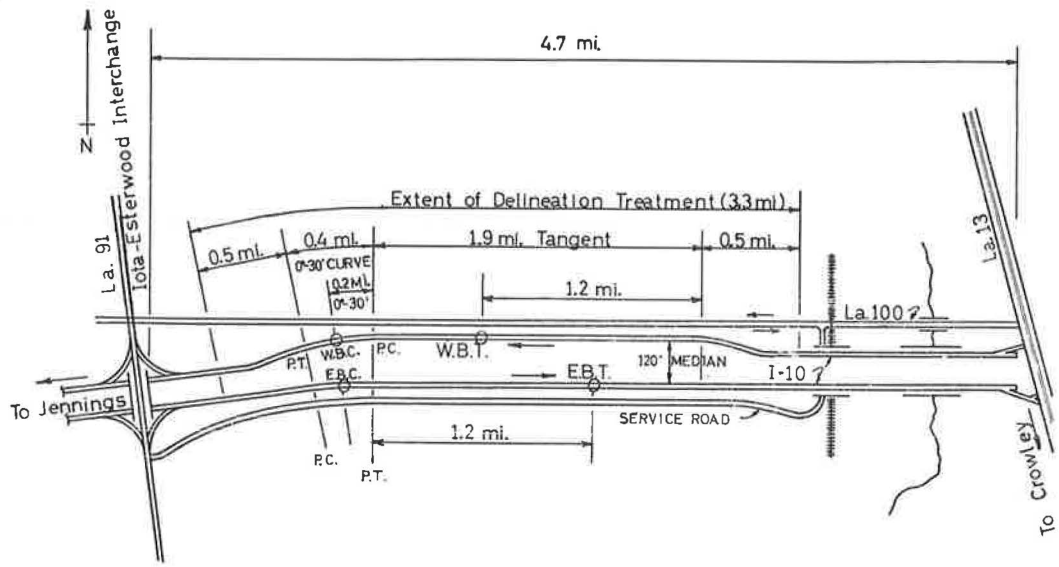

Figure 3. Experimental design: location of test sections in east end of I-10 between Crowley and Jennings.

3. Light condition: (a) daylight, (b) twilight, and (c) night.
4. Vehicle type: (a) passenger vehicles, pickup trucks, (b) single-unit trucks, and (c) heavy trucks (tractor with semitrailer, etc.).
5. Travel direction, length of travel on I-10 before test section: (a) eastbound—11 to 12 miles, and (b) westbound—2 to 3 miles.

Experimental Design

To evaluate these variables, a field design was used as shown in Figure 3. The 4.7-mile Crowley end of the I-10 section selected for these studies provided a 0.4-mile long (0° -30') curve and a 1.9-mile long tangent, back-to-back, both separated by a 120-ft wide median. Four study points were then selected: WBC, WBT, EBT and EBC (Fig. 3).

By studying both sections in both directions variables 2 and 5 were covered. On any given day measurements were made at one point for all vehicles that passed from about 1:30 p.m. to 11:30 p.m.; this covers variables 3 and 4. Variable 1 was covered by first studying traffic operation under nondelineated conditions; then post delineators were placed every 200 ft over approximately 3 miles extending 0.5 mile beyond each end of the test sections and studies repeated, and finally post delineators were removed and the same length of roadway was edge striped with solid white lines on both sides of each roadway. The order of conducting these studies (i.e., by section and 1st vs 2nd day of measurements) under each delineation condition was chosen by random selection. Field studies began on June 27 and were completed on August 29, 1963.

Analysis of traffic volumes from placement charts for nondelineated conditions in the first two weeks of July 1963 showed the average hourly volumes in one direction over 3-hr day periods and 3-hr night periods (Table 1). Because of a relatively low traffic volume on I-10, it was necessary to conduct studies under a given set of conditions at least one day and two nights to collect a usable sample of at least 100 (preferably 150) for each light condition.

TABLE 1
AVERAGE HOURLY VOLUMES

Condition	Shoulder Lane			Median Lane		
	Autos	Trucks	Total	Autos	Trucks	Total
Day (2-5 p.m.)	78	8	86	10	0	10
Night (8-11 p.m.)	28	2	30	2	0	2

Measurement Procedures

The speed of every vehicle passing through the test sections was measured with a radar speed meter with a range of 500 ft and accuracy of ±2 mph. Each vehicle's placement within the roadway was measured through use of a Bureau of Public Roads placement tape connected to a 20-pen recorder providing placement accuracy of ±0.3 ft. The use of this combination of equipment required only one tape across the road thereby reducing the suspicion of a speed trap; Louisiana State Police use the two-tube speed-clock system in measuring speeds.

At each of the four stations where measurements were made, an Interstate route marker was erected opposite a transverse joint in the roadway. This served a dual purpose in that it marked the study point for succeeding studies at that location and provided a mount for the radar speed meter.

The radar speed meter antenna was mounted behind a special route marker which had the zero in 10 changed to a circular shape with a 6-in. inside diameter. The inside of the numeral was cut out and a piece of plexiglass that had been painted with transparent Interstate blue paint placed over the hole. The radar antenna was therefore not evident to the passing motorist.

The vehicle detector for placement measurements was placed across the 24-ft pavement directly over the transverse joint and held in place by special clamps nailed into the joint. This detector was placed each day at noon and removed by midnight.

Special extension cables permitted recording equipment for both placement and speed measurement to be located on adjoining service roads. La. 100 runs parallel to and north of I-10 in this section with its south pavement edge located 78 ft off to the north pavement edge of the westbound I-10 roadway in the 1.9-mile tangent section. A service road runs parallel to and south of I-10 in this section with its north pavement edge located 49 ft off of the south pavement edge of the eastbound I-10 roadway in the 1.9-mile tangent section. It was felt that with recorders, personnel, and vehicles located on these frontage roads, drivers would be less likely distracted by the study operation.

One man could operate the recording station keeping watch on recorder operation and periodically placing time checks onto the chart. He also coded vehicle type and out-of-state marks onto the placement chart for later analysis purposes. A typical setup is shown in Figure 4.

Supplementary Studies

In order to obtain a check on the validity of the primary point studies and to obtain additional information of interest to this project, a number of supplementary studies were conducted.

Speed Studies. —In an attempt to see if the presence of a vehicle detector across the road and/or personnel off the roadside were affecting vehicle speed at the point of measurement, speed measurements were made simultaneously upstream and downstream from the test station on one day during each set of studies.

A man was stationed some 1,500 ft upstream from the station with a stop watch timing vehicle speed over 2 pavement slabs (117 ft). The downstream check was made with a second radar speed meter located 2,000 ft beyond the test station, the extra distance accounting for the fact that the radar meter detects speeds some 500 ft upstream from the meter's location. At all three points, each vehicle was identified as to make and color for later correlation. Analysis of the data provided a study of individual vehicle speed patterns and speed distributions at each point.

Placement Studies. —A second placement tape and recorder were located at the downstream speed measuring point generally on the same days that speeds were being checked there. The purpose of these studies was to ascertain if a different detector location would result in a different average placement and placement distribution. All

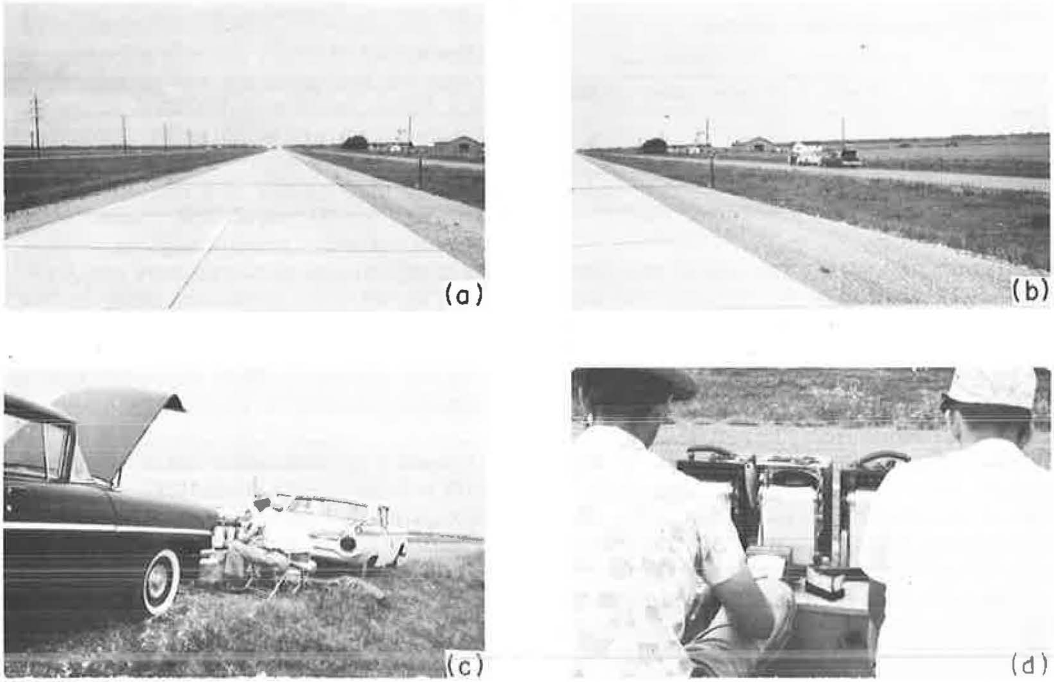

Figure 4. Typical equipment setup for speed and placement measurements: (a) drivers' eye view, (b) observers' vehicle location, (c) observers' location, and (d) measurement recorders.

of these studies were conducted on days when the main station was located on the eastbound tangent (EBT).

Interview Studies. —In an attempt to learn more about the composition of traffic using I-10 and to assess driver opinion of delineation treatments, two interview studies were conducted. The first was conducted on the last night of post delineation (August 12). The second was conducted on the last night (August 29) of point studies under edge-striped conditions.

The interview station in both cases was set up at the Crowley terminal of the eastbound roadway on the single-lane off-ramp. Two interviewers handled the station and a State policeman was on hand to direct traffic just ahead of the station.

Test-Vehicle Studies. —It was contended that the point studies might not provide the most sensitive measure of delineator effectiveness; therefore, it was felt necessary to conduct preliminary investigations to determine the feasibility of two test-vehicle techniques to provide such a measurement. It was hypothesized that the path followed by a vehicle through a test section would be a more sensitive or dynamic measure of delineator effectiveness than measurements at a single point within the section.

A university vehicle was equipped with a tach-generator unit driven off the vehicle's transmission. This unit is connected to a milliammeter recorder which provides a continuous profile of the vehicle's speed. In addition, a control box contains several switches which enable the operator to code in the location of the check points and other events that may affect the results.

One technique, "test driver," utilizes this vehicle when fitted out with a 16-mm magazine-load motion-picture camera mounted on the left rear door of the vehicle. A test driver is used with this technique, and the path followed by the vehicle over 2 or 3 miles of roadway is recorded by the camera. Individual frames are exposed at about 100-ft (of distance traveled) intervals through a solenoid actuated by the tach-generator unit. A distance indicator mounted on the vehicle's front bumper extends

into the camera's field of view and appears near the top of each picture. The distance of the vehicle's left front tire from the roadway centerline can then be determined and a continuous placement profile obtained. Figure 5 shows the equipment setup for this procedure.

Although a very accurate placement measurement can thus be obtained, the technique has one inherent disadvantage. The driver, however unfamiliar or familiar he may be with the project, is in a somewhat artificial situation. He realizes that something unusual is going on, and his normal driving pattern may be greatly affected. It may be difficult to separate the delineation effect from the driving pattern.

A second technique, "car following," eliminated the above disadvantage. In this procedure the door-mounted camera is replaced by another 16-mm camera equipped with an 85-mm zoom lens and mounted on a tripod set up on the back seat of the test vehicle. Vehicles actually using I-10 were selected at random and followed at a constant distance of approximately 250 ft for at least two miles of roadway. Individual frames are again exposed at about 100-ft intervals of travel distance. One possible disadvantage of this technique may be that some drivers may become aware of the vehicle following them and think it is a police vehicle.

Measurement of the sample vehicle's speed was obtained by recording the camera vehicle's speed. This measurement depended on maintaining the camera vehicle at a constant distance and adjusting its speed whenever the sample vehicle changed speed.

One difficulty that was experienced with the car-following technique was night photography. A special fast (ASA320) negative type film was used with limited success with many samples lost due to underexposure. By illuminating the indicator at night, very satisfactory pictures were obtained with the test-driver procedure.

With both techniques, a number of frames on each film were referenced to known points along the roadway so that curve and tangent data could be separated.

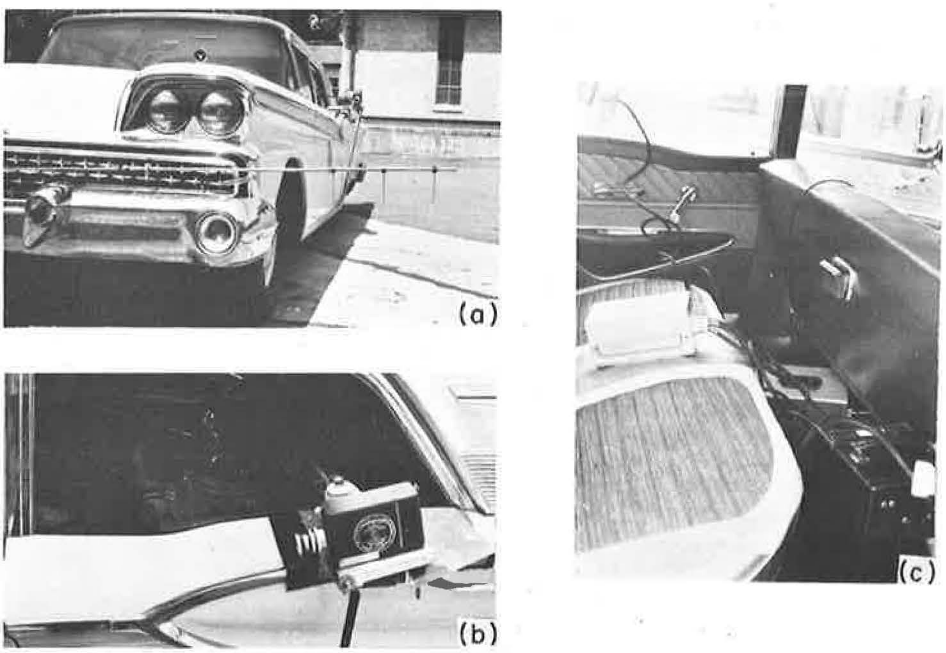

Figure 5. Equipment setup for the "test-driver" procedure: (a) camera-indicator relationship, (b) side-mounted camera, (c) control box, tach-generator and speed recorder in back seat of test vehicle.

Data Analysis

As soon as field data were received, procedures were initiated to process data into a form suitable for analysis.

Point Studies.—The first step in the process was to decode 20-pen chart indications into placement readings utilizing Bureau of Public Roads special tables. At the same time, the vehicle-speed values were read from the speed meter record. Then utilizing periodic time checks, data on both charts were matched to obtain a speed value and a placement value for each vehicle.

These values for independent vehicles were then transferred to data summary sheets. Vehicles were considered independent if they were not preceded by another vehicle closer than 6 seconds in time in either lane. Since volumes of median lane vehicles were very low, less than 10 percent of total at night, only data for shoulder lane vehicles were completely processed (see Table 1).

The data on the summary sheets were keypunched into cards and verified thus permitting any computer analyses deemed necessary. All data processing steps were completely checked before keypunching.

The initial analyses determined average values and standard deviations of the data. In addition, analyses of variance (F-test) and analyses of differences in means were performed.

Supplementary Point Studies.—Supplementary speed and placement data were similarly reduced for analysis purposes, and tabulations of speeds for the three special eastbound tangent studies were made for comparison with main station data.

Test-Vehicle Studies.—The films obtained in the test-vehicle studies were analyzed with a special time-and-motion projector with built-in frame counter. For test-driver runs, pictures were projected on a special white sheet of paper that was ruled off to fix the location of the vehicle-mounted indicator and mark the intersection of the indicator points with the ground. The projector operator then advanced the film frame by frame, lined up the picture as necessary and took the placement reading off the sheet (Fig. 6a).

With the car-following studies, the pictures were projected on a different white paper sheet on which a variable scale was drawn. The projector operator positioned each picture so that a 12-increment scale just fitted between the edge of pavement and roadway centerline and passed through the rear wheels of the vehicle in the picture. The distance in feet (and fraction thereof) between the left rear wheel and the roadway centerline could then be measured (Fig. 6b).

With both procedures, the projectionist obtained a tabulation of film frame numbers and corresponding vehicle-placement values. Vehicle speed and roadway check points were also referenced to frame numbers to complete the data. The placement data were then plotted frame by frame to provide a placement profile for analysis purposes. It was hypothesized that if delineation was effective, it would be reflected in a smoother placement profile than one where no delineation existed.

RESULTS

Point Studies

Median lane vehicles and trucks in the shoulder lane constitute small percentages of total volume on the test section. Data for median lanes were not processed, and trucks in the shoulder lane were excluded from the main analyses.

It is commonly accepted that a speed sample of 100 vehicles is satisfactory for analysis purposes, although one of 150 or more would be desirable. Because of low night volumes in the test sections, it was necessary to collect data on two nights to obtain a sufficient sample. Almost all of the results presented represent combined data for two days or two nights.

The principal results of these studies are summarized in Tables 2 and 3 presenting average values and standard deviations. The average values are also shown in Figure 7. Typical speed and placement distributions are shown in the Appendix.

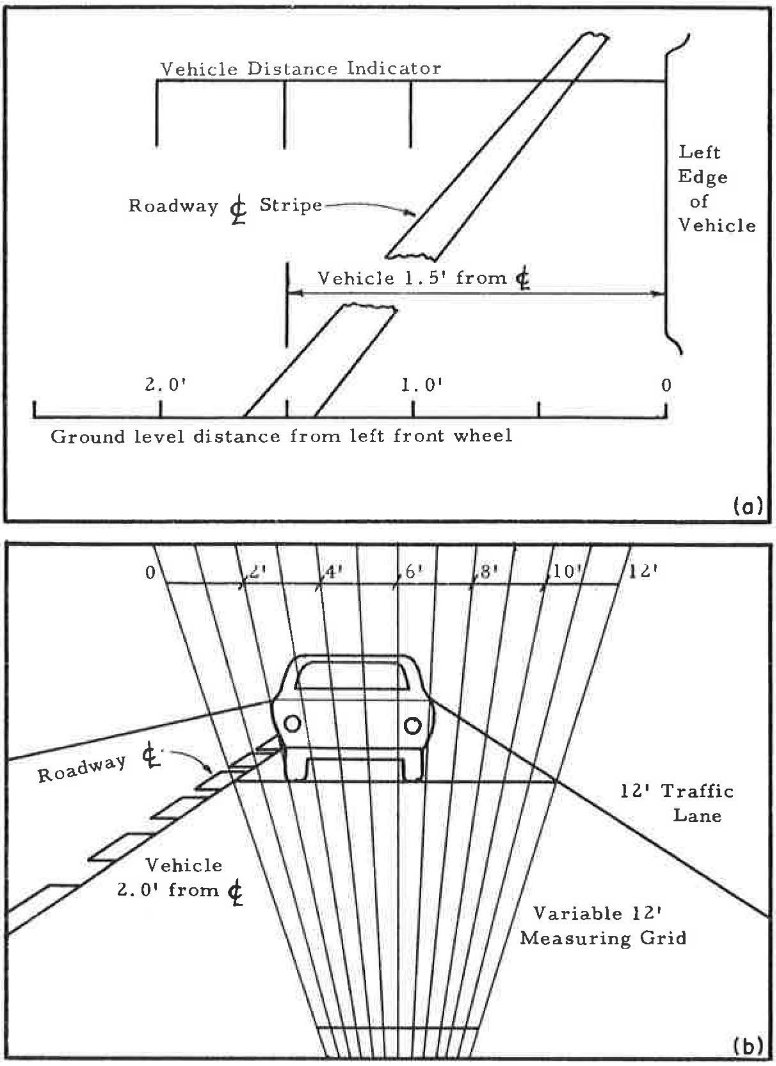

Figure 6. Film analysis techniques for test-vehicle placement-profile determinations: (a) test-driver technique, (b) car-following technique.

From the practical standpoint, it appears that the differences in speed or placement values are not significant. In general, speeds measured under post-delineated conditions are lower than those found under nondelineated conditions, a reversal of what was expected, but these differences are less than 2 mph which is the accuracy limit of the measurement. Also, vehicle placement at night was generally almost a foot closer to the centerline of the pavement than during the day, and there is no appreciable difference in placement, with one exception, under different delineation conditions.

To identify any significant differences in these measurements, an analysis of variance was performed on the averages in Tables 2 and 3. Tables 4 and 5 provide the following results:

1. Mean speeds measured under nondelineated conditions were significantly (at the 5% level) higher than those measured under either post-delineated or edge-striped conditions.

TABLE 2

VEHICLE SPEED VALUES—AVERAGES AND STANDARD DEVIATIONS*

Test Section	Light Condition	Nondelineated			Post Delineated			Edge Striped		
		Sample Size	Avg. Spd. (mph)	Std. Dev.	Sample Size	Avg. Spd. (mph)	Std. Dev.	Sample Size	Avg. Spd. (mph)	Std. Dev.
Eastbound tangent (EBT)	Day	501	58.8	7.6	415	57.3	8.2	503	58.8	7.1
	Night	225	59.3	8.7	235	57.4	9.0	239	59.7	8.2
Westbound tangent (WBT)	Day	416	59.2	8.1	361	57.3	7.6	500	56.8	8.4
	Night	176	59.6	9.7	158	57.8	8.5	176	56.9	7.9
Eastbound curve (EBC)	Day	163	60.9	8.1	410	60.6	8.1	526	58.1	8.6
	Night	168	59.1	9.2	170	59.0	7.6	153	58.3	8.3
Westbound curve (WBC)	Day	214	59.0	6.8	383	59.2	7.1	296	58.6	7.5
	Night	112	58.5	9.3	185	57.8	8.1	164	58.6	8.4

*Radar speed meter accuracy is ±2 mph.

TABLE 3

VEHICLE PLACEMENT VALUES—AVERAGES AND STANDARD DEVIATIONS*

Test Section	Light Condition	Nondelineated			Post Delineated			Edge Striped		
		Sample Size	Avg. Place-ment (ft)	Std. Dev.	Sample Size	Avg. Place-ment (ft)	Std. Dev.	Sample Size	Avg. Place-ment (ft)	Std. Dev.
Eastbound tangent (EBT)	Day	501	7.37	0.99	415	7.36	1.09	503	7.13	0.99
	Night	225	7.81	1.02	235	7.83	1.26	239	7.73	1.12
Westbound tangent (WBT)	Day	416	6.96	0.98	361	6.93	0.91	500	6.72	0.98
	Night	176	7.68	1.08	158	7.59	1.00	176	7.77	1.07
Eastbound curve (EBC)	Day	163	7.45	1.26	410	7.36	1.05	526	7.34	1.08
	Night	168	7.62	1.18	170	7.49	1.20	153	8.93	0.97
Westbound curve (WBC)	Day	214	7.33	1.17	383	7.47	1.28	296	7.67	1.28
	Night	112	8.38	1.70	185	8.13	1.35	164	8.50	1.23

*Vehicle placement is the measurement in feet between the center of vehicle to the edge of pavement; accuracy of this measurement is of the order of ±0.3 ft.

2. Mean placements measured at night were significantly (at the 1% level) closer to the roadway centerline than those measured during the day.

3. Mean placements of vehicles in the westbound curve section were significantly (at the 1% level) closer to the roadway centerline than those in the westbound tangent section.

4. There were no significant differences between mean speeds measured under daylight conditions and those measured at night.

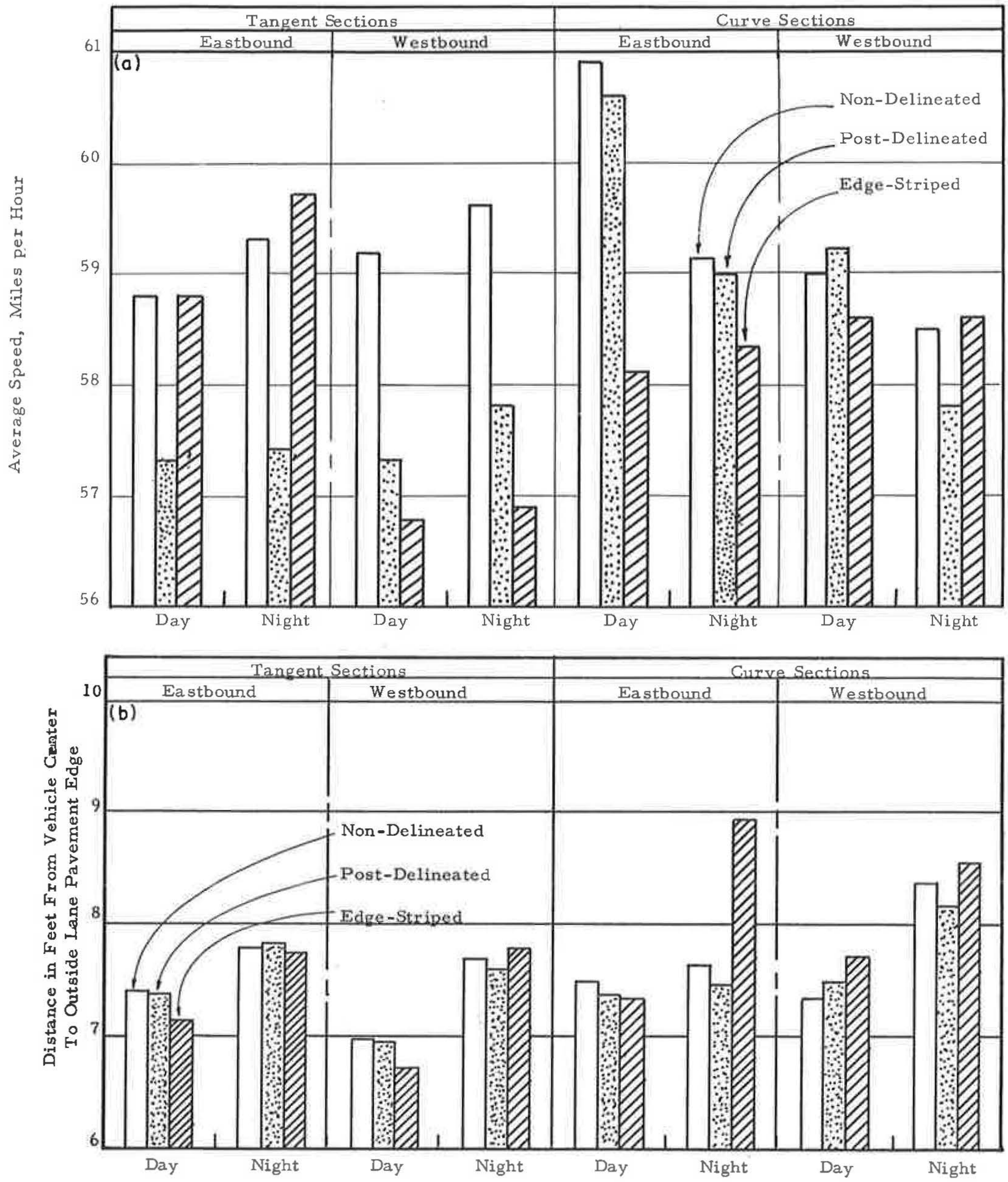

Figure 7. Comparison for all test sections: (a) average vehicle speeds, and (b) average vehicle placements.

5. There were no significant differences in mean speeds between any of the test sections.

6. There were no significant differences in mean placements between any of the delineation conditions.

7. There were no significant differences in mean placements between eastbound and westbound test sections.

TABLE 4

SUMMARY OF ANALYSIS OF VARIANCE OF AVERAGE VEHICLE SPEEDS

Source	Sum of Squares	D. F.	Mean Square	F
Light condition (day vs night)	0.28	1	0.28	0.34
Delineation condition (ND vs PD vs ES)	5.77	2	2.89	3.52
Sections (EBT, WBT, EBC, WBC)	5.91	3	1.97	2.41
Residual (error)	13.98	17	0.82	
Total	25.94	23		
Delineation breakdowns*:				
ND vs (PD+ES)	5.74	1	5.74	7.00**
PD vs ES	0.03	1	0.03	0.04
Subtotal	5.77	2		
PD vs (ND+ES)	1.14	1	1.14	1.39
ND vs ES	4.63	1	4.63	5.65**
Subtotal	5.77	2		
ES vs (ND+PD)	1.77	1	1.77	2.16
ND vs PD	4.00	1	4.00	4.88**
Subtotal	5.77	2		
Section breakdowns:				
Tangents vs curves	3.23	1	3.23	3.94
EBT vs WBT	1.14	1	1.14	1.39
EBC vs WBC	1.54	1	1.54	1.88
Subtotal	5.91	3		
Eastbound vs westbound	2.67	1	2.67	3.26
EBC vs EBT	1.84	1	1.84	2.24
WBC vs WBT	1.40	1	1.40	1.71
Subtotal	5.91	3		

*ND = Nondelineated, PD = post delineators, ES = edge striped.
**Significant at 5 percent level.

To see if there were certain groups of drivers that might provide a more sensitive measure of differences, the data cards were sorted in two different ways and means and standard deviations determined. The first sorting placed the cards into three groups according to the speed of the vehicle; the second, into two groups according to placement.

One of three speed groups consisted of all those vehicles traveling within the 10-mph pace groups of 55 to 64 mph as observed on the speed distribution curves (see Appendix). The other two groups were made up of all vehicles traveling slower than the pace group and all those traveling faster. Figure 8 summarizes the results of this analysis. One obvious characteristic is the faster a vehicle is traveling the closer it travels to the centerline of the roadway.

Since the pace group generally had a large enough sample size and was the most uniform group by speed, it was the only one for which the data were further analyzed. An analysis of variance on pace-group placement data is given in Table 6. The results show the same sources of variation to be significant as were shown in Table 5; however, the level of significance for the difference between the westbound curve and westbound tangent placements was only 5 percent as compared to 1 percent in the previous analysis.

The two-group placement sorting did not produce any results worth noting in this paper.

Table 7 gives the results of a statistical analysis commonly applied to "before and after" speed studies. Kennedy, Kell and Homburger (11) state that in this procedure:

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE OF AVERAGE VEHICLE PLACEMENTS

Source	Sum of Squares	D. F.	Mean Square	F
Light condition (day vs night)	2.92	1	2.92	34.76**
Delineation condition (ND vs PD vs ES)	0.18	2	0.09	1.07
Sections (EBT, WBT, EBC, WBC)	1.30	3	0.43	5.15*
Residual (error)	1.43	17	0.084	
Total	5.83	23		
Delineation breakdowns:				
ND vs (PD+ES)	0.00	1	0.00	0.00
PD vs ES	0.18	1	0.18	2.02
Subtotal	0.18	2		
PD vs (ND+ES)	0.09	1	0.09	1.07
ND vs ES	0.09	1	0.09	0.95
Subtotal	0.18	2		
ES vs (ND+PD)	0.18	1	0.18	2.02
ND vs PD	0.00	1	0.00	0.00
Subtotal	0.18	2		
Section breakdowns:				
Tangents vs curves	0.95	1	0.95	11.42**
EBT vs WBT	0.21	1	0.21	2.50
EBC vs WBC	0.14	1	0.14	1.67
Subtotal	1.30	3		
Eastbound vs westbound	0.00	1	0.00	0.00
EBC vs EBT	0.08	1	0.08	0.95
WBC vs WBT	1.22	1	1.22	14.53**
Subtotal	1.30	3		

*Significant at 5 percent level.
**Significant at 1 percent level.

...[I]t is necessary to estimate the standard deviation of the difference in means by use of the equation [σ has been substituted for s (11)]:

$$\hat{\sigma} = \sqrt{\sigma^2_{\bar{x}_b} + \sigma^2_{\bar{x}_a}}$$

where:

$\hat{\sigma}$ = standard deviation of the difference in means;

$\sigma^2_{\bar{x}_b}$ = mean variance ... of the "before" study; and

$\sigma^2_{\bar{x}_a}$ = mean variance ... of the "after" study.

If the difference in mean speeds is greater than twice the standard deviation of the difference in means, i.e.

$$(\bar{x}_b - \bar{x}_a) > 2\hat{\sigma}$$

where:

$\bar{x}_b$ = mean speed of the "before" study

$\bar{x}_a$ = mean speed of the "after" study

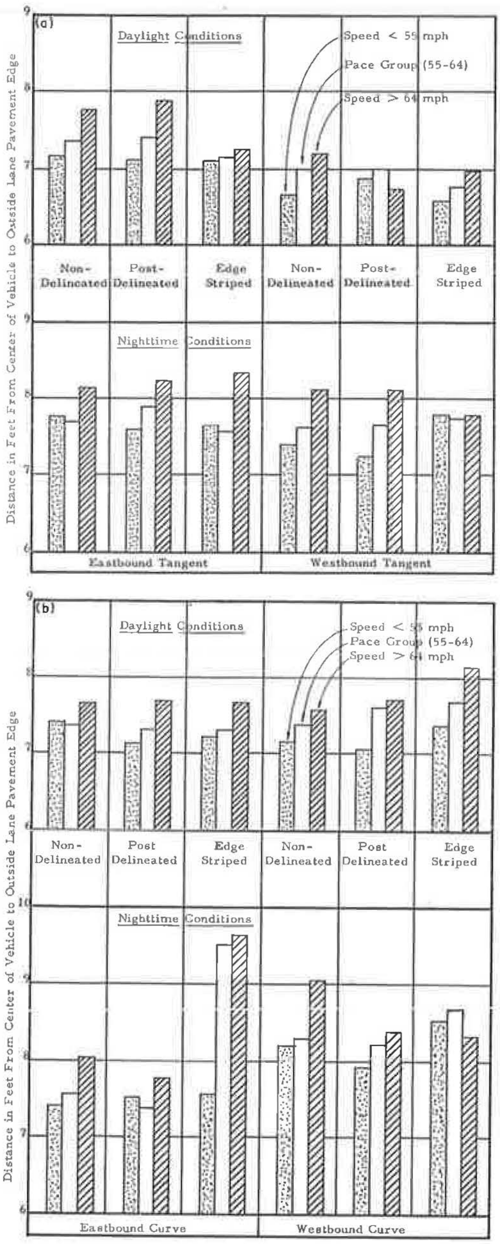

Figure 8. Comparison of average vehicle placements: (a) tangent sections, and (b) curve sections.

. . . it can be said with 95% confidence that the observed difference in mean speeds is significant (the change in conditions has significantly affected the mean speed).

This analysis was also applied to placement data as shown in Table 9. In all cases, the nondelineated daytime conditions serve as the control value being compared, it being hypothesized that this condition provides drivers with their best visibility.

There are several inconsistencies in results (Tables 7 and 8); however, the following results appear to be consistent.

1. Mean speeds in all test sections at nighttime under nondelineated conditions were not significantly different from daylight mean speeds under the same delineation condition.

2. Mean placement values in all test sections under post-delineated daylight conditions were not significantly different from mean placement values under nondelineated daylight conditions.

3. Mean placement values in all test sections under edge-striped nighttime conditions were significantly different from mean placement values under nondelineated daylight conditions.

4. Mean placement values in both tangent sections under both post-delineated and edge-striped nighttime conditions were significantly different from mean placement values under nondelineated daytime conditions.

In interpreting these results, it should be remembered that the accuracy of field measurements was of the order of ±2 mph for speeds and ±0.3 ft for placement values. This could negate the statistical significance of several of the above stated comparisons.

Additional before and after mean comparisons were made generally using the nondelineated nighttime condition as a control value, it being hypothesized that this condition provides drivers with the worst visibility. Tables 9 and 10 present these analyses with the following results.

TABLE 6

ANALYSIS OF VARIANCE FOR PLACEMENT OF PACE SPEED GROUP

Source	Sum of Squares	D. F.	Mean Square	F
Light condition (day vs night)	3.04	1	3.04	17.37**
Delineation condition (ND, PD, ES)	0.32	2	0.16	0.91
Sections (EBT, WBT, EBC, WBC)	1.43	3	0.48	2.74
Residual (error)	2.97	17	0.175	
Total	7.76	23		
Section breakdowns:				
Tangents vs curves	1.18	1	1.18	6.74*
EBT vs WBT	0.10	1	0.10	0.57
EBC vs WBC	0.15	1	0.15	0.86
Subtotal	1.43	3		
Eastbound vs westbound	0.00	1	0.00	0.00
EBC vs EBT	0.17	1	0.17	0.97
WBC vs WBT	1.26	1	1.26	7.20*
Subtotal	1.43	3		

*Significant at 5 percent level.
**Significant at 1 percent level.

TABLE 7

STATISTICAL ANALYSIS OF DIFFERENCES IN MEAN SPEEDS DAYLIGHT "BEFORE" CONDITIONS

Test Section	Delineation and Light Conditions: Before	After	Difference in Means $(\bar{x}_b - \bar{x}_a)$	$2\hat{\sigma}$	Significant Difference in Means
Eastbound tangent	ND-DL*	PD-DL	+1.500	1.053	Yes
	ND-DL*	ES-DL	0.000	0.928	No
	ND-DL*	ND-NT	-0.500	1.344	No
	ND-DL*	PD-NT	+1.400	1.356	Yes
	ND-DL*	ES-NT	-0.900	1.260	No
Westbound tangent	ND-DL	PD-DL	+1.900	1.127	Yes
	ND-DL	ES-DL	+2.400	1.093	Yes
	ND-DL	ND-NT	-0.400	1.664	No
	ND-DL	PD-NT	+1.400	1.568	No
	ND-DL	ES-NT	+2.300	1.432	Yes
Eastbound curve (curve to right)	ND-DL	PD-DL	+0.300	1.500	No
	ND-DL	ES-DL	+2.800	1.474	Yes
	ND-DL	ND-NT	+1.800	1.904	No
	ND-DL	PD-NT	+1.900	1.723	Yes
	ND-DL	ES-NT	+2.600	1.847	Yes
Westbound curve (curve to left)	ND-DL	PD-DL	-0.200	1.179	No
	ND-DL	ES-DL	+0.400	1.275	No
	ND-DL	ND-NT	+0.500	1.988	No
	ND-DL	PD-NT	+1.200	1.511	No
	ND-DL	ES-NT	+0.400	1.608	No

*DL = daylight; NT = nighttime.

TABLE 8

STATISTICAL ANALYSIS OF DIFFERENCES IN MEAN PLACEMENTS DAYLIGHT BEFORE CONDITIONS

Test Section	Delineation and Light Conditions		Difference in Means ($\bar{x}_b - \bar{x}_a$)	$2\hat{\sigma}$	Significant Difference in Means
	Before	After			
Eastbound tangent	ND-DL	PD-DL	+0.010	0.139	No
	ND-DL	ES-DL	+0.240	0.125	Yes
	ND-DL	ND-NT	-0.440	0.162	Yes
	ND-DL	PD-NT	-0.460	0.187	Yes
	ND-DL	ES-NT	-0.360	0.170	Yes
Westbound tangent	ND-DL	PD-DL	+0.030	0.136	No
	ND-DL	ES-DL	+0.170	0.131	Yes
	ND-DL	ND-NT	-0.720	0.189	Yes
	ND-DL	PD-NT	-0.630	0.186	Yes
	ND-DL	ES-NT	-0.810	0.188	Yes
Eastbound curve (curve to right)	ND-DL	PD-DL	+0.090	0.223	No
	ND-DL	ES-DL	+0.110	0.219	No
	ND-DL	ND-NT	-0.170	0.269	No
	ND-DL	PD-NT	-0.040	0.270	No
	ND-DL	ES-NT	-1.480	0.252	Yes
Westbound curve (curve to left)	ND-DL	PD-DL	-0.140	0.207	No
	ND-DL	ES-DL	-0.340	0.218	Yes
	ND-DL	ND-NT	-1.050	0.374	Yes
	ND-DL	PD-NT	-0.800	0.255	Yes
	ND-DL	ES-NT	-1.170	0.250	Yes

TABLE 9

STATISTICAL ANALYSIS OF DIFFERENCES IN MEAN SPEEDS NIGHTTIME BEFORE CONDITIONS

Test Section	Delineation and Light Conditions		Difference in Means ($\bar{x}_b - \bar{x}_a$)	$2\hat{\sigma}$	Significant Difference in Means
	Before	After			
Eastbound tangent	ND-NT	PD-NT	+1.900	1.651	Yes
	ND-NT	ES-NT	-0.400	1.572	No
	PD-NT	ES-NT	-2.300	1.582	Yes
Westbound tangent	ND-NT	PD-NT	+1.800	1.992	No
	ND-NT	ES-NT	+2.800	1.886	Yes
	PD-NT	ES-NT	+1.000	1.802	No
Eastbound curve	ND-NT	PD-NT	+0.100	1.837	No
	ND-NT	ES-NT	+0.800	1.954	No
	PD-NT	ES-NT	+0.700	1.778	No
Westbound curve	ND-NT	PD-NT	+0.700	2.123	No
	ND-NT	ES-NT	-0.100	2.193	No
	PD-NT	ES-NT	-0.800	1.772	No

TABLE 10

STATISTICAL ANALYSIS OF DIFFERENCES IN MEAN PLACEMENTS
NIGHTTIME BEFORE CONDITIONS

Test Section	Delineation and Light Conditions: Before	Delineation and Light Conditions: After	Difference in Means ($\bar{x}_b - \bar{x}_a$)	$2\hat{\sigma}$	Significant Difference in Means
Eastbound tangent	ND-NT	PD-NT	-0.020	0.213	No
	ND-NT	ES-NT	+0.080	0.199	No
	PD-NT	ES-NT	+0.100	0.219	No
Westbound tangent	ND-NT	PD-NT	+0.090	0.228	No
	ND-NT	ES-NT	-0.090	0.228	No
	PD-NT	ES-NT	-0.180	0.226	No
Eastbound curve	ND-NT	PD-NT	+0.130	0.259	No
	ND-NT	ES-NT	-1.310	0.240	Yes
	PD-NT	ES-NT	-1.440	0.242	Yes
Westbound curve	ND-NT	PD-NT	+0.250	0.392	No
	ND-NT	ES-NT	-0.120	0.388	No
	PD-NT	ES-NT	-0.370	0.275	Yes

1. There was no significant difference among mean speeds measured at night under any delineation condition on curve sections only.
2. The mean speed measured at night under post-delineated conditions was significantly lower than those measured under both nondelineated and edge-striped conditions for the eastbound tangent section only.
3. On the westbound tangent section only the mean speed measured at night under edge-striped conditions was significantly lower than the mean speed measured under nondelineated conditions.
4. There was no significant difference among mean placements measured at night under any delineation condition on tangent sections only.
5. The mean placement of vehicles measured at night in curve sections under edge-striped conditions was significantly closer to the centerline than that measured under post-delineated conditions.
6. In the eastbound curve section only the mean placement of vehicles measured at night under edge-striped conditions was significantly closer to the centerline than that measured under nondelineated conditions.

Supplementary Studies

Speed Studies. —As previously outlined, speed studies (upstream and downstream stations on EBT) were conducted on only one day under each of three delineation conditions. By matching vehicle descriptions it was possible to obtain the speed at all three stations for each of a total of 335 passenger cars on the three days. Again trucks were eliminated because of the small sample, but they generally maintained a relatively constant speed through all three stations, and speeds were relatively slow.

How well each sample at the main station represents the total sample collected at that station is shown in Figure 9 and given in Table 11.

The variation of speeds between the three stations was different on each of the 3 days, but there appears to be a general tendency of vehicles slowing down between the upstream station and the main station.

Downstream Placement Studies. —Supplementary placement data were obtained at a location downstream from the main station on the eastbound tangent one day only under each delineation condition. Because of manpower shortages, the first day's study was

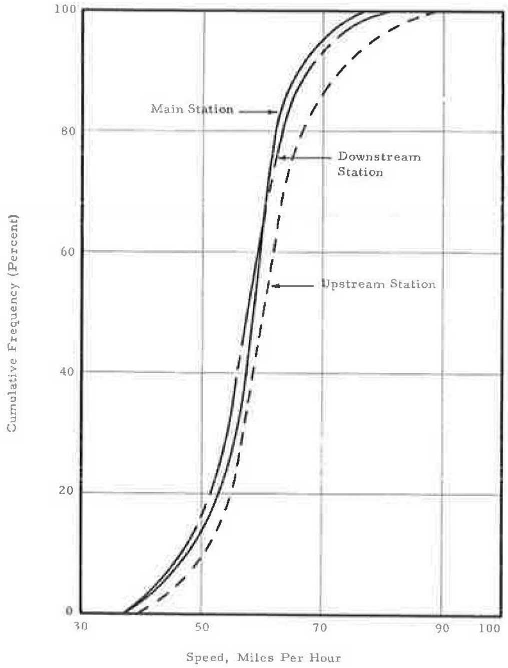

Figure 9. Cumulative frequency curves for 3-station spot-speed studies for combined data for all 3 conditions.

obtained with the second placement tape only 300-ft downstream so that the second 20-pen recorder could be manned by the main station operator. The other studies were conducted with the tape 2,000-ft downstream.

The results of these studies are shown in Table 12 and tend to show that the placement results would not vary significantly with location within a given test section. Again vehicles were identified at each station by brief descriptions, and only those downstream values which could be correlated to main station data were used. (Note how well the downstream sample seems to represent the main station total population.)

Interview Studies. —Interviews of eastbound drivers exiting I-10 at Crowley under both delineation conditions yielded the origin and destination data given in Table 13. Questions pertaining only to post delineators derived the following information.

1. Some 92.5 percent of the drivers said that they had seen the delineators although 25 percent of these had to be drawn out in questioning to be sure they had seen them.

TABLE 11

EASTBOUND TANGENT MAIN STATION MEAN SPEEDS
(Comparison of Sample Vehicles With Total Population)

Date	Delineation Condition	Main Station Total Population		Three Speed Sample	
		Number	Mean Speed	No.	Mean Speed at Station
7/17/63	Nondelineated	221	59.97	98	61.22
8/2/63	Post delineated	228	56.22	122	56.73
8/29/63	Edge striped	238	56.48	115	56.51

2. Of the 8 drivers who did not see the delineators, 5 were from out-of-state and 7 were driving this highway for the first time. Of those who saw the delineators: (a) 6 percent said they could get along without them; (b) 73.5 percent said they thought the delineators were helpful in driving or just that they liked them.

3. More enthusiastic in their support of the delineation were 20.5 percent with such comments as "best thing since the white line," "beautiful," and "wonderful, they're a big help."

Questions asked only to drivers passing through the test section under edge-striped conditions revealed:

1. A majority (59.5%) of these drivers said they had noticed the edge striping. Of this group, (a) 4.3 percent said they could get along without the striping; (b) 87.0 percent said that the striping was helpful; and (c) 8.7 percent were enthusiastic in their support of the striping.

TABLE 12

COMPARISON OF DOWNSTREAM PLACEMENTS WITH MAIN STATION PLACEMENTS

Date	Delineation Condition	Light Condition	Sample				
			Main Station			Downstream	
			No.	Mean Placement (ft)		No.	Mean Placement (ft)
				All Veh	Downstream Veh		
7/2/63	Nondelineated	Day	185	7.014	7.009	171	7.259
8/2/63	Post delineated	Day	228	7.715	7.154	153	7.327
		Night	157	7.767	7.802	139	7.927
8/29/63	Edge striped	Day	238	7.289	7.283	147	7.401
		Night	93	7.517	7.562	76	7.912

TABLE 13

O AND D DATA FOR EASTBOUND I-10 FOR TRAFFIC AT CROWLEY, LA.

O and D Characteristics	Test Section Delineation	
	Post Delineators	Edge Striping
1. Sample size		
a. Drivers of autos only	106	80
(1) Male	No breakdown	74
(2) Female	No breakdown	6
b. Interviews used	106	74
2. No. of passengers		
a. Driver alone	24.5%	41.9%
b. Only 1 passenger	30.2%	25.7%
c. 5 or more passengers	14.1%	12.1%
3. Vehicle registration		
a. Louisiana	82.1%	87.8%
b. Out-of-state	17.9%	12.2%
4. Trip origins		
a. Acadia Parish	12.3%	17.6%
b. Between Acadia Parish and Texas	55.6%	58.1%
c. Texas	29.2%	24.3%
5. Trip destinations		
a. Acadia Parish	47.2%	41.9%
b. Lafayette or Vermillion Parishes (east of Acadia Parish)	36.8%	43.2%
6. Trip ends at home	85.9%	81.0%
a. Origins	(34%)	(31.7%)
b. Destinations	(66%)	(68.3%)
7. Travel frequency on I-10 since delineated		
a. First time	39.6%	29.7%
b. More than once, but no more than once/week	33.1%	23.0%
c. Average one trip/day	11.3%	20.4%
8. Had driven entire 14.7-mi length of I-10 from Jennings before being interviewed	86.8%	83.8%

2. Two-thirds (67.6%) of the drivers said they had noticed the placement tape they crossed some 2 miles back from the interview station. Of these, (a) 38.2 percent did not know what it was; (b) 56.4 percent thought it was a traffic counter; (c) 5.4 percent thought it was a speed trap; and (d) 10.9 percent slowed down after passing it.

Test-Vehicle Studies

Because of the financial limitations of this project, it was not possible to conduct extensive test vehicle studies. Although the motion-picture film required is relatively inexpensive at $8.00 per 100-ft roll (processed), it costs several times that amount to obtain vehicle-placement data off the film through projection techniques.

Within these limitations, however, it was possible to obtain a total of about 60 test-driver runs through the test sections under all 3 delineation treatments and under both daylight and nighttime conditions. In addition, about 100 vehicles were followed under the same set of conditions, and distance-lapse photographs were obtained from the following test car; however, insufficient available light resulted in the loss of most of the night studies due to underexposure of even the fastest movie film available.

The completion of projected picture analysis in each type of test-vehicle study provided a frame-by-frame listing of vehicle placement with respect to the roadway centerline for either the test vehicle (where driven by a "test driver") or the vehicle "followed" by the test vehicle. A typical "placement profile," as obtained from either study, is shown in Figure 10.

Each placement profile was then analyzed over the lengths corresponding to the test sections passed through by the test vehicle. The two most important characteristics of each profile are the frequency of directional changes (D) by the vehicle and the average amplitude ($\bar{A}$) of the profile. These characteristics were used as the two main variables in an expression of the Placement Profile Smoothness Index (PPSI) as follows:

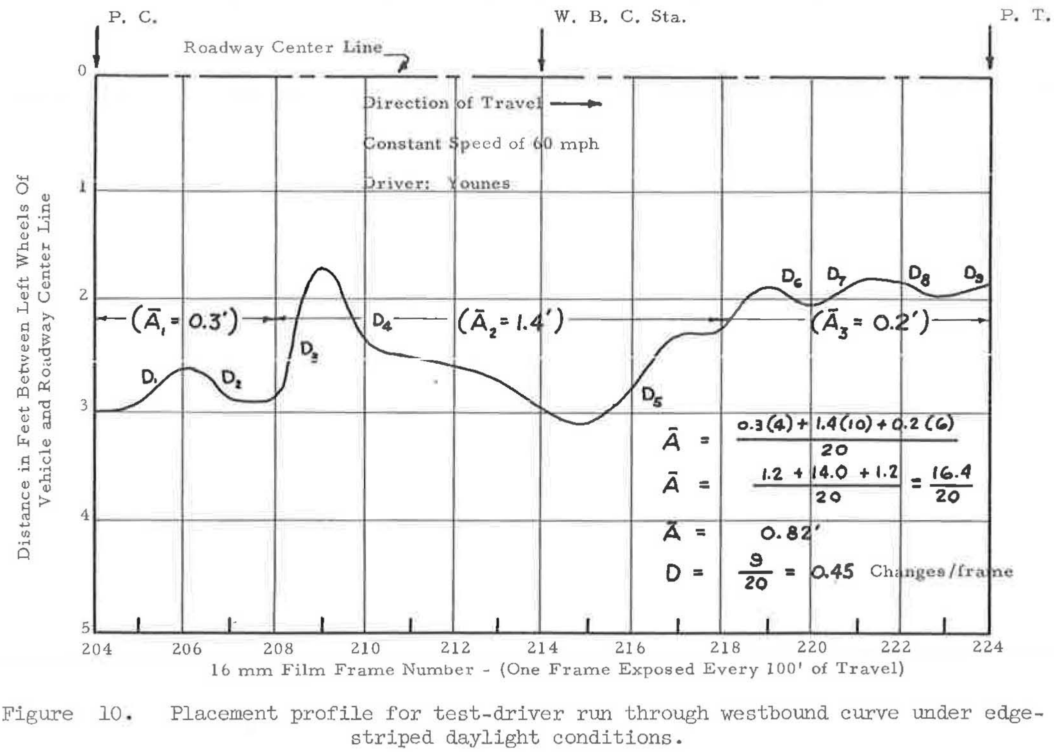

Figure 10. Placement profile for test-driver run through westbound curve under edge-striped daylight conditions.

$$\text{PPSI} = \frac{60}{\overline{V}} \frac{\overline{P}'}{D\,\overline{A}}$$

where

$\overline{V}$ = Average speed of test-vehicle through a test section, in mph;

$\frac{60}{\overline{V}}$ = speed ratio, unitless;

$\overline{P}'$ = adjustment factor based on the average placement ($\overline{P}$) of left wheels of vehicle in outside lane during run through a test section (see Table 14);

D = frequency of directional changes per picture frame in total run through a test section; and

$\overline{A}$ = average amplitude of placement profile through a test section, in feet.

The determination of the PPSI relationship was based on the following considerations.

1. As the frequency of directional changes and the average amplitude of the profile increase, the PPSI decreases, and the profile is considered rougher.
2. The approximate average operating speed through the test sections has been shown as 60 mph and it was felt that drivers of slower vehicles had more control over their vehicle than those going faster than 60 mph, hence the factor ($60/\overline{V}$).
3. Vehicles whose left wheels were 3.00 ft from the roadway center line were approximately centered in the outside lane of the test section, and it was felt that any vehicle generally operating off-center was in a relatively less desirable lane position. Vehicles near the outside edge of the pavement were in danger of leaving the pavement, and those near the roadway centerline (lane line) would possibly come in conflict with inside lane vehicles. The former condition was considered twice as detrimental as the latter.
4. A perfectly smooth placement profile would be a straight line 3.00 ft off the roadway centerline where $\overline{A}$ and D both equal zero and PPSI = ∞.

Based on this relationship, a total of 79 test-driver section runs under all experimental conditions and 44 daytime car-following section profiles were evaluated. The resulting profile characteristics were used to calculate PPSI values which were then averaged by section and experimental condition (Table 15).

Since the PPSI is a totally new characteristic, the reader has no way of knowing what significance the values in Table 15 have. As an aid to their interpretation, Figure 11 was prepared for an assumed average speed of 60 mph and average placement of 3.00 ft. Several "iso-PPSI lines" were drawn arbitrarily dividing the chart into eight profile type areas.

The results shown in Table 15, therefore would appear to substantiate the hypothesis that placement profiles obtained under daylight or delineated nighttime conditions were smoother than those obtained under nondelineated nighttime conditions. Placement profiles for test drivers under daylight conditions tended to be smoother than those obtained for vehicles followed by the test vehicle.

TABLE 14

PLACEMENT ADJUSTMENT FACTORS

$\overline{P}$	$\overline{P}'$	$\overline{P}$	$\overline{P}'$	$\overline{P}$	$\overline{P}'$
0.00'	0.75	2.00'	0.92	4.00'	0.83
0.25	0.77	2.25	0.94	4.25	0.79
0.50	0.79	2.50	0.96	4.50	0.75
0.75	0.81	2.75	0.98	4.75	0.71
1.00	0.83	3.00	1.00	5.00	0.67
1.25	0.85	3.25	0.96	5.25	0.63
1.50	0.875	3.50	0.92	5.50	0.58
1.75	0.90	3.75	0.88	5.75	0.54
2.00	0.92	4.00	0.83	6.00	0.50

Adverse Weather Observations

Although it was hoped that detailed studies could have been made under adverse weather conditions (i.e., rain and/or

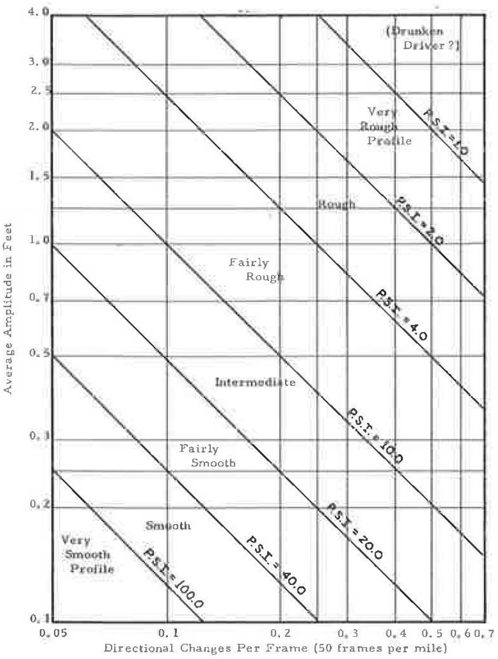

Figure 11. PPSI variation for average speed = 60 mph and average placement = 3.00 ft.

fog) it was impossible to do so for the following reasons:

1. The speed and placement equipment used for the primary studies of this investigation were inoperable under such conditions.
2. Such conditions were infrequent throughout the period during which field data was collected.
3. Test-car photography would be ineffective.

The researchers were, however, able to drive through the test sections, with post delineators in place, during a very heavy rainstorm and made the following observations:

1. The painted centerline (lane line) stripe was "washed out" by the rain and was ineffective as delineation.
2. The post delineators were definitely visible and gave a certain degree of confidence in following the road, which was not felt when driving along nondelineated portions of I-10 adjacent to the test sections.

TABLE 15

COMPARISON OF AVERAGE PLACEMENT PROFILE SMOOTHNESS INDICES

Experimental Conditions	WBT Only	EBT Only	Combined Tangents	WBC Curve L	EBC Curve R
Car-following, daylight	3.18* (11)**	3.50 (12)	3.35 (23)	3.59 (10)	3.01 (11)
Test driver:					
1. Daylight-combined Delineation conditions	6.78 (10)	4.88 (9)	5.88 (19)	4.97 (7)	7.65 (6)
2. Nighttime					
Nondelineated	3.69 (6)	5.05 (5)	4.31 (11)	3.55 (4)	3.77 (5)
Post delineators	6.82 (4)	4.47 (3)	5.81 (7)	7.29 (3)	5.77 (3)
Edge striped	5.33 (3)	4.29 (4)	4.74 (7)	4.33 (3)	4.00 (4)

*PPSI value.
**Number of values determining average.

GENERAL OBSERVATIONS

Speed and Placement Point Studies

Although a number of the speed and placement variations determined by this research were shown to be statistically significant, these results do not appear to be too important.

The significant differences in mean speeds generally are of the order of ±2 mph which is the accuracy limit of the radar speedmeter. In addition, most of the significant differences in speeds were decreases which tend to refute the hypothesis that delineation would increase night speeds. Had night speeds under delineated conditions been about 5 mph greater than night speeds under nondelineated conditions, however, it could have been said that the delineation was effective.

It was expected that nighttime placements would be closer to the roadway centerline than daylight placements based on the results of others previously cited (6, 7, 10). The amount of the significant placement difference ranges from 0.3 to over 1 ft which should not greatly affect vehicle operation on the roadway although vehicles that are closer to the centerline may have some influence on vehicles passing them in the inside lane. The significant difference in placement on the westbound curve as compared to the westbound tangent may be due to the direction of curvature being to the left.

The type of measurements obtained in this research as well as the subsequent data reduction procedures were subject to equipment and human errors. However, it is felt that adequate precautions were maintained to minimize the occurrence of such errors and that the results thereby obtained accurately reflect the speed and placement of most vehicles using the test sections of I-10.

The supplementary downstream placement studies tended to show that the same relative placement results would have been obtained regardless of placement tape position, and therefore the selected study points within each section were satisfactory. Although the supplementary speed studies showed many vehicles' speed at the main station to be lower than their upstream or downstream speeds, the main station speeds are considered representative. More than likely this effect was due to the drivers noticing the upstream observers coupled with visibility of vehicles parked near the main station. During regular operations, the first indication of observers was at the main station and the radar speedmeter picked up the vehicle speeds before drivers were aware of the observers.

The location of the placement tape on the pavement joint was effective in disguising its presence, particularly at night. Very few drivers thought that it was a speed trap since only one tape was used. The Louisiana State Police use two tapes at speed traps utilizing the electric speed clocks.

Some local residents that used the I-10 test sections almost daily were continually aware of the observers presence, and no doubt some knew what was being measured; a few such drivers were observed to vary their speed when passing by the main station. However, these drivers were in a minority as shown by the O-D data given in Table 13.

It might be considered that a major limitation of this research might be the fact that all studies were conducted on the four sections of the single segment of I-10 near Crowley, but project budget limitations precluded additional research at other sites. The site selected was considered most favorable due to its location relative to Baton Rouge and the relatively low traffic volumes providing predominantly independent vehicles.

Interview Studies

About two-thirds of the interviews conducted under edge-striped conditions were obtained by relatively inexperienced interviewers, which probably accounts for the fact that only 56 percent of the drivers were recorded as having seen the edge striping. As generally indicated on the interview forms, the question posed was "Did you notice the roadside delineation in the past two miles of your trip?" The term delineation was not one that many drivers understood, and unless the interviewer followed this question with one mentioning the specific type of delineation, it was not definitely known if they had missed seeing the delineation. Such questioning in the first study revealed that 92 percent of the drivers had seen the post delineators.

Test-Vehicle Studies

The results obtained from the test-vehicle studies should only be considered as supplementary to the primary studies of speed and placement. Since these studies involved

previously untried procedures, they were too limited in scope to produce very significant results.

The test-driver technique had too few replications for each driver to determine adequately the effect of driver variability and to separate this effect of driver from the effect due to delineation conditions. The test drivers were in an artificial situation, and because of this, there is some question as to how well their placement profiles represent the driving population. This was borne out by the results given in Table 15 which showed that on the average test-driver placement profiles were smoother than placement profiles for vehicles that were followed.

The car-following technique met with partial failure in that high-speed motion-picture films were incapable of recording sufficient detail at night. It is possible that a faster lens or infrared technique might have produced satisfactory results, but such method development was not included as a part of this project. The car-following technique is considered better than the test-driver technique because the driver is not in an artificial situation; however, the test vehicle cannot follow the sample vehicle too closely or the driver may become aware of being followed and alter his normal driving pattern.

The PPSI determination was arbitrarily set up based on the basic characteristics of the placement profile, although some traffic researchers may recognize a similarity to Greenshields' "Quality Index" which was studied prior to development of this procedure (13). A more thorough analysis of more extensive studies would be required before a final equation and adjustment factors could be established. (Moreover, measures of stability for complex wave forms should be applied.) It is felt, however, that the relationship used in this study was satisfactory to show the nature of the results obtained.

CONCLUSIONS

Based on the results of the investigations conducted during this research and in view of the limitations of these investigations, the following conclusions appear to be in order.

1. Neither roadside post-mounted reflective delineators nor edge-stripe delineation have any significant effect on the speed or placement of passenger-car vehicles passing through the outside lane of delineated sections of an Interstate highway under fair weather conditions.

    a. Although speeds measured under nondelineated conditions were significantly (statistically) higher than those measured under either post-delineated or edge-striped conditions, these differences are not considered significant from a practical standpoint.

    b. Although some "before and after" comparisons of vehicle placements showed statistically significant differences, the general analysis of variance showed no statistically significant differences due to delineation treatment.

2. In general, passenger-car vehicles in the outside lane travel some 6 to 12 in. closer to the roadway centerline when their speeds exceed 64 mph than when their speeds are less than 55 mph.

3. In general, passenger-car vehicles in the outside lane travel some 3 to 9 in. closer to the roadway centerline at night than during the day.

4. Drivers of passenger vehicles at night are almost unanimous in their feeling that roadside delineation is helpful to their driving on the Interstate Highway.

5. Although test-vehicle results gave some indication of delineator effectiveness, the significance of this indication is unknown since the methods used have not been sufficiently tested for sensitivity to the variables involved.

RECOMMENDATIONS FOR FURTHER STUDY

Inasmuch as measurements of traffic operational characteristics of speed and placement during this research were not sensitive enough to illustrate any delineation

effectiveness, which drivers apparently believe to exist, the following recommendations are suggested for further investigation of this problem.

1. Development of the test-vehicle technique should be carried to the point of being able to analyze placement profiles for the effects due to roadway geometrics, delineation, etc. This would require extensive studies with a large sample of both test drivers (with several replications each) and cars followed. The latter sample would depend on the successful development of the night photography technique.
2. Use of the galvanic skin response (GSR) technique on a sample of test drivers should be tried in an attempt to identify any comforting effect that delineation may provide. This may be a particularly effective means for obtaining data under adverse weather conditions. It is felt that such conditions would form a much better base for showing delineator effectiveness than fair weather conditions.
3. Once a more effective measurement is developed, studies should be conducted at more than one Interstate location. Also, treatment variations such as delineator type, location and spacing could be effectively evaluated.
4. In the research just completed, delineation treatments were varied on the same test section locations with only one treatment being evaluated at a time. An alternate approach would provide a site where several treatments could be randomly ordered simultaneously along an Interstate highway thereby providing an opportunity to evaluate the differences in operation of the same population of drivers under all delineation treatment conditions.

ACKNOWLEDGMENTS

The author appreciates the financial sponsorship of the Louisiana Department of Highways and the U. S. Bureau of Public Roads. He is further indebted to several employees of the Louisiana Department of Highways for their assistance during the field study phase of this research. Several employees of the Division of Engineering Research at Louisiana State University were also very helpful at various stages of this research and in the preparation of this report. The Division also provided funds for the purchase of several pieces of equipment necessary for conducting the research.

Special thanks are due to Sam I. Thornton, who as the Graduate Research Assistant on this project, very ably directed much of the field work and data analysis procedures. Roger Wise assisted Mr. Thornton in all of the primary field studies and a number of student assistants participated in supplementary field studies, served as test drivers, and reduced the field data.

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Appendix

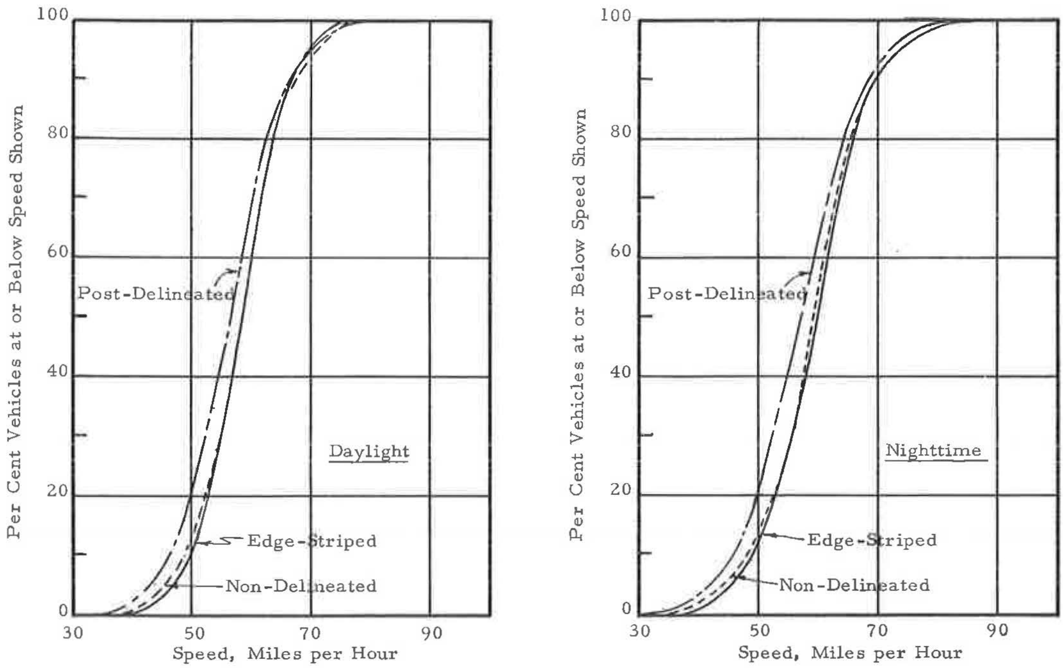

Figure A-1. Cumulative frequency curves for spot speeds at eastbound tangent station.

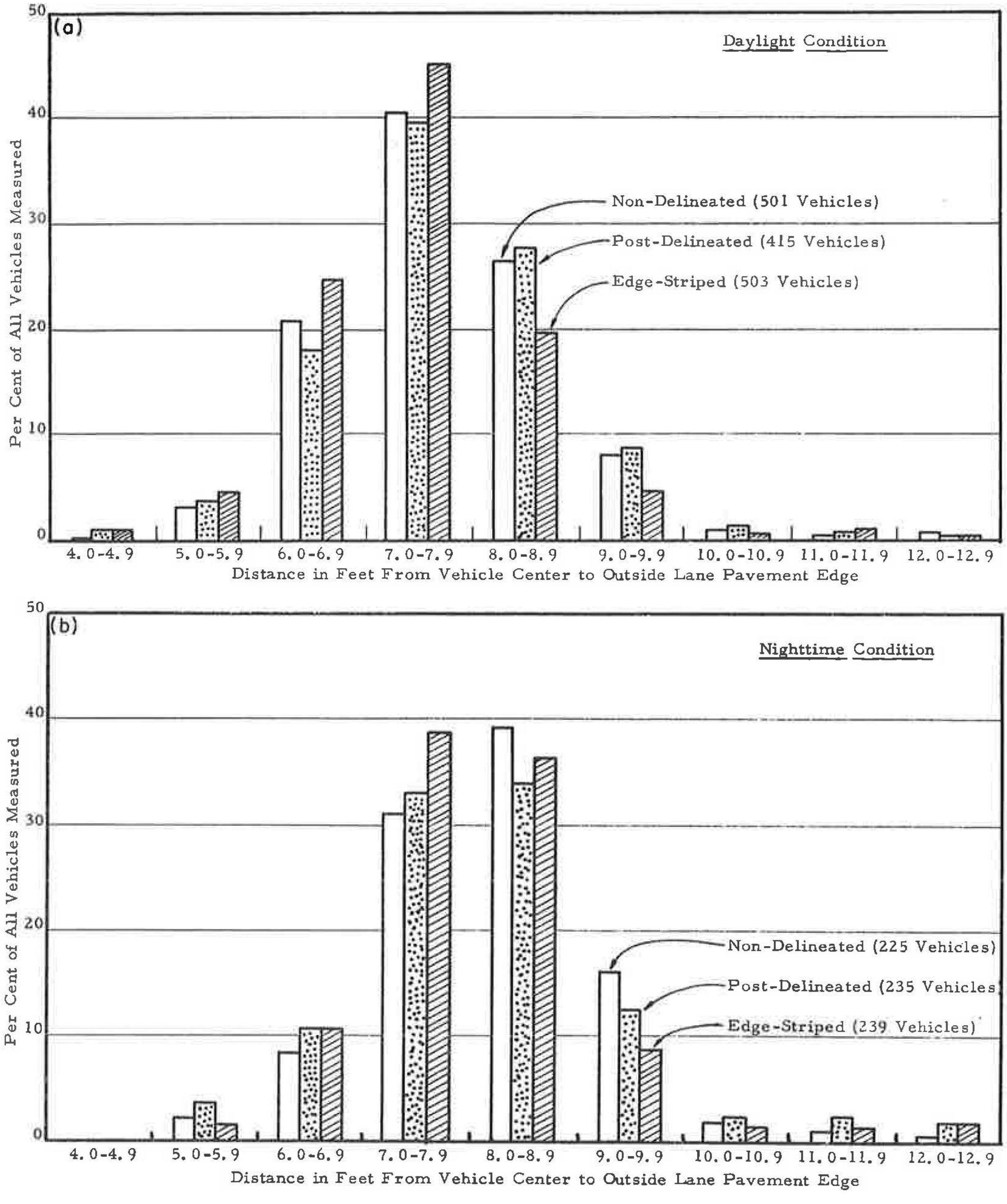

Figure A-2. Frequency distributions of vehicle placements at eastbound tangent station: (a) daylight, and (b) nighttime.

History of Median Development in Illinois

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Designs for medians of divided highways have gone through an extended period of development involving the trial installation of many different median widths and cross-sections. Myriad design variations have been created on the basis of administrative decisions supported by individual engineering judgment and the qualitative analysis of gradually accumulating needed data on the traffic safety and service benefits from medians. Some knowledge of these activities and the thoughts accompanying them is essential to a proper understanding of current median design philosophy. This history is a summary of such thought and activity, from 1930 to the present, in Illinois. Although the discussion is primarily concerned with reasons for the adoption or elimination of specific median design features in Illinois, other states have probably had much the same history.

After years of experimenting with different widths of medians for rural highways it was decided that a 40-ft width was the desirable minimum. Where possible, medians wider than this minimum are now used because of the decrease in headlight glare, reduction in cross-median accidents, and frequent economical improvement in roadway alignment. It is often desirable from the traffic and cost standpoints to construct such wide medians even in built-up city areas. However, in most cases of constructing a highway with full control of access in urban areas, it is considered necessary to use a narrower median and consider the installation of a suitable median barrier.

For routes with no control of access in cities, the cost of right-of-way normally limits the design to the narrow median types or, in some cases, to no median at all. It is currently believed that an easily mounted or flush-type narrow median (less than 6 ft wide) should not be used where there is need for numerous left-turn movements. Such movements should be limited to intersections or provided for by the construction of adequate left-turn lanes in the median.

[Editor's Note: The original manuscript of this paper was accompanied by an illustrated inventory of 422 medians constructed in Illinois and a detailed inventory, in tabular form, of dimensions, surfacing, location, design, construction dates, etc. Space limitations and cost of publication prohibit their inclusion herein; however, the Board will provide this material at cost of reproduction upon request—Supplement XS-6 (Highway Research Record 105).]

Paper sponsored by Committee on Operational Effects of Geometrics.

•THE history of median development in Illinois was compiled as part of a study aimed at the determination of desirable widths and cross-sections for medians of divided highways. Aside from whatever purely historical value it may have, this report is intended to provide a summary of the thoughts involved in the development of what are currently believed to be acceptable median designs for the various sets of conditions that have been encountered throughout the state. It presents some indication of the extent to which various types of medians are believed to have provided the intended traffic safety and service benefits, but deals primarily with the reasons behind the adoption or elimination of specific median design features.

An inventory of median dimensions, surfacing, location, design and construction dates, and other pertinent data was completed. It was prepared in tabular form to serve as a reference guide to designers and researchers in analyzing apparently successful designs to determine what harmonious combinations of factors are responsible for success in providing the desired traffic safety and service benefits. It was felt that use of such an inventory would decrease any tendency toward unnecessary repetition of the process of evolution of these designs at different times in other areas as a result of the subsequent development of the same design conditions. The work toward improvement of currently accepted median designs could thus be directed more in the light of past efforts than along the path of past efforts. [This detailed inventory is not included herein.]

The inventory contains information pertaining to 422 medians. The information was verified by the ten district offices of the Illinois Division of Highways to insure accuracy of the basic data. Although the combined experience of engineers throughout Illinois is reflected in the discussion of these medians, a majority of the information regarding median development stems from the 45 years of experience accumulated by Hugo E. Surman, retired Engineer of Design and former member of the American Association of State Highway Officials Committee on Planning and Design Policies.

All medians have been classified according to design intent as nondeterring, deterring or nontraversable. The criteria for such classifications are somewhat arbitrary because they are based on current opinions of designers concerning the effects of the various median cross-sections on the propensity of drivers to make intentional turns across the median. Having been derived from personal observation and judgment, these criteria can serve only as a general guide in median design.

Nontraversable—A median designed to prevent intentional crossing.

a. Slopes steeper than or equal to 1 vertical in 1 horizontal with a 3-ft minimum vertical dimension.
b. Continuous barrier (cables, guardrail, etc.).
c. Double ditch with slopes steeper than or equal to 1 vertical in 5 horizontal (5:1) and depths greater than or equal to 3 ft.
d. Medians with continuous heavy planting.
e. Curbs:
   (1) Straight-faced, vertical curbs with heights greater than or equal to 6 in.
   (2) Rolled curbs with heights greater than 9 in.
   (3) Rolled curbs with heights greater than or equal to 6 in. for median widths less than or equal to 5 ft.

Deterring—A median designed to discourage intentional crossing.

a. Width greater than or equal to 50 ft.
b. Crown greater than or equal to 1 ft in 30 ft of median width; greater than or equal to 6 in. in 3 ft of median width.
c. Slopes steeper than or equal to 1 vertical in 5 horizontal (5:1).

d. Curbs:
   (1) Straight-faced, vertical curbs with heights greater than 4 in. and less than 6 in.
   (2) Rolled curbs with heights greater than 4 in. and less than or equal to 9 in. for median widths greater than 5 ft.
   (3) Rolled curbs with heights greater than 4 in. and less than 6 in. for median widths less than or equal to 5 ft.

e. Turf surface.

Nondeterring—A median intended to be easily crossed. It is nondeterring if it fails to meet all of the above criteria.

Photographs and typical cross-sections representing 24 different groups of medians having the same general characteristics are included in an Appendix to provide the reader with a clear impression of the design features of the 422 medians contained in the inventory. These illustrations are cross-referenced to the original inventory.

HISTORY OF MEDIAN DEVELOPMENT IN ILLINOIS

The state's two bond issue systems of highways[1] were constructed during the 1920's and early 1930's. The amount of traffic and the number of registered cars and trucks during that period were only a fraction of present-day figures. Legal traffic speeds were very much lower; first 30, then 45 mph. There was little necessity for either the channelization of intersections or the design and construction of medians except in the Chicago metropolitan area. Such designs often could not be effectively used even in Chicago because of inadequate widths of right-of-way. Several hundred miles of 40-ft pavements were squeezed into existing right-of-way. This was the result of a State policy to require only a 60-ft width of right-of-way and its willingness to accept existing right-of-way widths whenever it was possible to construct the pavement within the limits. In most cases this meant accepting substandard features such as narrow shoulders and bridges, very shallow ditches, entrance culverts too close to the pavement, and, in some cases, only a 16-ft pavement. The construction of the second bond issue system of highways was well along before the State changed its policy to require wider right-of-way. The first bond issue act did not permit the construction of highways within cities of more than 2,500 population except in Cook County where the limit was 20,000 population. All of the pavements built under the two bond issue acts were of 2 lanes with the exception of the 40-ft pavements built in the Chicago metropolitan area and a very limited mileage of 9-ft, 1-lane pavements specified in the Second State Bond Issue Act. The construction of 1-lane pavements was prompted by the thought that it would be better to have half a road all the way than a whole road half the way.

By the early 1930's all of the $160 million provided by the two bond issue acts had been invested in highways and the two systems were practically completed. This was with the help of Federal-aid funds. The State then operated on a pay-as-you-go plan which provided an annual construction program, varying from $20 to 30 million of state and Federal-aid funds for the construction of additional roads not included in the bond issue acts.

It was against this historical background that the Illinois Division of Highways started to give consideration to the design and construction of medians in highways. The earliest designs were planned in the 1930's and these were greatly influenced by inadequate widths of right-of-way. Because of limited funds available for the construction of highways, the officials of the Division of Highways did not feel justified in expending large amounts of money for additional right-of-way. It is not the intention to be critical of that policy, but it is unfortunate that it was the cause of limiting many median

[1] Routes 1 through 46 were provided for in the Durable Hard Roads Act, June 22, 1917 ($60,000,000); Routes 47 through 185, plus unfinished segments of Routes 1 through 46, were provided for in the Second State Bond Issue Act, June 29, 1923 ($100,000,000). See Illinois Revised Statutes, Chap. 121, Sec. 266-281.

designs of a later date when right-of-way costs had skyrocketed because of adjacent property developments. There were exceptions such as US 66 where sufficient right-of-way was secured in the early 1940's to permit a 40-ft median width to be used on many miles of this route. However, this policy did apply to other sections of US 66 where narrower medians were used with the knowledge that they were not considered desirable. The lack of sufficient legal tools in acquiring right-of-way was a major influence in many of the median designs. This situation was not improved until the State Supreme Court upheld the legality of the Freeway Act in 1953 and the Quick-Taking Act in 1957.

When the Illinois Division of Highways first gave consideration to the design of highway medians, there was practically no information on this subject. It was, therefore, necessary for the State to start on its own. The ten different districts were given a free hand to develop designs with only nominal supervision from the main office. Most of the early designs were limited to the narrow median types because they were constructed on improved streets and highways under the restrictions imposed by the policy regarding right-of-way.

Many of the principles employed in these early designs were sound. Others were changed considerably as the gradually increasing mileage of highways and streets with medians offered an opportunity to observe the traffic operation benefits and maintenance requirements of medians. Experience indicates that the chief advantages of medians are to separate opposing traffic lanes, to provide an intervening area to give cars that inadvertently get onto the median a chance to recover, to reduce headlight glare, to discourage U-turns except at designated locations, and to provide space for median lanes, temporary parking of disabled vehicles, storage of snow, and location of signs and other necessary highway facilities.

The following comments in regard to individual median designs in Illinois are limited primarily to those designed or approved by the Illinois Division of Highways during the time that Mr. Surman was connected with the Bureau of Design in that Division, from 1921 to 1955. The typical designs will be referred to by cross-section number (Appendix) and the design number from Table 1 of the original inventory is also given. In many instances, reference design numbers are given in tabulated notes to the typical cross-sections.

Cross-section 13 (number 2 in Table 1 of the inventory) is the famous reversible lane design prepared by the city of Chicago. It has several 8-in. steel median curbs that can be raised or lowered to provide extra one-way traffic lanes during rush-hour traffic. In general, the design has been successful, but there has been some difficulty during brief periods when snow and ice conditions have caused malfunctioning of the device for raising and lowering the steel curbs.

Cross-section 9 (number 3) is in a densely built-up area of East St. Louis where additional right-of-way for a wider median would have been expensive. Number 4 is at a relocation site with deep cuts and fills. The 2-ft median width was used because of the lack of side entrances requiring left-turn lanes in the median.

Cross-section 7 (number 17) was an experimental design consisting of bituminous ribs placed 12.5 ft apart across a 4-ft median to warn traffic of being in an off-limit area. This type was discontinued in favor of corrugated portland cement concrete designs that proved to be more durable.

Cross-section 6 (number 18) is on a bypass which is partly in the city of Barrington where right-of-way is restricted. Traffic can cross the median for the purpose of entering the property on the opposite side. This was not too serious when the median was designed in the early 1950's, but since that time traffic volumes have increased to the point where random turns across the median are often quite hazardous even though traffic speeds are limited.

Cross-section 2 (numbers 21 and 22) are medians at the outer limits of the city of Chicago on built-up streets. The corrugated 4-ft concrete median has the same purpose as indicated for cross-section 6 (number 18). This type of median is becoming popular for city streets where right-of-way is limited and where traffic is permitted to cross the median at any point between intersections. Narrow raised medians (such as cross-section 2, numbers 38-40 in the inventory) are also easily fitted into existing right-of-way, but the corrugated medians give a better warning to encroaching traffic.

Numbers 51, 82 and 95 from Table 1 of the inventory (see cross-sections 2 and 6) are corrugated 4-ft medians on built-up streets with restricted right-of-way. Although varying in detail they give an excellent warning to encroaching traffic.

Flush and slightly raised medians less than 6 ft in width have been used extensively on built-up city streets in commercial areas with low traffic speeds. However, with traffic increases far above the expected volumes, the need to prevent random crossing of these narrow medians in midblock areas has become increasingly apparent. The advantage of having access to commercial establishments across the median is greatly diminished when the traffic volume exceeds about 900 veh/hr on 4-lane facilities. Turns across the median become extremely hazardous, if not impossible, and traffic flow is greatly impeded by slow-moving or stopped vehicles preparing to turn from the left traffic lane.

The design date of cross-section 1 was 1941 (1, pp. 7-19 and 7-20; 2, pp. 334-336). The rounded cross-section was intended to lessen the shock to encroaching vehicles and to reduce the chances of overturning. This precast version of the rounded narrow median was not built elsewhere in Illinois but the basic principle is reflected in more recent designs (see cross-section 2, references to numbers 96 and 145). The rounded cross-section also allows rain to help remove the sand and cinders that accumulate on narrow corrugated medians when abrasives are used for snow and ice control.

Cross-section 9 (number 101) and cross-section 11 (number 208) were designed to eliminate U-turn and crossing maneuvers except at intersections. Experience seems to indicate that both designs are effective in deterring such maneuvers, although only cross-section 11 (number 101) has the combination of width and curb height deemed necessary to prevent intentional crossing. Advances in the design of vehicles for greater stability have reduced the clearance between the road surface and the lowest extremity of the frame or body for most modern passenger cars[2]. As a result, many vehicles on the road today would become trapped in straddling a narrow median with a vertical dimension greater than or equal to 6 in. (cross-section 9, number 101). Further progress in lowering the center of gravity of passenger cars may soon reduce the average road clearance to about 4 in., thereby reducing the minimum height of curb required to discourage or prevent intentional U-turn and crossing maneuvers.

Number 110 of cross-section 9 is the same basic design as number 101. It was considered to be the best type of median for this location because there is little need for turning movements and the right-of-way width is restricted by a railroad on the east side and a bluff on the west side.

Cross-section 7 (number 98), cross-section 9 (number 105) and cross-section 10 (number 122) are also nontraversable-type medians. Numbers 98 and 122 are on built-up streets with restricted right-of-way and number 105 is near a signalized major intersection with a built-up service area where indiscriminate turns across the fast-moving opposing traffic streams would be extremely hazardous.

The variable median width for number 133 (see cross-section 9) was dictated partly by the right-of-way restrictions imposed by the location of the road between a railroad and the Illinois River bluff and partly by the conditions existing on the portion of this route which serves as a built-up street in the town of Peoria Heights.

Number 143 (cross-section 7) is on Lake Shore Drive in Chicago. The 6-ft width was used to permit more protection for traffic signals and to afford greater safety for pedestrians who find it necessary to stop at the median in crossing the wide street. Such a design also provides some space for emergency and maintenance activities.

The high curbs and crown on number 152 (cross-section 10) were intended to discourage intentional turns across the median. This median is on a street with a railroad abutting on the south side and thus has only a few side entrances.

Some examples of medians that are the widest that could be used within the right-of-way width secured several years in advance are numbers 153 and 154 (see cross-section 11); 158 and 159 (cross-section 5); and 171, 172, 183, 184, 195-198 and 201 (cross-section 11). Pavement resurfacing has practically covered the curbs at some of these locations (see number 183, left-hand photograph, cross-section 11).

[2]For example, road clearance is 6 in. for 1963 Oldsmobile F85 and Buick Special, 5-3/4 in. for 1963 Chevy II and 4 in. for 1963 Corvair.

The lack of visibility of curbs under certain conditions is one of the objections to placing them adjacent to the pavement edge. If the curb on the median cannot be readily seen during low-visibility conditions, it is a hazard to traffic. Delineation of the left extremity of the authorized path of vehicle travel is one of the primary functions of medians in achieving proper separation of opposing traffic streams (3, p. 1). Some field experiments (carried out on only channelization medians at intersections) with reflective paints have seemed to indicate that a solid yellow line on the top or face of rolled curbs is not as effective as a yellow dashed line (8-ft yellow dashes, 16 ft apart). There have also been some attempts at providing better visibility by use of construction materials of contrasting colors. This appears to provide somewhat better delineation of the curbed median except in cases where a median of approximately the width of a traffic lane is surfaced with the same material as that used on the adjacent traffic lanes, making it appear to some drivers as an additional lane (see numbers 174 and 175, right-hand photograph, cross-section 11).

Number 154 (cross-section 11), north of Chicago on US 41, was the first median constructed in District 1. This raised, curbed median has subsequently been replaced with a depressed median to eliminate the hazard created by melted snow that would run onto the pavement from the raised median and freeze.

The 36- to 52-ft widths of median for numbers 202-204, 206 and 207 (cross-section 7) were chosen by the Chicago Park District with the thought that the median could be narrowed in the future, if necessary, for the purpose of providing additional traffic lanes.

Number 217 (see cross-section 11) is mostly in cut. The variable width median with curbs seemed to be the most practical and economical to provide reasonable safety. There are no side entrances.

The nondeterring 4-ft concrete median on Ill. 23 north of DeKalb (cross-section 6, number 14) was used to permit traffic to cross at the numerous roadside entrances. The 4-lane pavement at this location replaced 1 mi of 9-ft concrete pavement built in the early years of this century. This 1-lane pavement was the first concrete pavement built on a country road in Illinois.

Number 227 (cross-section 14) is a 4-ft flush median surfaced with bituminous concrete. It divides the 2-lane pavement of US 66 on the east side of the city of Springfield and was intended to be temporary. Two more lanes were to be added, at which time the asphalt was to be removed and a raised median constructed. This has not been done. However, a new bypass, I-55, is being built for US 66 traffic at Springfield.

Numbers 221 to 225 (cross-section 14) are 4-ft flush concrete medians that were used because of the large number of turning movements on the built-up streets involved. In the meantime, traffic volumes have increased to the point where attempted turns across the median cause unwarranted congestion during rush hours.

The Chicago mesh-type median (cross-section 7, number 1) was one of the more recent experiments with low-cost traversable type medians for use in urban areas on built-up streets. However, due to the extremely thin concrete sections, mesh-type medians were lacking in durability. The remaining sections of this type of median are scheduled for removal in the near future.

Number 228 (cross-section 14) is a 6-ft flush median on a road located along the bottom of a high bluff adjacent to the Mississippi River. It was considered temporary until the balance of the road is constructed into Grafton, at which time it is to be changed to a nontraversable type because of the few locations where cross-median turning movements are demanded.

The slightly raised 20-ft medians (cross-section 6, numbers 186-188) were some of the earliest to be considered flush-type designs. One thing in their favor was low construction cost. Because of the increased traffic at these locations, safety considerations could lead to depressing and paving the median areas and/or adding continuous median barriers at some time in the future.

The concrete V-gutter adjacent to the edge of the pavement on Calumet Expressway (cross-section 15, number 265) reduces maintenance costs because it prevents erosion of the earth shoulders and side slopes. The use of gutters for this purpose on the

inside edge of superelevated pavement on horizontal curves is also common practice in rural areas (see photographs, cross-section 22). Paved or stabilized shoulders greatly reduce the need for such gutters in rural areas where erosion control vegetation can be readily established. However, the heavy applications (about 2.6 lb of deicing chemicals per square foot of expressway surface area during an average winter) of deicing salts for winter maintenance in the Chicago area prevent luxurious growth of erosion control vegetation on the side slopes of medians. Gutters at the outside edge of a stabilized median shoulder would be less of a hazard to traffic and would carry away much of the salt-laden surface runoff from Chicago expressways, although the cost of providing the gutters and mowing the grass in the center of the median may be, in the case of medians less than 30-ft wide, greater than the cost of paving or stabilizing the entire median area. The median on Edens Expressway has recently been paved as shown in Figure 1.

Number 231 (cross-section 16) was a design for a roadway relocation where the abutting property was improved and the cost of a wider median would have been excessive. Traffic speeds are restricted in this area. Numbers 232 and 233 (cross-section 15) could have been wider medians without excessive cost.

The 30-ft median (numbers 237-239, 249 and 261; see cross-sections 15, 16 and 18) was built on an appreciable mileage of highways in Illinois during the process of gradual recognition of the traffic safety and service benefits of wider medians. It is somewhat narrow for a 3-ft depth of ditch. However, it offers a deterrent to illegal U-turns and, except for obstacles such as culvert headwalls and steep side slopes on crossover embankments, it provides some chance for recovery of vehicles getting onto the median. The increased width of shoulder (10 ft) on some mileage with this type of median (see cross-section 15, number 253) is a very desirable feature.

Numbers 265-353 (see cross-sections 15, 16, 22 and 24) are all 40-ft wide with minor variations in type and width of shoulders and depth and shape of ditch. Although some of the designs were completed after 1955, the width of median for most of these projects was decided years earlier when right-of-way was being secured. After years of experimenting with different widths of medians for rural highways, it was decided that a 40-ft width was the desirable minimum to achieve the majority of benefits obtainable.

The 44-ft width was chosen for numbers 360 and 361 (see cross-section 15) because of the wider inside shoulders (10 ft) used on this portion of US 66. The shallow ditch was used for number 266 (cross-section 15) because rock was encountered at the base of the pavement.

Numbers 366-368 (see cross-section 16) represent the beginning of the use of medians wider than the desirable minimum to lessen headlight glare and to help decrease the chance of cars getting into opposing traffic lanes. The use of a 50-ft median

Figure 1. Edens Expressway at Dundee Road.

also allowed economical improvement of the alignment on portions of numbers 382 and 383 (cross-section 16).

The 64-ft medians (numbers 385-388 of cross-section 23) and 80-ft medians (numbers 405-421 of cross-section 23) with a double ditch were used in an attempt to keep cars out of opposing traffic lanes when the drivers inadvertently run into the median area. They have proven to be effective in this regard. Interim results from a current investigation of all inadvertent vehicle encroachments on more than 20 mi of I-57 (numbers 405-421) show that less than 2 percent of the encroaching vehicles crossed the median, whereas slightly more than 15 percent were found to have crossed the 40-ft medians on US 66 and I-74 (4, p. 46). In the case of number 385, the soil from the ridge between the two median ditches was later used as the subgrade for additional through traffic lanes constructed in the median, thus eliminating the need to bring in borrow soil across the existing pavements.

Some of the principal factors governing current thinking in median design are type of highway or street (i.e., whether there is full, partial, or no control of access), amount of traffic and its permissible speed, built-up street or open country, cost, and available funds.

If the highway has full control of access, such as on the Interstate System, the tendency is toward wider medians for rural highways. Here the thoughts concerning details of median design more often include a stabilized shoulder not less than 10-ft wide, 4 to 1 or flatter side slopes, and no obstructions such as culvert headwalls, drainage inlets, steep side slopes on crossover embankments and ditch checks, etc. It is, of course, deemed necessary to permit certain signs for the guidance of traffic to be placed within the side slope areas and, in the case of median widths greater than about 75 ft, trees are permitted among the shrubs and ground cover plantings that are often employed in narrower medians. Grade separation structure supports are also placed in the median area and are protected from collision by the construction of a suitable guard fence. Even where such highways traverse built-up city areas it is often deemed feasible from the traffic and cost standpoints to construct a wide median. In some cases, such as in the Chicago Congress Street project (Dwight D. Eisenhower Expressway), it was desirable to design a wide enough median to permit the construction of a rapid-transit railroad between the dual pavements. However, in cases of constructing a highway with full control of access within the built-up areas of cities, it is considered necessary from the cost standpoint to use a narrow median except in those cases where total acquisition between two existing streets is to be accomplished. Here median widths can be determined on the basis of the then existing right-of-way. A narrow median, if necessary, is probably not too objectionable when traffic speeds are restricted and left-turns across the median are prevented. The installation of a suitable median barrier should be considered in such cases and any curbs or gutters should be placed at the outside edges of the shoulders (5, p. 27).

In cases where dual pavements are built with only partial control of access, additional design features, such as median lanes and traffic signs and signals are introduced within the median area. The details of current designs for median lanes are in accordance with those outlined by the Committee on Planning and Design Policies of the American Association of State Highway Officials. Grade separations are provided for the more heavily traveled intersecting highways. Other rural intersections and intermediate crossovers are often reduced in number by the construction of frontage roads. Those that remain are treated on the basis of their traffic importance and in accordance with AASHO design policies regarding median lanes and at-grade intersections.

For routes with partial control of access in cities, the cost of acquiring additional right-of-way normally limits the design to the narrow median types. Medians are usually of the nontraversable type with the minor intersections limited to right-turn movements only. Those intersections having heavy cross traffic are generally provided with median lanes for left-turn traffic and controlled by 3-cycle traffic signals. It is considered desirable that such medians have a minimum width of 6-ft to protect pedestrians as well as traffic signs and signals. Another type of median used for city streets where right-of-way is restricted is the narrow corrugated type. It is usually

employed where there is a minimum volume of left-turn movements. Adjacent to intersecting streets the median is more often of the deterring or nontraversable type not less than 6-ft wide. It is currently believed that an easily mounted or flush-type narrow median (less than 6-ft wide) should not be used where there is need for numerous left-turn movements. Such movements should be limited to intersections or provided for by the construction of adequate left-turn lanes in the median.

Accident records and traffic capacity analyses clearly indicate that 4-lane pavements should not be built on rural highways without some control of access, and that all should be designed with opposing lanes separated by a median area (6, p. 135; 2, p. 90). Complete control of access gives maximum benefit to traffic, and no control gives the most benefit to commercial developers and the least to traffic.

During the past several years many cities have adopted one-way streets. These generally do not require medians; however, in many cases traffic is channelized at intersections by placing narrow medians or some other type of divider to mark the lanes for turning movements.

The inclusion of medians as a part of both rural and urban multilane pavements has undoubtedly saved many lives even though no design has yet been devised which will prevent a driver from inadvertently getting into a median area. Current studies of vehicle encroachments on the medians of urban expressways and rural freeways in Illinois indicate that the numbers of vehicles inadvertently getting into the median are from 4 to 14 per year per mile of divided highway (4). This definitely places a limitation on those designs conceived with the thought that medians need not serve as a safe vehicle stopping or recovery area. It is true that alertness and attention to road conditions, as well as to other drivers, every minute of the time, is the best way to avoid accidents, but maximum consideration of "what drivers will do" instead of "what drivers ought to do" is the best way to design medians.

ACKNOWLEDGMENTS

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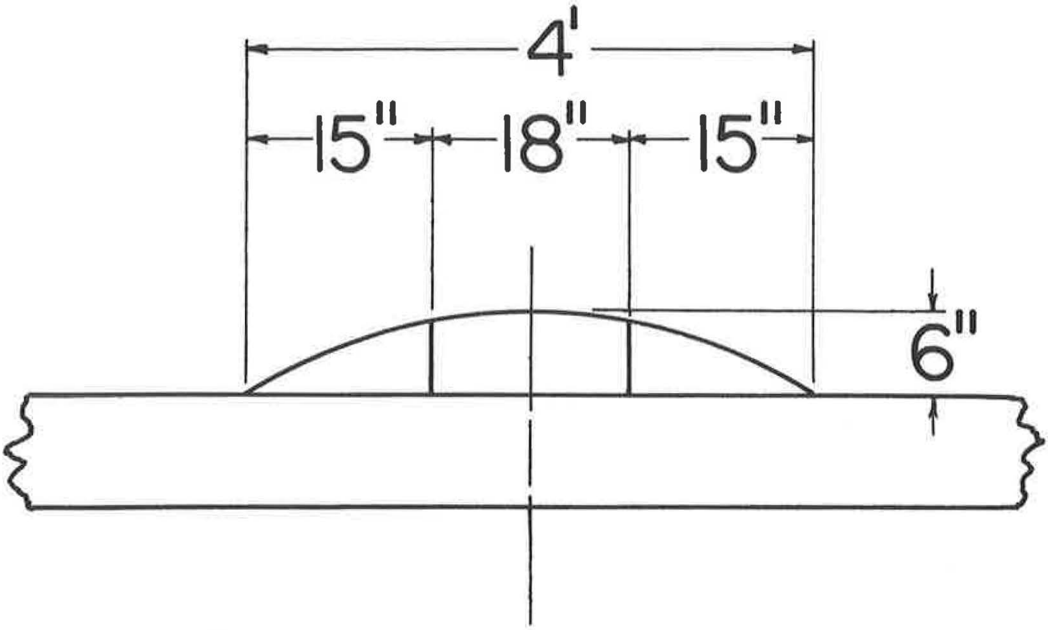
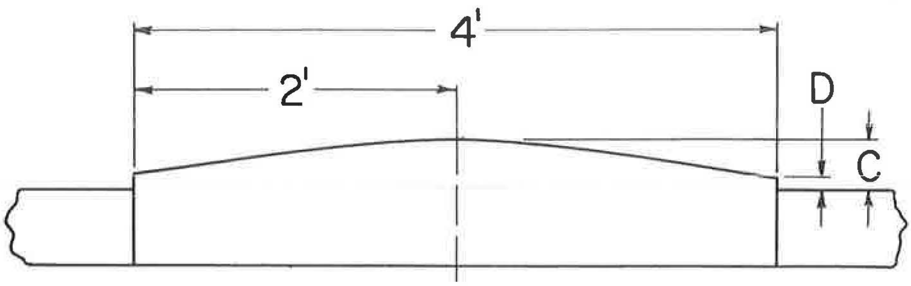


CROSS-SECTION I
(Reference No. 97)



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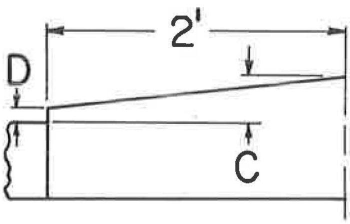
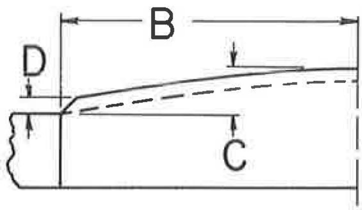
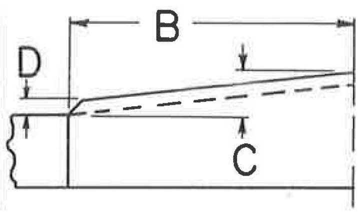


(VAR. B)



(VAR. C)



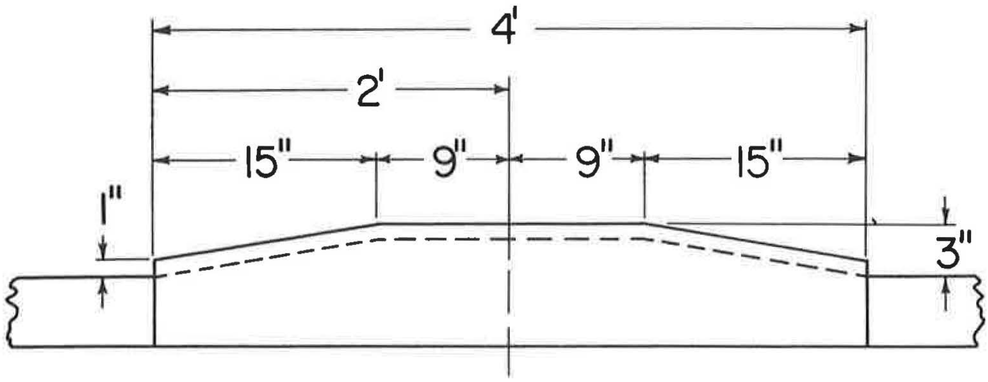
(VAR. D)

VAR. A

VAR. B

VAR. C

VAR.	B	C	D	MISC.	Ref. No.
Aa		1-3/4"	3/4"	Circular Arc	24
Ab		2"	3/4"	Circular Arc	51
Ba		2"	1"	Straight Crown	38-40
Bb		2¼"	1¼"	Straight Crown	82
Ca	2'	1-3/4"	3/4"	Circular Arc Corrugated	25,26
Cb	2'	2"	1"	Circular Arc Corrugated	41
Cc	2'	2"	1¼"	Circular Arc Corrugated	43-45
Cd	2'	2¼"	1¼"	Circular Arc Corrugated	52-78
Ce	2'	2-3/4"	1-3/4"	Circular Arc Corrugated	83,84
Cf	2'	3"	2"	Circular Arc Corrugated	94
Cg	3' &Var.	6"	6"	Circular Arc Corrugated	145
Da	2'	1½"	½"	Straight Crown	19-23
Db	2'	2"	1"	Straight Crown	42
Dc	2'	2¼"	1¼"	Straight Crown	79-81
Dd	2'	4"	1"	Straight Crown	96
De	2' &Var.	2¼"	1¼"	Straight Crown	131



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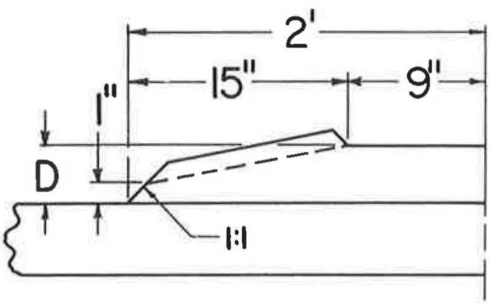
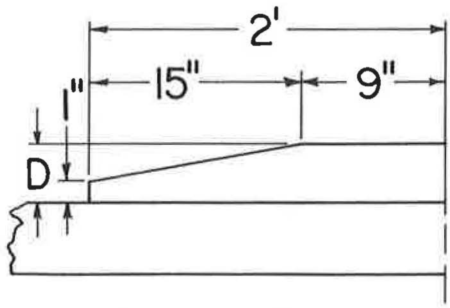


(VAR. B)



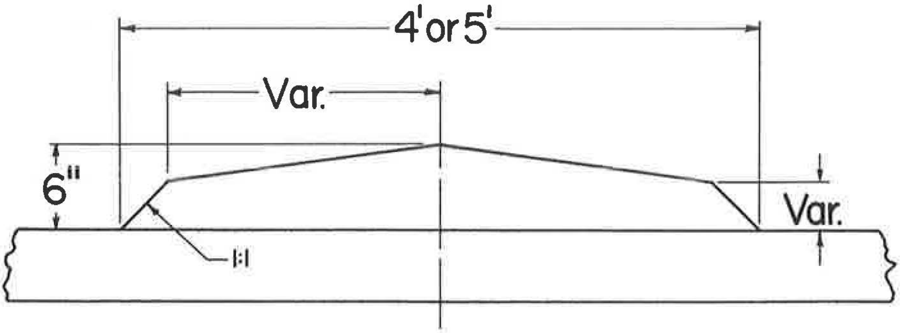
(VAR. C)

VAR. A

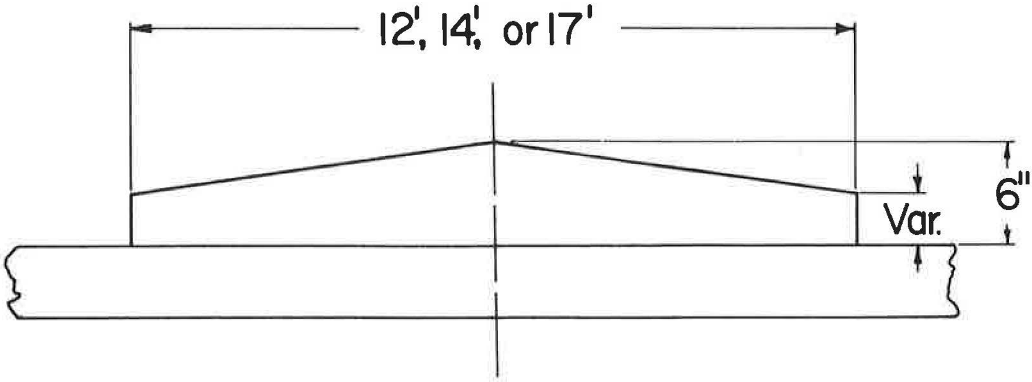
VAR. B

VAR. C

VAR.	MISC.	REFERENCE TABLE I
A	Corrugated (depressed)	87,89-92
B	Corrugated (raised)	93
C	Corrugated (raised)	88

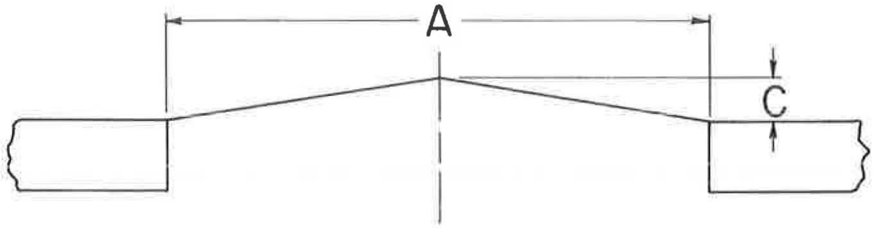


CROSS SECTION 4
(Reference Nos. 124, 125, 141)

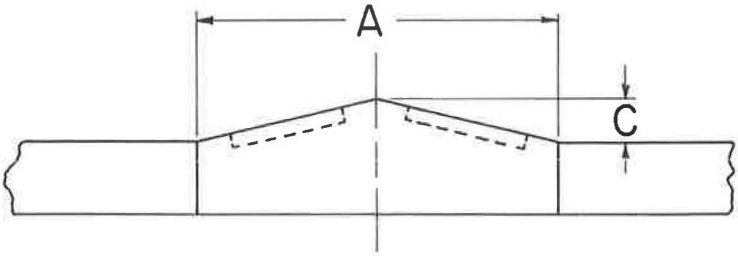


CROSS-SECTION 5

(Reference Nos. 158-160, 168, 181)

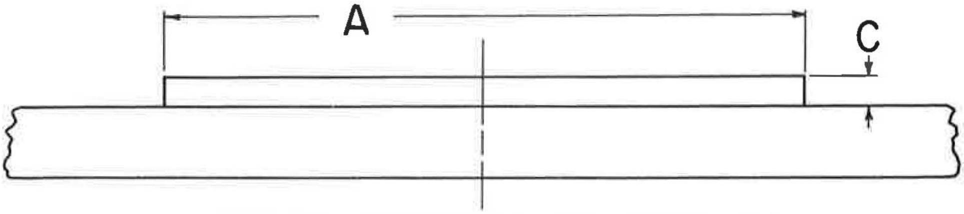


CROSS-SECTION 6 (VAR. A)

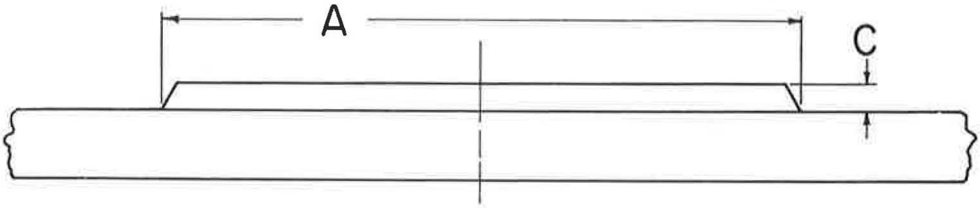


(VAR. B)

VAR.	A	C	MISC.	Ref. No.
Aa	3'	2''	P.C.C.Surface	13
Ab	4'	¼''	P.C.C.Surface	14
Ac	4'	1''	P.C.C.Surface	15
Ad	4'	1½''	P.C.C.Surface	18
Ae	4'	2''	P.C.C.Surface	27-37
Af	6'	2''	P.C.C.Surface	142
Ag	8'	2''	P.C.C.Surface	151
Ah	20'	3''	Turf	186-188
B	4'	4''	Depressed Side Ribs	95



CROSS-SECTION 7 (VAR. A)

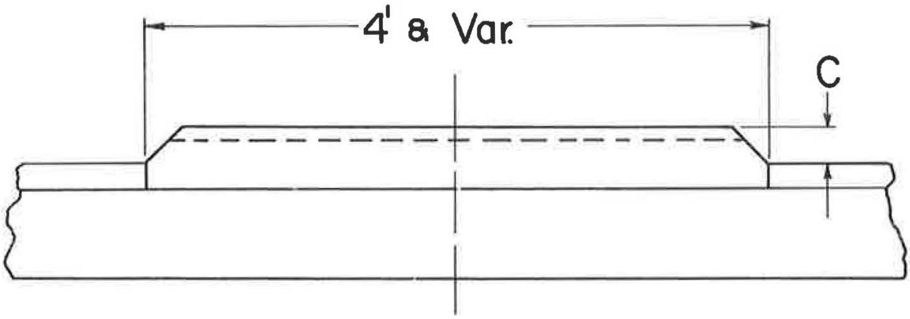


(VAR. B)

VAR. A

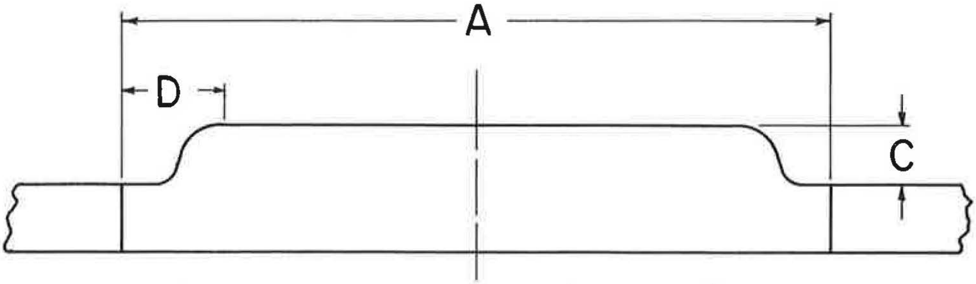
VAR. B

VAR.	A	C	MISC.	Ref. No.
Aa	1'	1"	Chicago Mesh Type	1
Ab	2'	6"	Chicago "Barrier"	5
Ac	3'	1"		7-12
Ad	4'	6"	Chicago "Barrier"	98
Ae	6'	6"	Chicago "Barrier"	143
Af	12'	6"	Chicago "Barrier"	156
Ag	36'	6"	Chicago "Barrier"	202
Ah	38'	6"	Chicago "Barrier"	203
Aj	40'	6"	Chicago "Barrier"	204
Ak	45'	6"	Chicago "Barrier"	206
Al	52'	6"	Chicago "Barrier"	207
Ba	4'	1"		16
Bb	4'	1"	Corrugated	17
Bc	4'	2"		46

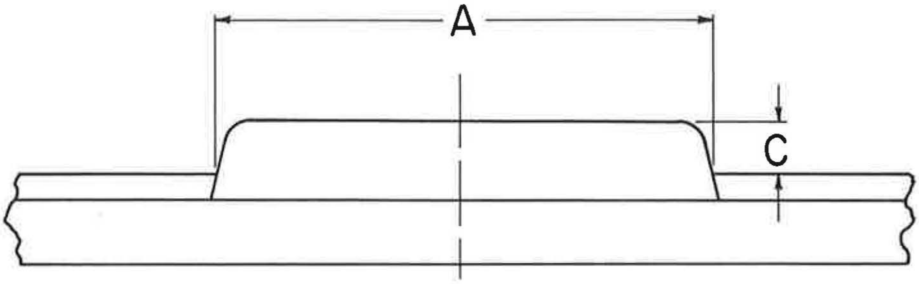


CROSS-SECTION 8

VAR.	C	MISC.	Ref. No.
Aa	2"	Not Corrugated	47,48
Ab	2"	Corrugated	49,50
Ac	2-3/4"	Not Corrugated	85
Ad	3"	Not Corrugated	86



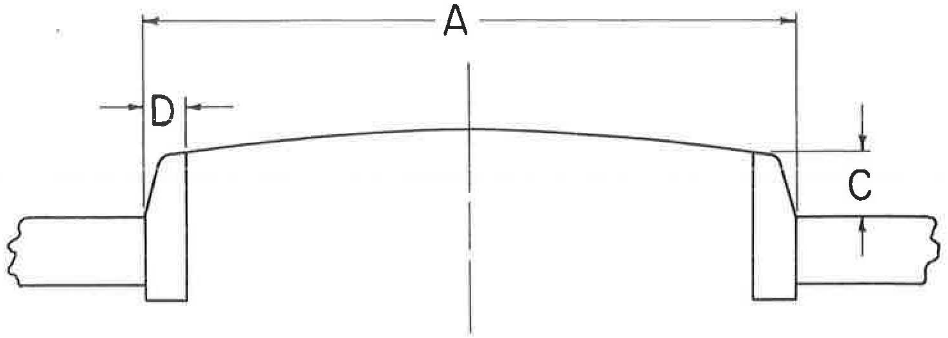
CROSS-SECTION 9 (VAR. A)



(VAR. B)

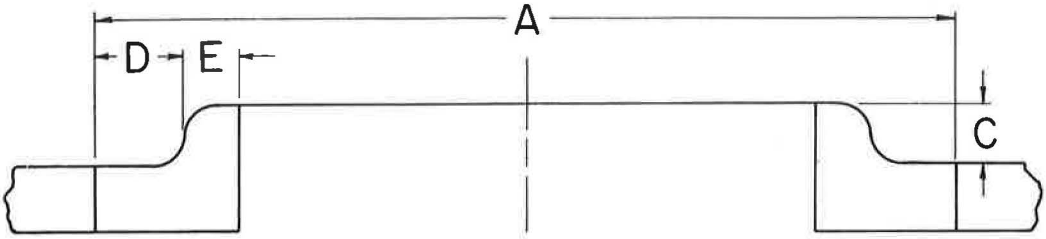
VAR. A **VAR. B**

VAR.	A	C	D	MISC.	Ref. No.
Aa	2'	4"	4½"	Before 1940	3,4
Ab	4'	6"	4"		99
Ac	4'	6"	9"	After 1940	100-119
Ad	4'	9"	6½"		126
Ae	4' &Var.	6"	9"		132-134
Af	6' &Var.	6"	9"		146,147
Ba	2-2/3' & Var.	6"	-		6
Bb	4'	6"	-		120
Bc	4' &Var.	6"	-		135



CROSS-SECTION 10

VAR.	A	C	D	MISC.	Ref. No.
Aa	4'	6"	7"	Straight Crown 0.25"/ft.	121,122
Ab	4'-12'	6"	7"	Rounded Top 1" Crown	128,129
Ac	4'-16'	6"	7"	Straight Crown	130
Ad	4' &Var.	6"	7"	Flat Top	137-139
Ac	5'	4"	7"	Flat Top	140
Af	6'	4"	7"	Flat Top	144
Ag	6' &Var.	6"	7"	Flat Top	148-150
Ah	10'	6"	7"	Rounded Top 3" Crown	152
Aj	12'	Var.	7"	Straight Crown 0.75"/ft.	155
Ak	12'	6"	10"	Flat Top	157
Al	12'	6"	7"	Rounded Top 1" Crown	161
Am	20'	6" &Var.	7"	Flat Top	189
An	24'	6" &Var.	7"	Rounded Top	193
Ao	40'	Var.	7"	Flat Top	205
Ap	Var.	6"	7"	Flat Top	211



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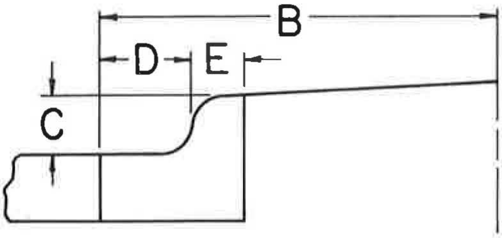

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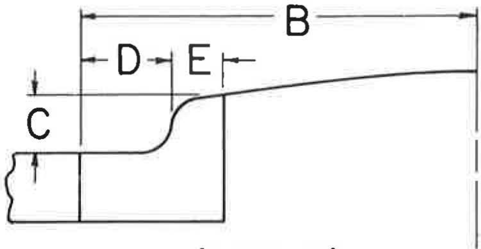
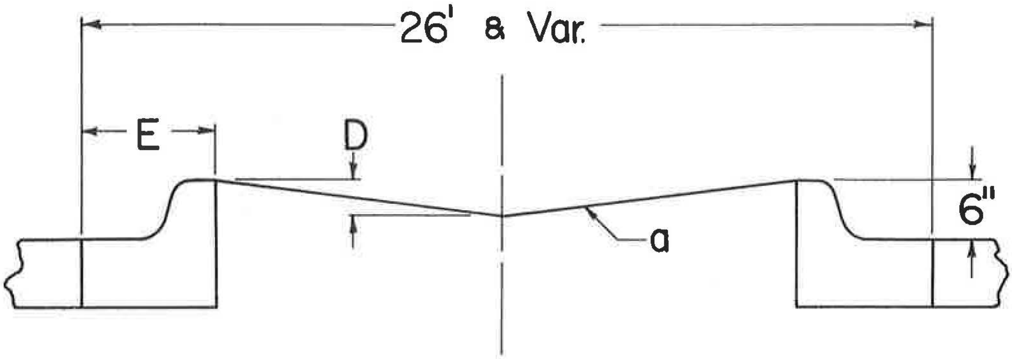


(VAR. C)

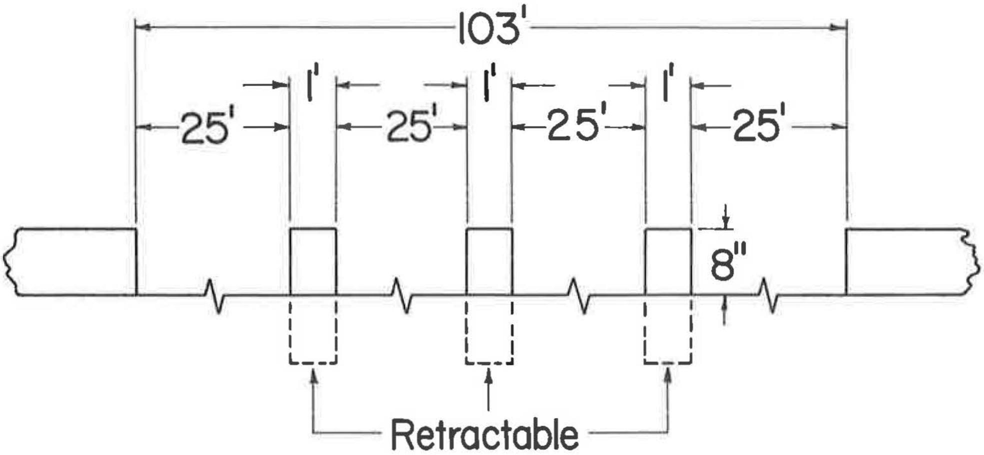
VAR.	A	B	C	D	E	MISC.	Ref. No.
Aa	4'	2'	6"	6"	7"	Flat Top	123
Ab	4'	2'	9"	6"	7"	Flat Top	127
Ac	12'	6'	9"	12"	7"	Flat Top	162
Ad	12' & Var.	6' &Var.	6"	6"	7"	Flat Top	163-165
Ae	14'	7'	4"	6"	7"	Flat Top	166
Af	14'	7'	6"	-	-	Flat Top	167
Ag	15'	7½'	7"	12"	7"	Flat Top	169
Ah	16'	8'	6"	6"	7"	Flat Top	174,175
AJ	16' & Var.	8' &Var.	6"	24"	7"	Flat Top	176
Ak	17'	8.5'	6"	12"	7"	Flat Top	179,180

VAR.	A	B	C	D	E	MISC.	Ref. No.
Al	17' & Var.	8.5' & Var.	6"	12"	7"	Flat Top	182
Am	20' & Var.	10'&Var.	8"	Var.	7"	Flat Top	192
An	Var.	Var.	6"	6"	7"	Flat Top	212
Ao	Var.	Var.	6"	-	-	Flat Top	213
Ba	15'	7.5'	6"	12"	7"	0.25"/ft. Straight Crown	170
Bb	15' & Var.	7.5' & Var.	6"	12"	7"	0.25"/ft. Straight Crown	173
Bc	16' & Var.	8' &Var.	6"	7"	6"	0.75"/ft. Straight Crown	178
Bd	18'	9'	4"	4-3/8"	7-5/8"	0.75"/ft. Straight Crown	183,184
Be	Var.	Var.	4"	4-3/8"	7-5/8"	0.5"/ft. Straight Crown	208
Bf	Var.	Var.	6"	6"	7"	0.75"/ft. Straight Crown	215
Bg	Var.	Var.	6"	-	-	0.75"/ft. Straight Crown	216
Bh	Var.	Var.	6"	-	-	0.5"/ft. Straight Crown	217
Ca	10' & Var.	5' &Var.	4"	4-3/8"	7-5/8"	Round Top 196' Radius	153
Cb	10' & Var.	5' &Var.	8"	12"	7"	Round Top 196' Radius	154
Cc	15' & Var.	7.5' & Var.	4" &Var.	4-3/8"	7-5/8"	Round Top 196' Radius	171
Cd	15' & Var.	7.5' & Var.	6"	12"	7"	Round Top Var. Crown	172
Ce	16' & Var.	8' &Var.	6"	7"	6"	Round Top	177
Cf	19'	9.5'	4"	4-3/8"	7-5/8"	Round Top 4" Crown	185
Cg	20'	10'	4"	4-3/8"	7-5/8"	Round Top 4" Crown	190,191
Ch	28'	14'	4"	4-3/8"	7-5/8"	Round Top	195
Cj	30'	15'	4"	4-3/8"	7-5/8"	Round Top 6" Crown	196-198
Ck	30' & Var.	15'&Var.	4"	4-3/8"	7-5/8"	Round Top 6" & Var. Crown	199,200
Cl	30' & Var.	15'&Var.	6"	4-3/8"	7-5/8"	Round Top 6" & Var. Crown	201
Cm	Var.	Var.	4"	4-3/8"	7-5/8"	Var. Crown	209,210



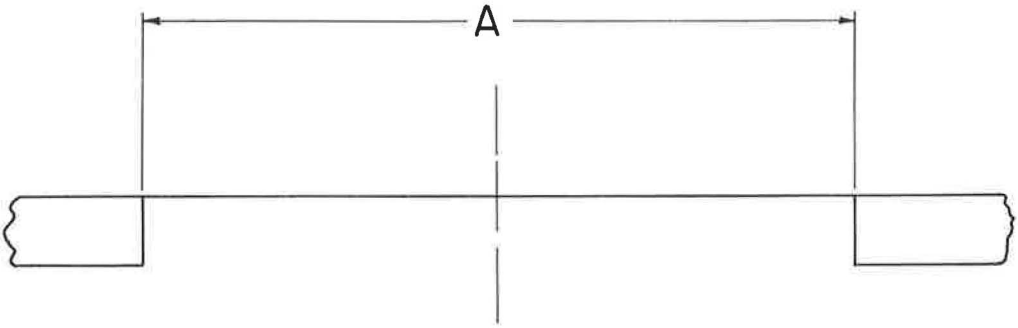
CROSS-SECTION 12

VAR.	D	E	a	MISC.	Ref. No.
Aa	6"	13"	26:1 & Var.	Curbed (depressed)	194
Ab	Var.	19"	1"/ft.	Curbed (depressed)	214



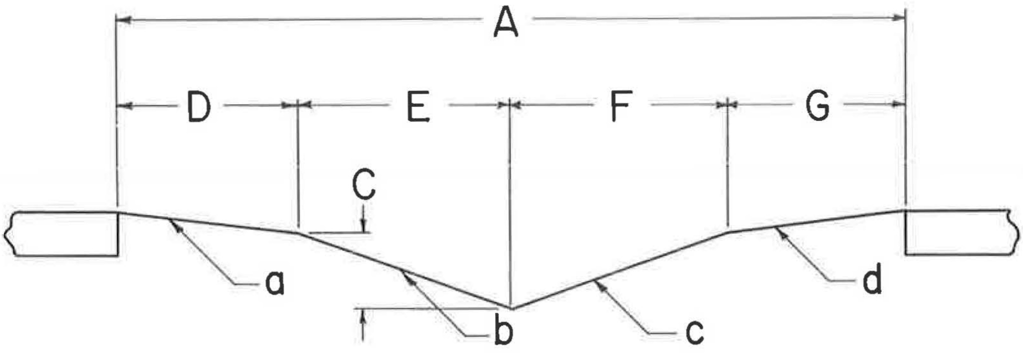
CROSS-SECTION 13

(Reference, No. 2)



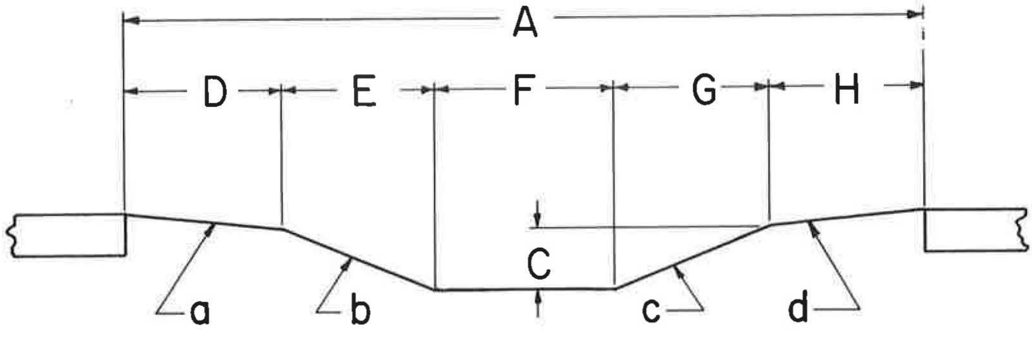
CROSS-SECTION 14

VAR.	A	MISC.	Ref. No.
Aa	4'	P.C.C.Surface	218-225
Ab	4'	Bituminous Concrete Surface	226,227
Ac	6'	Crushed Stone Surface	228
Ad	24'	Turf	229



CROSS-SECTION 15

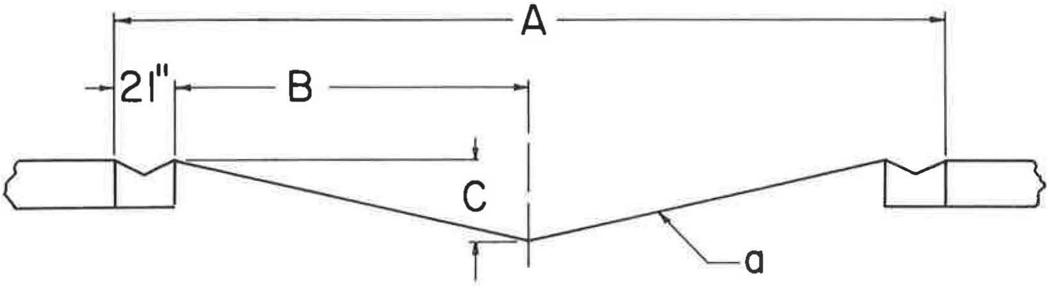
VAR.	A	C	D	E	F	G	a	b	c	d	MISC.	Ref. No.
Aa	20'	2'	6'	4'	4'	6'	0.75"/ ft.	2:1	2:1	0.75"/ ft.		232
Ab	21'	2'	7'	4'	4'	6'	0.75"/ ft.	2:1	2:1	0.75"/ ft.		233
Ac	30'	1½' & Var.	10'	5'	5'	10'	0.75"/ ft.	3:1 & Var.	3:1 & Var.	0.75"/ ft.		238
Ad	30'	3'	6'	9'	9'	6'	0.75"/ ft.	3:1	3:1	0.75"/ ft.		244-249
Ae	30'	3'	6'	9'	9'	6'	0.5"/ ft.	3:1	3:1	0.5"/ ft.		250-252
Af	30'	3' &Var.	6'	9'	9'	6'	0.75"/ ft.	3:1 & Var.	3:1 & Var.	0.75"/ ft.		253
Ag	30'	3' &Var.	6'	9'	9'	6'	0.5"/ ft.	3:1 & Var.	3:1 & Var.	0.5"/ ft.		254-261
Ah	30'	3' &Var.	6'	9'	9'	6'	0.75"/ ft.	3:1 & Var.	3:1 & Var.	0.75"/ ft.		262
Aj	40'	2' &Var.	11'	9'	9'	11'	0.75"/ ft.	3.6:1 & Var.	3.6:1 & Var.	0.75"/ ft.		265
Ak	40'	2' &Var.	10'	10'	10'	10'	0.75"/ ft.	4.5:1 & Var.	4.5:1 & Var.	0.75"/ ft.		266
Al	40'	3'	6'	12'	14'	8'	0.75"/ ft.	4:1	Var.	0.75"/ ft.		268,269
Am	40'	Var.	10'	10'	10'	10'	0.75"/ ft.	Var.	Var.	0.75"/ ft.		351
An	40' & Var.	2' &Var.	10'	10'	10'	10'	0.75"/ ft.	4.5:1	4.5:1	0.75"/ ft.	Rounded Ditch 9' Radius	354
Ao	40' & Var.	Var.	10'	Var.	Var.	10'	0.75"/ ft.	Var.	Var.	0.75"/ ft.		358
Ap	44'	3'	6'	12'	12'	10'	Var.	4:1	4:1	Var.		360,361



CROSS-SECTION 16

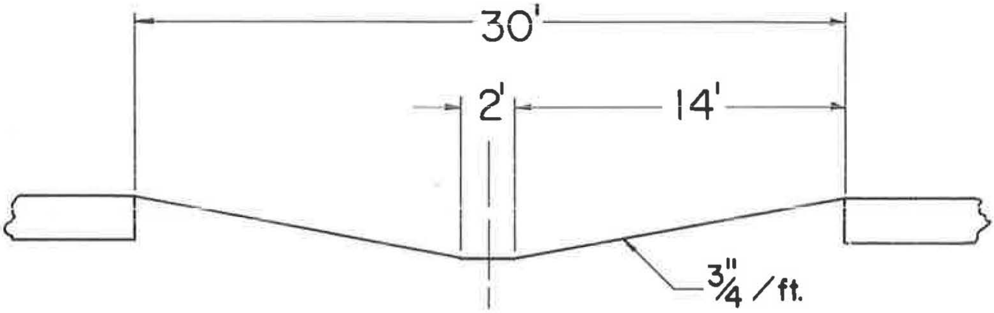
VAR.	A	C	D	E	F	G	H	a	b	c	d	Ref. No.
Aa	20'	1'	6'	3'	2'	3'	6'	0.75"/ ft.	3:1	3:1	0.75"/ ft.	231
Ab	26'	2' &Var.	6'	6'	2'	6'	6'	0.5"/ ft.	3:1 & Var.	3:1 & Var.	0.5"/	235,236
Ac	30'	2'	6'	8'	2'	8'	6'	0.75"/ ft.	4:1	4:1	0.75"/ ft.	239
Ad	30'	2' &Var.	6'	8'	2'	8'	6'	0.5"/ ft.	4:1 & Var.	4:1 & Var.	0.5"/ ft.	240
Ae	30'	2.5' & Var.	7.66'	6.33'	2'	6.33'	7.66'	0.48"/ ft.	4:1	4:1	0.48"/ ft.	241-243
Af	37' & Var.	2.875' & Var.	6'	11.5' & Var.	2'	11.5' & Var.	6'	0.5"/ ft.	4:1	4:1	0.5"/ ft.	263
Ag	39' & Var.	2' &Var.	6'	8'	2'	8'	6'	0.5"/ ft.	4:1 & Var.	4:1 & Var.	0.5"/ ft.	264
Ah	40'	2.875'	8'	11'	2'	11'	8'	0.5"/ ft.	3.82:1	3.82:1	0.5"/ ft.	267
Aj	40'	3'	6'	12'	2'	14'	6'	0.75"/ ft.	4:1	4-2/3: 1	0.75"/ ft.	270
Ak	40'	3'	6'	13'	2'	13'	6'	0.5"/ ft.	4-1/3: 1	4-1/3: 1	0.5"/ ft.	271-293
Al	40'	3'	6'	13'	2'	13'	6'	0.75"/ ft.	4-1/3: 1	4-1/3: 1	0.75"/ ft.	294-304
Am	40'	3'	8'	11'	2'	11'	8'	0.5"/ ft.	3-2/3: 1	3-2/3: 1	0.5"/ ft.	305-326
An	40'	3'	10'	9'	2'	9'	10'	0.75"/ ft.	3:1	3:1	0.75"/ ft.	327

VAR.	A	C	D	E	F	G	H	a	b	c	d	Ref. No.
Ao	40'	3' &Var.	6'	13'	2'	13'	6'	0.5"/ ft.	4-1/3: 1 & Var.	4-1/3: 1 &Var.	0.5"/ ft.	330
Ap	40'	3' &Var.	6'	13'	2'	13'	6'	0.75"/ ft.	4-1/3: 1 & Var.	4-1/3: 1 &Var.	0.75"/ ft.	331-335
Aq	40'	3' &Var.	6' &Var.	13'&Var.	2' &Var.	13'&Var.	6' &Var.	0.5"/ ft.	4-1/3: 1 & Var.	4-1/3: 1 &Var.	0.5"/ ft.	336-338
Ar	40'	3' &Var.	8'	11'	2'	11'	8'	0.5"/ ft.	3-2/3: 1 & Var.	3-2/3: 1 &Var.	0.5"/ ft.	339-346
As	40'	3' &Var.	6'	11'-5"	2'	14'-7"	6'	0.5"/ ft.	3-3/4: 1 & Var.	3-3/4: 1 &Var.	0.5"/ ft.	350
At	40'	Var.	6'	13'	2'	13'	6'	0.5"/ ft.	4:1 & Var.	4:1 & Var.	0.5"/ ft.	352
Au	40'	Var.	6'	13'	2'	13'	6'	0.5"/ ft.	Var.	Var.	0.5"/ ft.	353
Av	40' & Var.	3'	8'	11' & Var.	2'	11' & Var.	8'	0.5"/ ft.	3-2/3: 1 & Var.	3-2/3: 1 &Var.	0.5"/ ft.	355
Aw	40' & Var.	3' &Var.	6' &Var.	13'&Var.	2' &Var.	13'&Var.	6' &Var.	0.5"/ ft.	4-1/3: 1 & Var.	4-1/3: 1 &Var.	0.5"/ ft.	356
Ax	42'	3'	6'	13'	2'	13'	8'	0.75"/ ft.	4:1	4:1	0.5"/ ft.	359
Ay	48'	3'	8'or 10'	15' or 13'	2'	15' or 13'	8'or 10'	0.25"/ ft.	5:1 or 4-2/3:1	5:1 or 4-2/3:1	0.25"/ ft.	362
Az	48'	3'	8'	15'	2'	15'	8'	0.75"/ ft.	5:1	5:1	0.75"/ ft.	363
Aaa	50'	2.5'	14.66'	9.33'	2'	9.33'	14.66'	0.48" to 0.72"/ft.	4:1	4:1	0.48" to 0.72"/ft.	364,365
Abb	50'	3'	6'	12'	10'	14'	8'	0.75"/ ft.	4:1	4-2/3: 1	0.75"/ ft.	366-368
Acc	50'	3'	6'	18'	2'	18'	6'	0.5"/ ft.	6:1	6:1	0.5"/ ft.	369
Add	50'	3' &Var.	8'	16'	2'	16'	8'	0.5"/ ft.	4:1 & Var.	4:1 & Var.	0.5"/ ft.	370,371
Aee	50'	3' &Var.	10'	12.5'	5'	12.5'	10'	0.5"/ ft.	4:1 & Var.	4:1 & Var.	0.5"/ ft.	372-374
Aff	50'	Var.	8'	16'	2'	16'	8'	Var.	Var.	Var.	Var.	375
Agg	50' & Var.	3'	8'	12'&Var.	10'&Var.	12'&Var.	8'	0.5"/ ft.	4:1	4:1	0.5"/ ft.	376
Ahh	50' & Var.	3' to 4'	8'	16'&Var.	2'	16'&Var.	8'	0.5"/ ft.	4:1 & Var.	4:1 & Var.	0.5"/ ft.	377,378
Ajj	50' & Var.	3' &Var.	10'&Var.	12'&Var.	6' &Var.	12'&Var.	10'&Var.	0.5"/ ft.	4:1	4:1	0.5"/ ft.	379
Akk	54'	3' &Var.	12'	14'	2'	14'	12'	0.48"/ ft.	4-2/3:1 & Var.	4-2/3:1 & Var.	0.48"/ ft.	380-384
All	64'	3' &Var.	8'	23'	2'	23'	8'	0.5"/ ft.	7-2/3:1 & Var.	7-2/3:1 & Var.	0.5"/ ft.	389-396
Amm	Var.	3'	10'	Var.	2'	Var.	10'	0.5"/ ft.	Var.	Var.	0.5"/ ft.	422



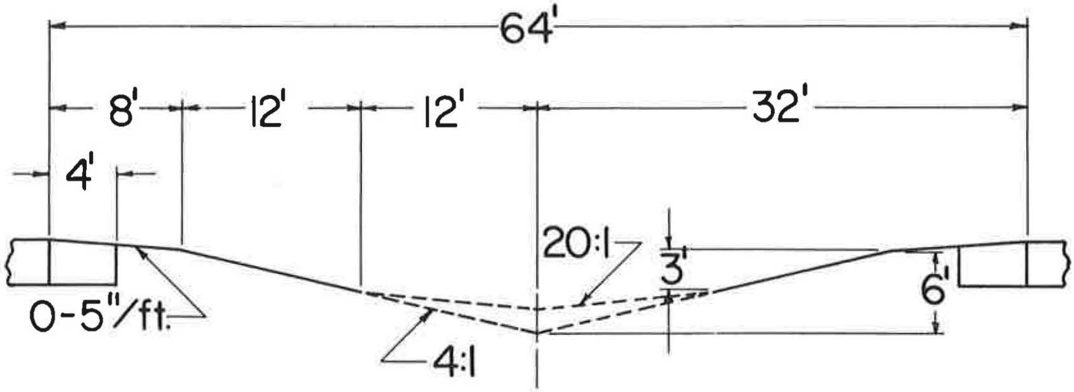
CROSS-SECTION 17

VAR.	A	B	C	a	MISC.	Ref. No.
Aa	18'-50'	Var.	Var.	0.875"/ ft.	Type B Gutter	230
Ab	25'	10.75'	7"	0.66"/ ft.	Type B Gutter	234



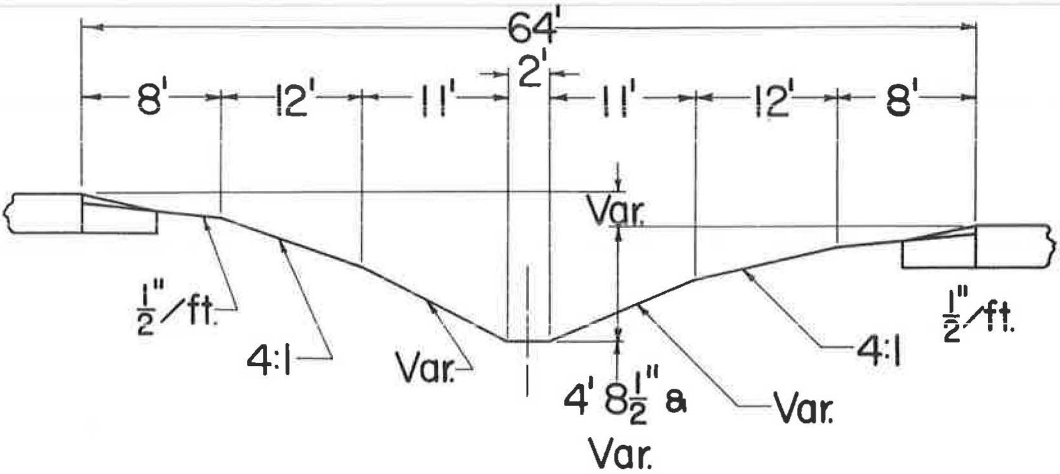
CROSS-SECTION 18

Reference No. 237

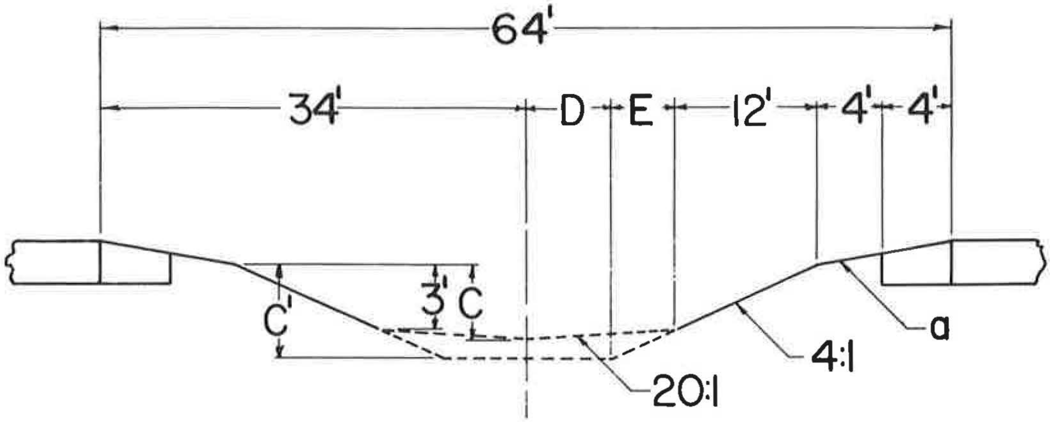


CROSS-SECTION 19

(Reference Nos. 399-401)

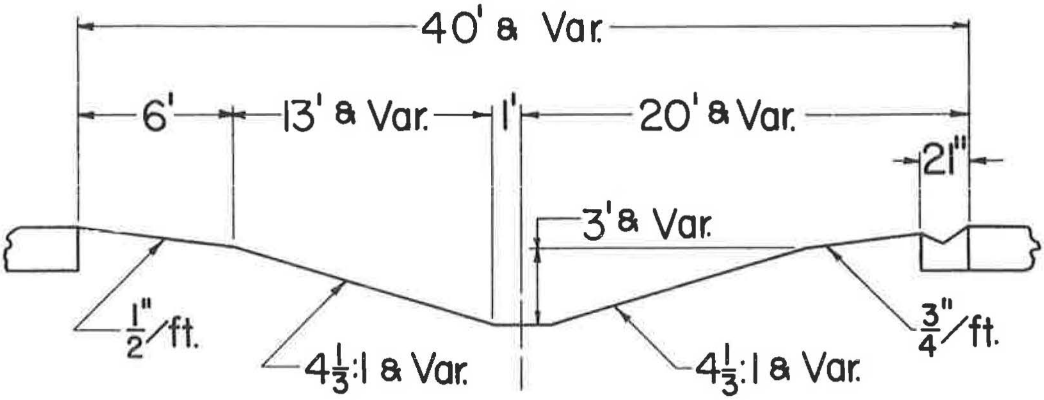


CROSS-SECTION 20
(Reference Nos. 402-404)



CROSS-SECTION 21

VAR.	C	C'	D	E	a	Ref. No.
Aa	3'-6-5/8"	5'-9"	1'	11'	0.75"/ft.	397
Ab	3'-7-1/5"	5'-3-3/4"	3'	9'	0.5"/ft.	398



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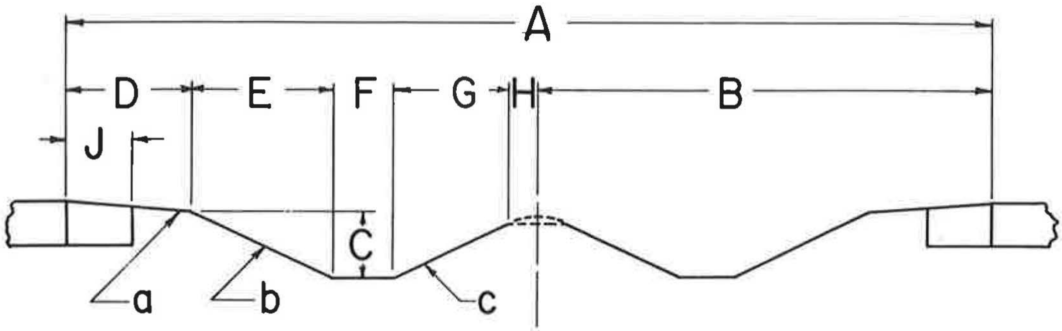
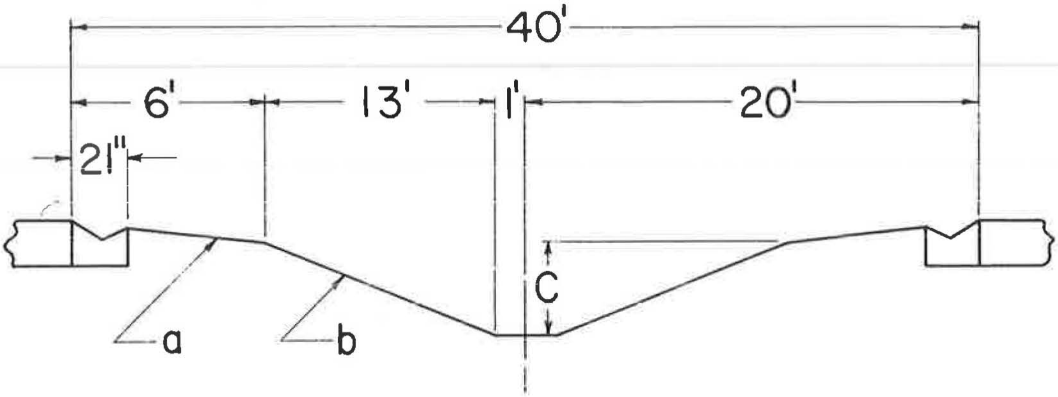


CROSS-SECTION 23

VAR.	A	B	C	D	E	F	G	H	J	a	b	c	Ref. No.
Aa	64'	32'	3'	6'	12'	2'	7'	5'	3'	0.5"/ ft.	4:1	2:1	385
Ab	64'	32'	3'	6'	12.5'	2'	6'	5.5'	3'	0.5"/ ft.	4:1	2:1	386
Ac	64'	32'	3' &Var.	8'	10.5'	2' &Var.	6'	5.5'	4'	0.5"/ ft.	3-1/3: 1	2:1	387,388
Ad	80'	40'	3'	8'	12'	2'	12'	6'	3'	1"/ft.	4:1	4:1	405-410
Ae	80'	40'	3'	8'	12'	2'	12'	6'	3'	0.5"/ ft.	4:1	4:1	411-416
Af	80'	40'	3'	8'	12'	2'	12'	6'	4'	0.5"/ ft.	4:1	4:1	417-419
Ag	80'	40'	3' &Var.	8'	12' & Var.	2'	12' & Var.	Var.	4'	0.5"/ ft.	4:1	4:1	420
Ah	80' & Var.	40' & Var.	3'	8'	12'	2'	12'	6'	3'	0.5"/ ft.	4:1	4:1	421



CROSS - SECTION 24

VAR.	C	a	b	Ref. No.
Aa	3'	0.75"/ ft.	4-1/3:1	329
Ab	3'- 5-5/8" & Var.	0.75"/ ft.	3.78:1	347
Ac	3'-6½" & Var.	0.75"/ ft.	Var.	348
Ad	3'-6½" & Var.	0.75"/ ft.	3.78:1	349

An Experiment with Evergreen Trees in Expressway Medians to Improve Roadway Delineation

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JANIS H. LACIS, Research and Planning Engineer, Illinois Division of Highways

Simulated median plantings were installed on selected portions of two Chicago expressways to determine whether this means of providing roadway delineation would significantly reduce the frequency of vehicle encroachment on the median. A complete record of encroachments was obtained during the winter for comparison with the number that occurred during the same portion of the previous year.

There was a significant reduction in the frequency of encroachment on the medians of both expressways, with the greatest reductions occurring on or near curved alignment where the hazard of headlight glare from opposing vehicles had previously been greatest. However, no attempt was made to measure the relative magnitude of the several roadway delineation benefits assumed to have contributed to the observed reductions.

The findings suggest the possibility of substantial improvement in the safety of divided highways through the development and use of median plantings appropriate to the needs of the driver under the various conditions imposed by roadway characteristics, driving conditions, and surrounding land use.

•THIS REPORT covers one phase of a study of medians of divided highways which was conducted by the Department of Civil Engineering, University of Illinois, in cooperation with the National Science Foundation, the Illinois Division of Highways and the U.S. Bureau of Public Roads. It presents the findings from an experimental use of evergreen trees in Chicago expressway medians to improve roadway delineation.

Results from studies of the frequency and nature of accidents involving vehicle encroachment on medians of divided highways in Illinois have suggested the possibility of generally insufficient roadway delineation on modern freeways and expressways. Encroachments on the median were observed to be concentrated at locations where roadway characteristics and the headlight glare from approaching vehicles would appear to make it difficult for drivers to judge roadway alignment (1). As a result of these observations an experiment was designed to determine whether an improvement in roadway delineation would significantly decrease the frequency of vehicle encroachment on highway medians.

Among the many factors affecting the choice of delineation materials in the experiment, the controlling considerations were assumed to be (a) the need to provide drivers with some relief from the headlight glare of opposing vehicles and (b) the need to provide the appearance of a third dimension to wide modern roadways which give the impression of having only two dimensions, length and width, particularly during low-visibility conditions. Plantings in the median have been credited with the achievement

Paper sponsored by Committee on Operational Effects of Geometrics.

of these purposes, although the lack of experience and research in this area has been pointed out (2, 3).

One argument in favor of median plantings is that the driver should occasionally have familiar three-dimensional objects relatively close at hand if he is to be kept constantly aware of the routine circumstances of driving. The average adult freeway driver of today has gained most of his driving experience on 2-lane highways and streets with narrow rights-of-way where he has become accustomed to the nearby telephone poles, fences, trees and shrubs that help to keep him almost effortlessly aware of his general speed and position on the roadway. Under the contrasting conditions found on freeways with wide, nearly level right-of-way, it has been noted that adult drivers often behave in such a way as to show basic ignorance of speed and distance relationships and of driver judgment time requirements (4). It has, therefore, been reasoned that the use of certain types of trees or shrubs in the median of modern freeways should increase the vertical angle of driver vision intercepting the median cross-section and give the driver a familiar basis for judging speed, distance and roadway alignment. In consideration of this argument and because of the assumed need to reduce headlight glare, median plantings were chosen for use as the delineating materials in this experiment.

The time and expense normally involved in the establishment of mature median plantings prompted a search for an acceptable type of simulated planting that could be installed immediately. An investigation of the cost and appearance of artificial trees, plastic shrubs and other possibly suitable materials led to the adoption of evergreen trees (leftover Christmas trees) as the most suitable and economical substitute for normal plantings.

The choice of study sites was limited by the need to perform the experiment on highways for which a record of vehicle encroachments on the median had previously been obtained. Furthermore, Chicago expressways were the only previously studied facilities with traffic volumes high enough to have yielded a possibly significant number of vehicle encroachments on the median within the useful life span of a cut evergreen tree. Selected portions of the Edens and Calumet Expressways were utilized to include both a lighted 6-lane facility with a narrow median (17. 6 ft) and an unlighted 4-lane facility with a relatively wide median (40 ft).

PROCEDURE

Leftover Christmas trees were obtained free of charge from Chicago area merchants during the last week of December 1959 and installed on the median barrier posts of the two expressway segments. The location and length of each installation and the details of expressway cross-sections are shown in Figures 1 and 2. Details of tree fastening and spacing are shown in Figure 3.

Beginning in January 1960 on the first day after completed installation of trees on each expressway, a complete record of vehicle encroachments was obtained for comparison with the number of encroachments that occurred during the same portion of the previous year without the trees. The collection of encroachment data required carefully planned frequent coverage of the entire length of the study sites to locate and evaluate properly the evidence of each vehicle encroachment. Project personnel worked closely with maintenance personnel and weather forecasters to prevent the loss of encroachment evidence due to changing weather conditions and maintenance activities. Intentional encroachments for the purpose of making U-turns or performing emergency activities across the median were not recorded.

The trees were removed after the first few warmer days of March when they began to defoliate.

FINDINGS

A summary of the results of the experiment is given in Table 1. The possible effects of the differences in weather conditions during the two periods of time were not considered in estimating the significance of the reductions in number of encroachments. Chicago area weather records show that there were 6 more days of low-visibility

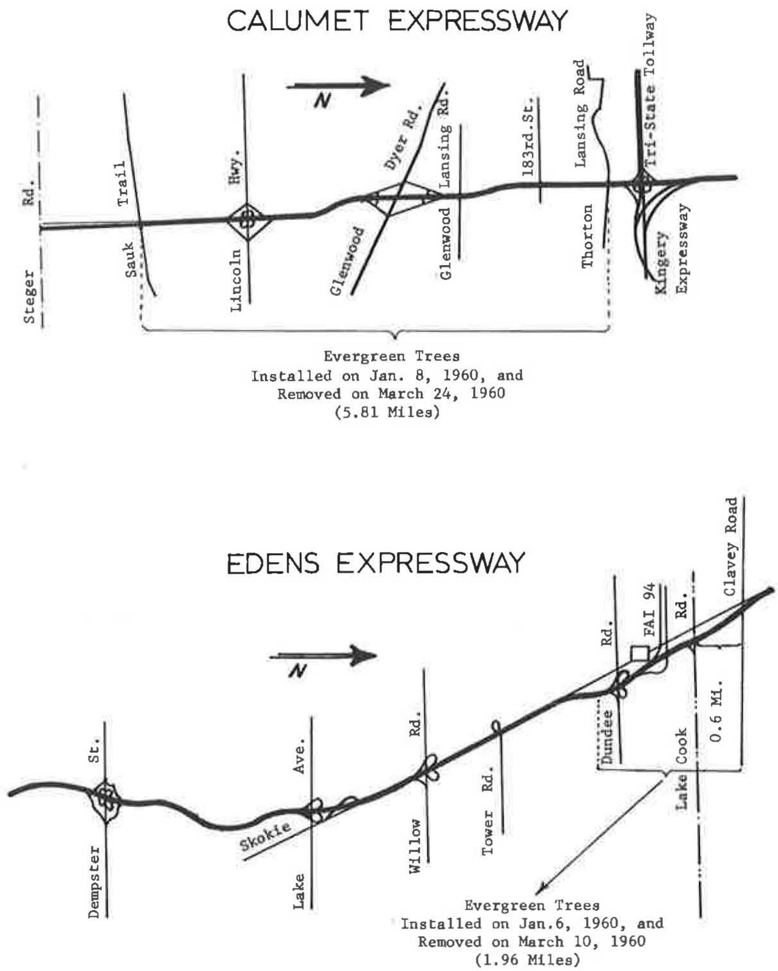


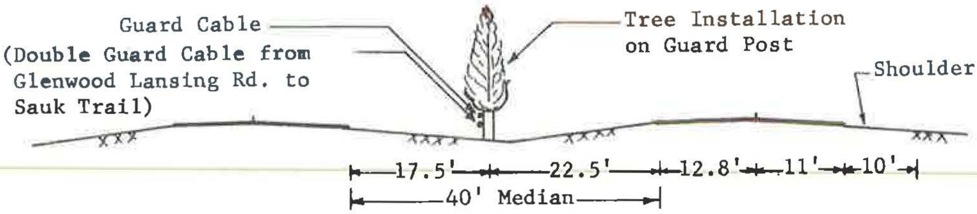
Figure 1. Test sites.

conditions and 5 more days of freezing drizzle or rain during the 1959 period of observation than during the 1960 period (Table 2). This may or may not have been offset by the 11 more days of snowfall and sleet that occurred during the second period. However, it appears that the slightly increased traffic volumes (Table 3) and included extra day of observation during the second period would probably have offset any differences in the effects of weather. The reductions in the number of encroachments due to the effects of the evergreen trees are, therefore, considered significant at the levels indicated in Table 1. That is, for the particular weather and traffic conditions and roadway characteristics involved in this study, it is assumed that the trees effectively reduced the number of vehicle encroachments on the median in that the observed reductions could have occurred by chance less than 2 times in 100.

DISCUSSION OF THE EXPERIMENT

Although this experiment was not based on the analysis of accident data collected by the police, an evaluation of pertinent accident records was made as part of the work on previously reported research (5) aimed at gaining a better understanding of the variables in accident reporting. The numbers of encroachments recorded by project personnel are given in Table 4 for comparison with the number of accidents reported by the police during the same periods of time.

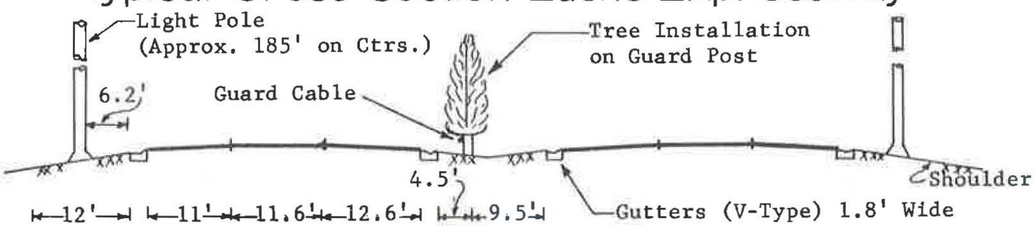
Typical Cross-Section Calumet Expressway



Calumet Expressway Median, Guard Posts and Cable

Calumet Expressway North From 183 rd St.

Typical Cross-Section Edens Expressway



Edens Expressway South From Lake Cook Rd. Overpass (F.A.I. 94 Overpass in Background)

Edens Expressway South From Entrance of F.A.I. 94 (Dundee Road Overpass in Background)

Figure 2.

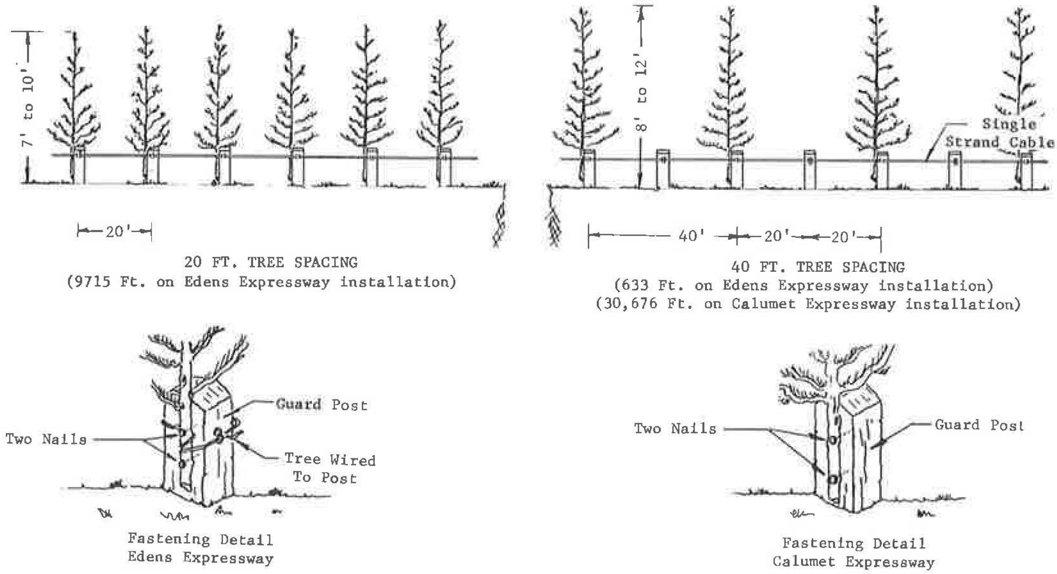


Figure 3. Installation of evergreen trees on expressway median.

TABLE 1

EFFECT OF EVERGREEN TREES ON ENCROACHMENTS

Expressway	Length (mi)	Days of Observation[a]	No. of Veh Encroachments on Median 1959	1960[b]	1961	Change 1959 to 1960 (%)	Significance[c] of Change
Edens	1.96	63	11	2	14	-82	P < .02
Calumet	5.81	74	13	3	—	-77	P < .02

[a]1959 and 1961 only (one extra day, Feb. 29, was included in 1960 observations).
[b]With trees.
[c]Mathematical model used for estimating significance is given in Appendix.

TABLE 2

CHICAGO AREA WEATHER
(Jan. 6 through March 24)

Year	Snowfall or Sleet (days) Jan.	Feb.	March	Total	Total Snow (in.)	Max. Snow on Ground (in.) Jan.	Feb.	March	Freezing Drizzle or Freezing Rain (days) Jan.	Feb.	March	Total	Low Visibility[a] (days) Jan.	Feb.	March	Total
1959	13	12	13	38	22.1	8	5	1	4	4	1	9	3	3	2	8
1960	11	23	15	49	32.0	2	7	7	1	3	0	4	0	0	2	2

[a]One-fourth mile or less because of fog, snow, etc.

TABLE 3

TRAFFIC VOLUMES ON CHICAGO EXPRESSWAYS

Expressway	Annual Avg. Daily Traffic 1957	1958	1959	1960	Avg. Daily Traffic for Period[a] 1957	1958	1959	1960	Avg. Daily Traffic During Winter[b] 1956-57	1957-58	1958-59	1959-60
Edens (at Lake Cook Rd.)	30,269	29,666	27,000[a]	25,500	24,700	25,560	22,720[c]	26,030	24,770	26,160	23,016[c]	25,810
Calvert (at Glenwood Lansing Rd.)	10,973	11,825	12,954	13,800	9,531	9,865	10,908	12,000	9,519	9,852	10,906	12,065

[a]From Jan. 1 through March 31.
[b]Dec. 1 through March 31.
[c]Opening of Illinois Toll Highway diverted traffic from the north end of Edens Expressway.

TABLE 4

SUMMARY OF ACCIDENTS AND ENCROACHMENTS ON MEDIANS OF CHICAGO EXPRESSWAYS

Expressway Location	All Reported Accidents[a]				Reported Median Accidents[b]			All Reported Accidents During Winter[c]				Reported Median Accidents During Winter[b, c]			Vehicle Encroachments on Median During Winter[c]		
	1957	1958	1959	1960	1958	1959	1960	1956-57	1957-58	1958-59	1959-60	1957-58	1958-59	1959-60	1957-58	1958-59	1959-60
Edens with trees	30	34	24	42	7	1	18	—	13[d]	19	19	1[d]	4	7	—	11[e]	2[e]
All of Edens	215	216	277	430	21	42	128	63[d]	63[d]	117	148	3[d]	14	34	56	73	41
Calumet with trees	13	12	31	63	1	15	28	—	2[d]	11	15	0[d]	5	7	—	13[f]	3[f]
All of Calumet	114	84	133	183	15	23	63	29[d]	32[d]	44	98	6[d]	14	23	—	38	30
Ingery	21	19	36	52			20	6[d]							7	9	14

[a]Does not include accidents at the grade intersection of Edens Expressway and Clavey Rd.
[b]Accidents involving encroachment of vehicles on the median as a part of the accident sequence.
[c]Winter months from Dec. 1 through March 31 except where noted.
[d]Includes accidents for January, February and March only (1957 accident case histories retired).
[e]For the period from Jan. 6 to March 10.
[f]For the period from Jan. 8 to March 24.

The observed decrease in the number of vehicle encroachments on the median after the installation of the trees is not reflected in the number of accidents reported by the police. However, little significance, if any, can be attached to this fact. An increasing amount of police surveillance was provided on these expressways during and immediately preceding the installation of the trees in the median and, because of the activities of project personnel, greater police attention was attracted to all types of accidents on both expressways. The novelty of the experiment and the publicity given to it by news media also served to generate attention. As a result, there was a considerable increase in the percentage of total median encroachments reported as accidents by the police; it quadrupled on Edens Expressway (Table 4). Fourteen of the 73 encroachments (19.2 percent) were reported by the police in the winter of 1958-1959, whereas 34 of the 41 encroachments (83 percent) were reported by the police in the winter of 1959-1960.

If the accident record for Edens Expressway were adjusted so as not to reflect this increased efficiency in accident reporting, it would show a decrease in both the total number of reported accidents and the number of reported median accidents during the winter of 1959-1960 on that portion where the trees were installed. For example, the total of 19 reported accidents during the winter of 1958-1959 would be compared with one-fourth of 19, or about 5, reported accidents for the winter of 1959-1960, and the 4 reported median accidents during the winter of 1958-1959 would be compared with one-fourth of 7, or about 2, for the winter of 1959-1960.

An identical type of adjustment in the accident record for the portion of Calumet Expressway where the trees were installed (from Sauk Trail to Thornton Lansing Rd.) cannot be made because of the grouping of certain types of accident data extracted from the accident reports for both Kingery and Calumet Expressways. However, an adjustment based on the observed average increase in efficiency of accident reporting on these two expressways (75 percent) produces the same type of result as was obtained for Edens Expressway. Both the total number of reported accidents and the number of reported median accidents became smaller during the winter of 1959-1960 where the trees were installed. This suggests that accident records are in general agreement with the previous findings if proper consideration is given to the limitations of accident records that have already been pointed out (5).

The most pronounced effect of the trees was observed on the portion of the installation on Edens Expressway north of Lake Cook Rd. Nearly half of this 0.6-mi length of the expressway is a long* 1-deg curve (Fig. 4) on which over half of the 11 encroachments occurred during the 1959 period of observation. The record of encroachments on this 0.6-mi portion for the period from Jan. 6th to March 10th in 1958, 1959, 1960 and 1961 is 8, 7, 0, and 8 encroachments, respectively. No encroachments occurred there in 1960 while the trees were in the median. It is possible that the greatest benefit from the trees at this location was the increased visibility of the median resulting from a reduction in the headlight glare suffered by northbound drivers approaching or negotiating the curve. However, because of the general lack of information regarding

*L = 1,575.00 ft, Δ = 15 deg 45 min, T = 792.54 ft, R = 5,729.65 ft.

Figure 4. View of evergreen trees in median of Edens expressway north from crossroad overpass structure at Lake Cook Rd.

the time of day during which the encroachments occurred, there is no proof that headlight glare actually contributed to the circumstances producing the encroachments. The direction of travel of the majority of the encroaching vehicles is the only direct evidence indicating that headlight glare reduction might have been the primary reason for such a pronounced decrease in encroachments at the curve. The only two encroachments that occurred along the entire tree installation on Edens Expressway originated from the southbound traffic stream, whereas most of the encroachments during other years originated from the northbound traffic stream on or near the curve (11 out of the 14 in 1961). This suggests the possibility that headlight glare reduction may have been a major factor in reducing the number of encroachments at this location.

Attempted measurements of the change in headlight glare resulting from the use of the trees were unsuccessful due to the malfunctioning of amplifying and recording equipment at low temperatures. The change in glare was quite obvious to observers driving south on Edens Expressway past the end of the portion with trees in the median. The photographs in Figure 5 roughly illustrate the increased night visibility of the left edge of the pavement next to the median due to the decrease in headlight glare on the portion with trees.

There appeared to be little difference in the amount of glare reduction provided by the two different tree spacings (20 and 40 ft), although a staccato effect from headlights flashing across the median between the trees was slightly noticeable with the 40-ft tree spacing. The staccato effect from headlights of opposing vehicles would probably be annoying if trees of this size were placed at a much greater spacing than about 40 ft.

The rising and setting sun produced a markedly annoying staccato effect much like driving along a field of corn when the sun is low. The shadows of the trees are noticeable in Figures 2 and 4. Several of the 186 expressway drivers interviewed at a gasoline

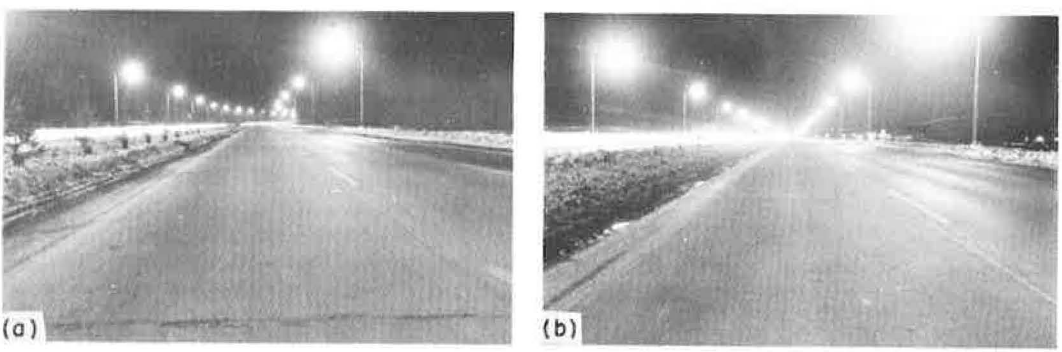


Figure 5. Median visibility from inside lane of Edens expressway: (a) with trees, and (b) without trees in the median (45-sec. exposure, f-16, medium speed panchromatic film, 10 cars passing on opposing roadway).

station near the north end of Edens Expressway mentioned this annoyance, and one user of Calumet Expressway even expressed it in a letter to the District Engineer. This staccato effect from sunlight places a limit on the desirable maximum height of closely and regularly spaced objects in the median. The height of such objects should extend above the driver's line of sight to the headlights of opposing vehicles but not higher than his line of sight to the horizon on the left if the sun rises or sets at any angle on his left. Solid row planting would probably be desirable in cases where these criteria cannot be met.

Nearly all of the drivers interviewed during the many consecutive days of snowfall and sleet in February 1960 expressed appreciation of the benefit of better roadway delineation provided by the trees. However, a great many of these persons were not aware of the fact that the trees had no roots, and, when so informed, most of them quickly changed their minds. The mere mention of the word "artificial" in connection with the trees seemed to alienate a lot of otherwise staunch supporters of the idea of trees in the median. This is unfortunate in one respect. The use of de-icer salts on the expressways has resulted in such high concentrations of chloride in the median soil that ordinary tree and shrub culture is almost out of the question (Fig. 6).

Samples of the upper 5 in. of median soil from random locations contained from 3,300 to 12,000 ppm total chloride calculated as sodium chloride. The effects of this high salt content were illustrated by the recent rapid demise of multiflora rose plantings in the expressway medians. The tolerable limit for most trees and shrubs is below 3,200 ppm soluble salt. Above this concentration there is abnormal development (6). Concentrations as low as 1,500 ppm will result in depressed growth and frequent injury during hot summers with low rainfall.

Below a depth of about 2 ft, the salt content of the median soil becomes tolerable, so there is still a possibility of some form of tree and shrub culture, even if not in the usual sense. The development of salt-resistant plant species or special methods of planting to prevent dissolved salt from seeping down along the trunk and roots of the plant may be possible. However, this approach may be considerably more expensive than the use of some of the more recently developed plastic trees and shrubs, disliked by a large portion of the driving public.

Figure 6. Windrow of de-icer salt piled up by passing vehicles on Edens Expressway.

An adjustment in the types and quantities of chemicals used as de-icing agents may be the best possibility for making the areas near the pavement more suitable for tree and shrub culture. It is reported that calcium chloride is only about one-tenth as toxic to vegetation as sodium chloride (7). Furthermore, calcium chloride is more effective in the control of snow and ice under certain pavement and weather conditions. The fact that it is considerably more expensive than sodium chloride has resulted in the testing and use of various mixtures of the two in many areas of the country (8). Further investigation along these lines may help to improve both the planting conditions and the economy of snow and ice control. In the meantime, types of delineation other than plantings should also be investigated.

Assuming that the greatest benefit from delineation is obtained at night (9), reflective delineators may be a partially acceptable alternate. In trial installations

Figure 7. Reflective delineators on Edens Expressway.

Figure 8. Delineator washing equipment and crew, Illinois Toll Highway Commission (warning vehicle accompanies truck).

on Chicago expressways, such as shown in Figure 7, the reflectors soon became covered with a film of dirt, but the cost of overcoming this fault should be worth the potential benefits (11, 12). The first annual washing of the 20,000 delineators and mile markers on the entire 187-mi Illinois Toll Highway System was accomplished in 12 working days and at a cost of only $3.24/mi. This includes the total cost of labor, materials and equipment (Fig. 8). The unit cost of cleaning delineators on Chicago area expressways should not be any greater, but the operation would have to be performed more frequently. The splash and spray from passing vehicles soon make reflective delineators ineffective in an area with an atmospheric dust loading as high as it is in Chicago (10). After only 2 wk of unusually damp winter conditions, the reflectors in the test installation shown in Figure 7 could barely be seen at night with the aid of high-beam headlights. The need of inexpensive self-cleaning reflective delineators is indicated. However, reflective delineators cannot be expected to provide all of the benefits that appear to be available from the use of trees or shrubs in the median. Some combination of materials, such as actual or simulated median plantings, roadside reflective delineators, and pavement markings will be required in the development of roadway delineation that will be nearly as effective under low-visibility conditions as under normally favorable driving conditions.

SUMMARY AND RECOMMENDATIONS

The simulated median plantings significantly reduced the frequency of vehicle encroachment on the medians of both expressways. The greatest reduction in encroachment frequency occurred on or near curved alignment where the hazard of headlight glare from opposing vehicles was previously most severe. Increased headlight reflection onto the pavement and additional traffic guidance during low-visibility conditions were also noted by observers and expressway users. However, measurement of the relative magnitude of each of these assumed roadway delineation benefits from the median plantings was not attempted. The extent to which each contributed to the observed reductions in encroachment frequency is, therefore, not known.

The safety benefits that appear obtainable from better roadway delineation justify considerably more research and development work on this and all possible means of improving the extent to which the median helps to delineate roadway alignment. Highway transportation has become such a vital part of our economy and daily activities that a constantly increasing amount of highway travel is performed under low-visibility conditions. It takes less than ⅛ mi of visibility to keep most drivers off the highway. One of the greatest limitations of driving under such conditions is the lack of per-

spective provided by the two-dimensional features of the practically level roadways of modern freeways and expressways. Reflective delineators are recognized by experienced state and turnpike authorities as an essential element in highway design (13), but reflectors are not always effective in providing the appearance of a third dimension on wide modern roadways. Median plantings help not only to provide some vertical dimension to the roadway both in daytime and at night but also help to reduce the headlight glare from opposing vehicles and the effects of negative delineation (1) produced by the headlights of vehicles on access ramps, frontage roads and other nearby facilities. Effort should be devoted to the development of the proper type, size, spacing and location of median plantings and the most desirable combinations of plantings, reflective delineators and pavement markings to suit the psychological needs of the driver under the conditions imposed by various combinations of roadway alignment, driving conditions, terrain, and surrounding land use.

The greatest current need from research in this area is information concerning the reasons for the observed effectiveness of delineation materials. Some of the more apparent delineation benefits may be only partially responsible for the accident rate reductions found in research. For example, a reduction in headlight glare may not have been the primary reason for the increased safety provided by the trees in this experiment. Negotiating curved alignment is a driving task requiring considerably more than the ability to see the roadway under the handicap imposed by headlight glare from opposing vehicles. Speed and distance determinations are also critical. Frequently, the most reliable basis for judging speed and distance relationships on modern freeway curves is the convergence illusion that occurs as the angle of driver vision intercepting the visible width of the pavement decreases to zero at the point where the pavement disappears around the curve. The rate of change of the angle of driver vision intercepting the pavement width at a given point ahead varies with degree of curvature, profile, pavement superelevation, and lateral position on the roadway as well as with speed and distance. However, the rate of change of the angle of driver vision intercepting the height of a tree ahead in the median varies almost exclusively with speed and distance. Such an improved basis for judging speed and distance relationships on curved alignment may have been a considerably more important safety factor than the decrease in headlight glare that was achieved through the use of trees in the 40-ft median of Calumet Expressway. If so, could an equal improvement be expected from the use of solid row plantings or glare screens (14) in the median? Do continuous screens or guardrails reinforce the convergence illusion sufficiently to eliminate the driver's need for individual three-dimensional objects that can be used as fixed reference points? Answers to such questions concerning the reasons for the observed effectiveness of delineation materials are needed.

Some measure of the relative extent to which each of the assumed delineation benefits contributes to increased safety is essential to the systematic development of ways and means of obtaining maximum effectiveness of the various types and combinations of delineation materials.

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Appendix

MATHEMATICAL MODEL FOR ESTIMATING SIGNIFICANCE OF RESULTS OF EXPERIMENT

In choosing a mathematical model for testing the significance of this use of evergreen trees in the median as an encroachment reducing measure, it was assumed that vehicle encroachments on the median occur according to a generalized Poisson process on the portions of Edens and Calumet Expressways chosen for study. In particular, the following is assumed:

1. The number of vehicle encroachments on the median occurring in non-overlapping time intervals are independent;
2. During any day, the probability that an encroachment on the median occurs in a small time interval, from t_0 to $t_0 + \Delta t$, is approximately proportional to the length of the time interval, Δt, and the factor of proportionality is a function of t, designated as $\lambda(t)$; and
3. The probability of more than one encroachment on the median in a small time interval, Δt, is negligible when compared to the probability of a single encroachment within that time interval.

This permits incorporating the observed phenomenon that $\lambda(t)$ varies during any day, being high for rush hour traffic and rather low at certain other times. If X is the random variable which describes the number of accidents that occur within the observed period,

$$P\left\{ X = k \right\} = \frac{e^{-\lambda} \lambda^k}{k!} \quad (1)$$

where λ is $T \int \lambda(t)\, dt$ and T is the number of days in the period of observation.

Another model leads to the same formulas. The assumptions are that each car passing over the portions of the expressways chosen for study has some unknown probability p (t) of encroaching on the median and that the time of passing is distributed according to a density function f (t). The dependence on t is allowed so as to emphasize that the probability does not remain constant throughout some time unit (day, week, etc.). Under these assumptions we have,

$$P\{\text{the probability of an encroachment}\} = \int P\{\text{encroachment, given that a car passes at time } t\}\, f(t)dt = \int p(t)\, f(t)dt = p_0 \quad (2)$$

Then, the probability that there are k encroachments when there is a total of N cars passing by on the expressways is given by

$$P\left\{ k \text{ encroachments} \right\} = \begin{bmatrix} N \\ k \end{bmatrix} p_0^{\,k} (1-p_0)^{N-k} \quad (3)$$

However, since N is large and p_O is small, this may be closely approximated by

$$P\left\{ \text{k encroachments} \right\} = \frac{e^{-\lambda}\lambda^k}{k!} \tag{4}$$

where $\lambda = Np_O$.

This model necessitates assuming that the cars act independently, but has the advantage over the usual formulation that it does not assume a constant probability of an accident (a vehicle encroachment on the median).

The conclusion with respect to the statistical analysis must be phrased with respect to the average probability p_O. λ_1 and λ_2 denote the values of the parameter before and after the evergreen trees were installed and X_1 and X_2 the corresponding random variables equal to the number of vehicle encroachments on the median. The total number of cars passing by on the expressways is assumed to be the same for the equal periods of observation before and after the evergreen trees were installed. This assumption makes the test more conservative because the traffic volume was slightly greater for the period of time during which the trees were employed in the median (see Table 3).

The following is to be tested:

$$H_O : \lambda_1 = \lambda_2$$

$$H_1 : \lambda_1 > \lambda_2$$

Assuming that H_O is true, the distribution of X_2, given $X_1 + X_2 = n$, is binominal based on n with $p = \frac{1}{2}$, i.e.,

$$P\left\{ X_2 = k \mid X_1 + X_2 = n \right\} = \begin{bmatrix} n \\ k \end{bmatrix} \begin{bmatrix} \frac{1}{2} \end{bmatrix}^n \tag{5}$$

The test: reject H_O if $X_2 \leq c$, where c is chosen so that

$$P\left\{ X_2 \leq c \mid X_1 + X_2 = n \right\} \leq \alpha \tag{6}$$

or

$$\sum_{k=0}^{c} \begin{bmatrix} n \\ k \end{bmatrix} \begin{bmatrix} \frac{1}{2} \end{bmatrix}^n \leq \alpha \tag{7}$$

For $n = 13$, $X_1 = 11$ and $X_2 = 2$,
$c = 3$ if $\alpha = 0.05$, and
$c = 2$ if $\alpha = 0.0112$.
For $n = 16$, $X_1 = 13$ and $X_2 = 3$,
$c = 4$ if $\alpha = 0.04$, and
$c = 3$ if $\alpha = 0.0106$.

Therefore, the observed results are judged significant at the indicated levels (1.12 and 1.06 percent) and it is concluded that the employment of evergreen trees in the medians of Edens and Calumet Expressways at the locations and under the conditions chosen for this study was effective in lowering the expected number of vehicle encroachments on the median.

Michaels (15) suggests that a more conservative test, chi square, should be used when X_1 values do not represent the data for two or more years. Results of chi square testing of this data indicate that the observed reductions are significant at the 5 percent level.

Effectiveness of Median Barriers

ROGER T. JOHNSON, Traffic Department, California Division of Highways

More than 200 mi of median barrier have been installed on the highest volume freeways in California since 1959. The two types of median barrier are cable chain link barrier and double blocked-out median barrier. They were installed to prevent cross-median head-on accidents. This study was initiated to determine the effect of the installation on all types of accidents. The construction and maintenance costs of the two barriers were also studied.

Cross-median head-on accidents have been eliminated by barrier installation, but property damage accidents and injury accidents have increased. Fatal accidents have decreased at barrier locations in spite of a few accidents involving the barriers which resulted in fatalities. The cost analysis revealed that the beam barrier is more expensive to install and that the cable barrier is more expensive to maintain.

•THIS IS a report on the effectiveness of median barriers on California freeways. An interim report on this study was published in December 1962. A before-and-after study was made of 26.6 mi of cable chain link barrier (Fig. 1) and 27.6 mi of double blocked-out metal beam barrier (Fig. 2). The various sections of each type of barrier have at least 1 yr each of before-and-after experience. The construction period was omitted from the study.

The remaining miles of median barrier had less than 1 yr of before or after experience and were, therefore, excluded from the before-and-after study. However, they are included in the statewide barrier study.

Median barriers are normally installed on freeways and expressways when one or more of the following conditions exist:

1. The traffic volume exceeds 60,000 veh/day;
2. The number or rate of cross-median accidents is high (0.46 cross-median accidents involving opposing vehicles per mile per year or 0.12 fatal cross-median accidents per mile per year); and
3. With initial, 8-lane construction the median is 22 ft wide or less.

The cable barrier is normally installed in medians with a width of 16 ft or more, and the beam barrier is normally installed in medians having a width of less than 16 ft. This is because the cable barrier will normally deflect up to approximately 8 ft when struck and also because 8 ft is the minimum clearance practical for parking a vehicle to repair damaged areas.

The status of the median barrier program as of January 1, 1964, was:

Paper sponsored by Committee on Operational Effects of Geometrics.

Figure 1. Cable chain link median barrier.

Figure 2. Double blocked-out metal beam barrier.

Status	Net Miles of Barrier		
	Cable	Beam	Total
Constructed	152.6	51.5	204.1
Under construction	69.7	22.0	91.7
Total	222.3	73.5	295.8

BEFORE-AND-AFTER STUDY

Effect of Median Barrier Installation on All Accidents

The effect of median barrier installation on accident rates is indicated by Table 1. Sections of highway where the beam barrier was installed had higher rates in both the before and after periods. Generally the beam barrier has been installed on freeways with narrower medians (less than 16 ft) which also tend to be the older freeways with higher volumes and lower geometric standards with an adverse effect on accident rates.

The rise in accident rates can be attributed primarily to the median barrier installation. The accident rate on all urban freeways has increased slightly during the past few years. However, the accident rate on urban freeways with median barriers has increased more than the statewide average for urban freeways. It is believed that the primary reason for the increase in accident rates is that the median barrier is a fixed object struck by out-of-control vehicles that might have recovered without incident if the barrier had not been installed.

Effect of Median Barrier Installation on Injury and Fatal Accidents

Injury and fatal accidents combined increased after median barrier installation (Table 1). The beam barrier increases injury and fatal accidents approximately twice as much as does the cable barrier. The beam barrier is considerably more rigid than the cable barrier and it is believed that this is the reason for the increased severity.

The ratio of the all accident rate to the injury and fatal accident rate is given in Table 1. The ratios in the before period are almost equal (2.2:1) and are normal for California freeways. In the after period, the ratio for the beam barrier is considerably lower than that for the cable, which is further evidence that the beam barrier increases the severity of accidents more than the cable barrier.

TABLE 1

EFFECT OF MEDIAN BARRIER INSTALLATION ON ACCIDENTS

Barrier Type	Length (mi)	MVM	All Accidents				Injury and Fatal Accidents				Ratio[a]
			No.	Rate	Rate Change		No.	Rate	Rate Change		
					Abs.	Percent			Abs.	Percent	
(a) Before Installation											
Cable	26.6	1,195.6	1,586	1.33	–	–	713	0.60	–	–	2.22:1
Beam	27.6	1,633.8	2,690	1.65	–	–	1,204	0.74	–	–	2.23:1
Total	54.2	2,829.4	4,276	1.51	–	–	1,917	0.68	–	–	2.22:1
(b) After Installation											
Cable	26.6	1,277.8	2,231	1.75	+0.42	+32	904	0.71	+0.11	18	2.46:1
Beam	27.6	1,608.5	3,330	1.98	+0.33	+20	1,612	0.96	+0.22	30	2.06:1
Total	54.2	2,958.3	5,561	1.88	+0.37	+25	2,516	0.85	+0.17	25	2.21:1

[a]Of all accident rate to injury and fatal accident rate.

Effect of Median Barrier Installation on Fatal Accidents

Both types of median barrier have been successful in preventing cross-median head-on fatal accidents. As indicated by Table 2, this resulted in a reduction in the number of fatal accidents and fatal accidents per 100 million veh-mi (MVM) in spite of an increase in non-cross-median fatal accidents. Chance variation could have accounted for part of the decrease in fatal accidents. However, there were almost 3 billion veh-mi of travel in each of the before-and-after periods.

There were 15 fatal accidents involving the barrier in the after period. There have been several other fatal accidents involving median barriers. However, these occurred in sections outside the limits of the before-and-after portion of this study.

In 10 of the 12 fatal accidents involving the cable barrier, a vehicle struck the barrier and spun, ejecting one or more persons; in the other, the vehicle involved went through the barrier. In 2 of the 3 beam barrier fatal accidents, there were ejections.

Accidents Involving Median

An accident involving the median is defined as an accident in which one or more cars enter the median. Table 3 indicates the effect of barrier installations on median accidents. Approximately 90 to 95 percent of the median accidents in the after period involved the barrier. Accidents involving the median increased by 88 percent where the cable barrier was installed, and at the beam barrier locations they increased 11 percent. This lends support to a widely expressed hypothesis that drivers would rather collide with the cable barrier than another object (fixed or moving) and that they are willing to take their chances with some other object or vehicle rather than collide with the beam barrier. In other words, drivers may be deliberately striking the cable barrier much more often than the beam barrier to avoid striking another object or vehicle. There is no way to prove this. On the contrary, according to the drivers' accounts of what they did, 7 percent of those hitting the cable barrier and 6 percent of those hitting the beam implied that it was deliberate.

Where cable barrier was installed, the rate for accidents involving the median increased 0.23 and the rate for accidents not involving the median increased 0.18 (Table 4). This tends to support the conjecture that drivers are now more willing to drive into the median to avoid another object or vehicle, provided a "soft" barrier is there to prevent contact with opposing traffic.

TABLE 2

EFFECT OF MEDIAN BARRIER INSTALLATION ON FATAL ACCIDENTS, 1959-1963

Barrier Type	Length (mi)	100 MVM	No. Fatal Accidents: All	Cross-Median	Non-Cross-Median	Involving Barrier	Rate	Rate Change: Abs.	Percent
(a) Before Installation									
Cable	26.6	11.96	31	9	22	(0)	2.59	–	–
Beam	27.6	16.34	31	13	18	(0)	1.90	–	–
Total	54.2	28.30	62	22	40	(0)	2.19	–	–
(b) After Installation									
Cable	26.6	12.78	21	1	20	(12)	1.64	-0.95	-37
Beam	27.6	16.81	27	0	27	(3)	1.61	-0.29	-15
Total	54.2	29.59	48	1	47	(15)	1.62	-0.57	-26
All Calif. urban freeways, 1960-1962:									
With barriers		32.88	54	–	–	–	1.64	–	–
Without barriers		182.50	481	–	–	–	2.64	–	–

TABLE 3

EFFECT OF MEDIAN BARRIER INSTALLATION ON ACCIDENTS INVOLVING MEDIAN

Barrier Type	Length (mi)	Before			After			Change in Rate	
		No. Accidents	MVM	Rate	No. Accidents	MVM	Rate	Abs.	Percent
Cable	26.6	308	1,195.6	0.26	629	1,277.8	0.49	+0.23	+88
Beam	27.6	443	1,633.8	0.27	511	1,680.5	0.30	+0.03	+11
Total	54.2	751	2,829.4	0.27	1,140	2,958.3	0.39	+0.12	+44

TABLE 4

EFFECT OF MEDIAN BARRIER INSTALLATION ON ACCIDENTS NOT INVOLVING MEDIAN

Barrier Type	Length (mi)	Before			After			Change in Rate	
		No. Accidents	MVM	Rate	No. Accidents	MVM	Rate	Abs.	Percent
Cable	26.6	1,278	1,195.6	1.07	1,602	1,277.8	1.25	+0.18	+17
Beam	27.6	2,247	1,633.8	1.38	2,819	1,680.5	1.68	+0.30	+22
Total	54.2	3,525	2,829.4	1.25	4,421	2,958.3	1.49	+0.24	+19

Where the beam was installed, the rate for accidents not involving the median increased 0.30, whereas the rate for accidents involving the median rose only 0.03. This indicates that drivers are reluctant to hit the beam barrier. However, proof of this may be difficult, if not impossible, to obtain.

Median Width

After barriers are installed, 90 to 95 percent of the accidents involving the median also involve the median barrier. It would be logical to assume that the wider the median, the less the barrier would be struck. Figure 3 indicates that this is true for the beam barrier. However, there are only two points with a sizable amount of experience, not enough to establish a trend. The cable barrier seems to be struck just as often in a wide as in a narrow median.

Regardless of the median width, the beam barrier is struck less often than the cable, indicating that the type of barrier rather than the median width determines how frequently the barrier is struck. This also indicates that drivers may be striking the beam barrier, doing very little damage to the barrier and driving away without reporting the accident. Because the cable barrier is relatively soft, vehicles may strike it and become entangled in the barrier or damage the barrier enough to result in a reported accident.

STATEWIDE BARRIER STUDY

All Accident Rates and Fatal Accident Rates

Figure 4 and Table 5 present the accident rate in each traffic volume range for freeways with and without median barriers. The freeways with barriers had higher rates, except at two points which represent less than 20 mi of median barrier. This is to be expected after noting the before-and-after portion of this study.

Figure 5 shows the fatal accident rates in each traffic volume range for freeways with and without median barriers. Generally, the freeways with median barriers had lower fatal accident rates. This is also to be expected after noting the before-and-after portion of this study. However, since fatal accidents are a relatively rare occurrence, chance variation could have accounted for part or all of the difference.

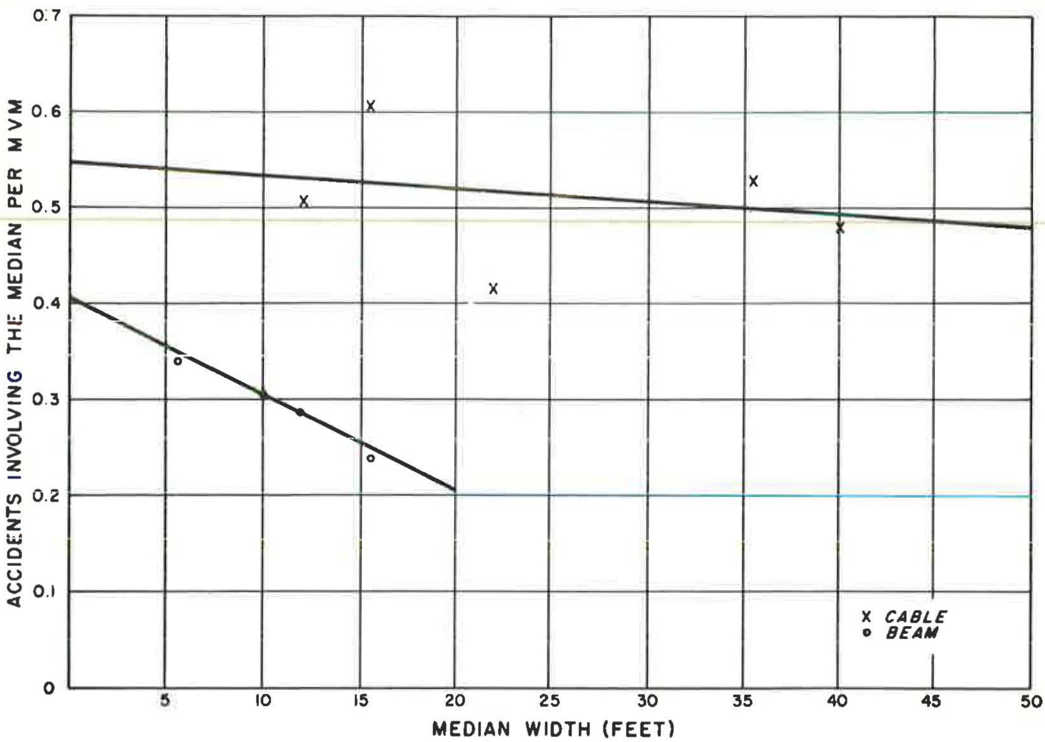

Figure 3. Accidents involving median vs median width.

Cross-Median Fatal Accidents

As indicated in Tables 6 and 7, median barriers have been effective in reducing cross-median fatal accidents. Almost all California freeways with traffic volumes of 60,000 veh/day or more now have median barriers in place or under construction. At the end of 1963, there were 24.5 mi of barrier on freeways carrying less than 60,000 veh/day but which had, before the barriers were installed, a high incidence of cross-median accidents. In spite of this, there are still about 20 cross-median fatal accidents per year on remaining freeways in California where the volume is less than 60,000 ADT. Approximately 7 of these 20 accidents are occurring on freeways with volumes between 40,000 and 60,000 ADT, and another 6 are occurring at volumes of 30,000 to 40,000 ADT.

Median Barrier Failures

Since median barriers were first installed, there have been 38 known instances where the barrier did not perform exactly as it should have and a vehicle came to rest partially or completely on the wrong side of the barrier. Only one of these instances involved the beam barrier and 37 involved the cable barrier. Five of the 38 were fatal accidents and three of the five involved vehicles in the opposing lanes.

Many different median widths and shapes are found on California freeways because of factors such as land values, curvature, and drainage. One of the situations conducive to vehicles going over or under the cables is shown in Figure 6 (sawtooth section). Vehicles hitting the barrier from the upper side tend to go over the cables and vehicles from the lower side tend to go under. The reason for constructing freeways in this manner on horizontal curves is to provide a channel for the drainage runoff from 48 ft of pavement. There are about 11.7 mi of freeway constructed in this manner in the Los Angeles area alone.

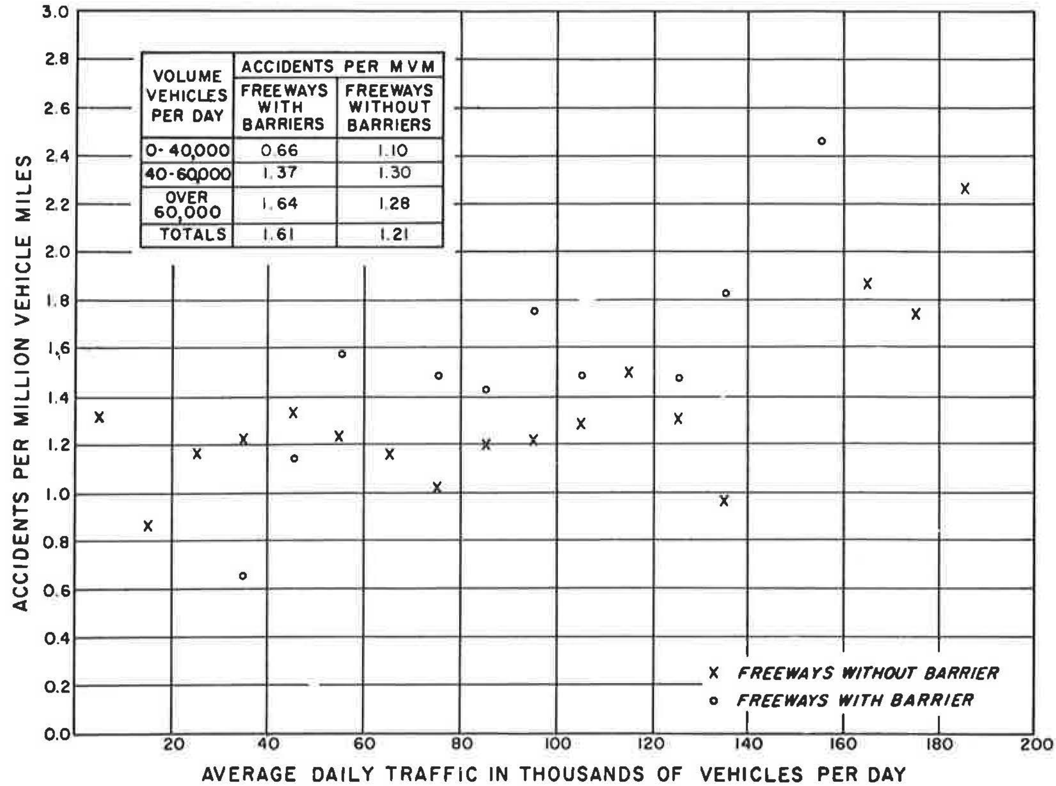

Figure 4. Accident rates vs average daily traffic, California urban freeways, 1960-1962.

TABLE 5

ACCIDENTS ON URBAN FREEWAYS IN CALIFORNIA WITH AND WITHOUT MEDIAN BARRIERS, 1960-1962

Freeways	Veh/Day	No. Accidents		MVM	Acc./MVM	Fatal Acc./100 MVM
		All	Fatal			
With barrier	0-40,000	25	0	38	0.66	—
Without barrier	0-40,000	7,898	255	7,178	1.10	3.55
With barrier	40-60,000	384	8	279	1.37	2.87
Without barrier	40-60,000	4,739	91	3,638	1.30	2.50
With barrier	>60,000	4,885	46	2,971	1.64	1.55
Without barrier	>60,000	9,522	135	7,434	1.28	1.82
Total						
With barrier		5,294	54	3,288	1.61	1.64
Without barrier		22,159	481	18,250	1.21	2.64

Since the cable height appears to be very critical, it seems reasonable to place the beam barrier in the sawtooth sections as shown in Figure 7. The beams can be placed at the proper elevations on each side of the barrier. Full-scale impact tests are under way to see if the cable barrier can be modified at sawtooth sections to prevent barrier failures.

As of January 1964, there were 22 fatal accidents in which a vehicle struck the barrier but did not go over or through the barrier. Five involved the beam barrier, and 17 involved the cable. When a vehicle strikes the cable barrier, it is slowed down

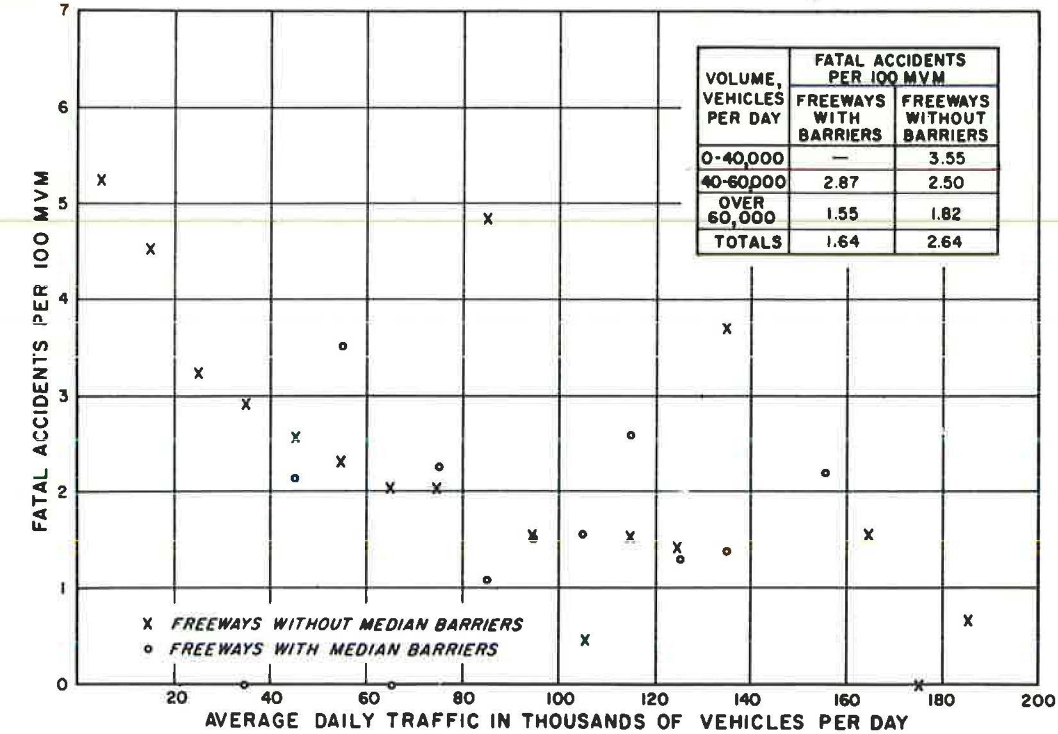

Figure 5. Fatal accident rates vs average daily traffic, California urban freeways, 1960-1962.

TABLE 6

CROSS-MEDIAN FATAL ACCIDENTS

Year	No. Acc.	Acc./Mi	Acc./100 MVM	Mi Barrier Completed
1959	45	0.065	0.51	0
1960	28	0.036	0.27	36
1961	33	0.038	0.28	33
1962	35	0.030	0.24	107
1963	41	0.031	0.25	29

primarily by friction between the cable and the left front of the vehicle. This imparts a moment to the vehicle and it tends to spin counterclockwise as it comes to a stop. The vehicles usually spin 90 to 270 deg. As they spin, occupants of the vehicles quite often are ejected and suffer fatal injuries. In 15 of the 17 cable barrier fatal accidents, the persons killed were ejected. This type of fatal accident could be almost completely eliminated by the use of seat belts.

TABLE 7

CROSS-MEDIAN FATAL ACCIDENTS, CALIFORNIA FREEWAYS, 1961-1963[a]

Veh/Day	Mi of Freeway		No. Accidents	
	Per Year	Cumul.	Per Year	Cumul.
0-10,000	225	225	3	3
10-20,000	293	518	3	6
20-30,000	158	676	15	21
30-40,000	119	795	17	38
40-50,000	56	851	14	52
50-60,000	55	906	11	63
60-70,000	39	945	10	73
70-80,000	16	961	6	79
80-90,000	25	986	5	84
90-100,000	20	1,006	3	87
100-110,000	26	1,032	5	92
110-120,000	14	1,046	2	94
120-130,000	14	1,060	6	100
130-140,000	20	1,080	1	101
140-150,000	2	1,082	1	102
150-160,000	6	1,088	2	104
160-170,000	3	1,091	4	108
170-180,000	11	1,102	1	109
180-190,000	3	1,105	0	109

[a]Freeways with traffic volumes >60,000 veh/day had median barriers in place during part or all of the 3-yr period; accidents took place before erection of barriers.

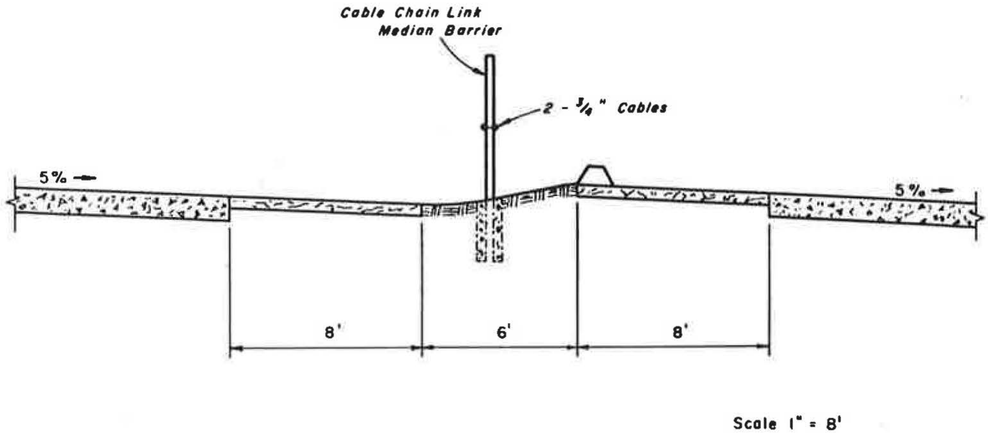

Figure 6. Existing sawtooth median.

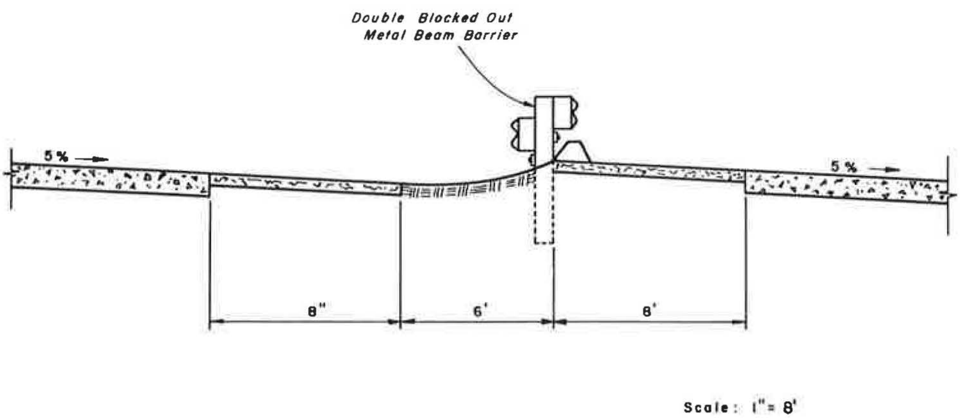

Figure 7. Proposed sawtooth median.

Concrete Median Barrier (Santa Monica Freeway)

The Santa Monica Freeway is an 8-lane elevated viaduct between the Harbor Freeway and the Santa Ana Freeway. It has 10 ft shoulders on the right of traffic and 8 ft on the left. The median width is 16 ft. The median is narrow because of the high cost of construction. A concrete median barrier was installed which would not deflect and involve cars in the opposing lanes (Fig. 8). The average daily traffic during the study period was 45,000, giving a total of 48.39 MVM. The accident record for this 2.48-mi section with barrier is as follows:

All accidents, 46 (0.95/MVM);
Accidents involving injury, 27 (0.56/MVM);
No fatal accidents; and
Accidents involving median, 10 (0.21/MVM).

Of the 10 accidents in which the barrier was struck, two involved property damage only and eight involved minor injuries.

Figure 8. Concrete median barrier with headlight glare screen.

The accident experience with this type of barrier is limited. The freeway has a low accident rate and the rate of accidents involving the median is low. Drivers may tend to avoid the median because of the concrete median barrier. If they are avoiding the median, they do not seem to be causing a lot of accidents on the traveled way.

The ADT (45,000) during the study period is extremely low for an 8-lane freeway, permitting a great deal of freedom and maneuverability in a crisis. This probably accounts for the low rates.

TABLE 8

MEDIAN BARRIER MAINTENANCE COSTS, 1959-1963

Freeway	Barrier Type	Length (mi)	MVM	Maintenance Cost ($)	Period (mo)	$/Mi/Yr	$/MVW
Nimitz	Cable	3.9	489.0	29,393	45	2,010	60
Nimitz	Beam	2.9	374.3	9,918	45	912	26
Santa Ana	Cable	3.3	271.0	25,116	27	3,383	93
Santa Ana	Beam	4.1	336.7	9,624	27	1,043	29
Hollywood	Cable	3.2	87.4	8,680	6	5,425	99
Hollywood	Beam	5.0	136.5	820	6	328	6
San Bernardino	Cable	3.8	38.0	4,611	6	2,427	121
San Bernardino	Cable	7.4	202.6	53,425	18	4,813	264
Total	Cable	36.65[a]	1,088.0	121,225		3,308	114
	Beam	26.70[a]	847.5	20,262		759	24

[a]Miles/year.

Maintenance and Construction Costs

The latest available median barrier maintenance costs are given in Table 8. Median barrier construction costs for 1962 were as follows:

Single blocked-out metal beam, $5.84/lin ft or $30,800/mi;
Double blocked-out metal beam, $8.66/lin ft or $45,700/mi; and
Cable chain link, $2.59/lin ft or $13,700/mi.

Consideration is being given to revising the design of the beam barrier slightly to reduce the construction costs.

The beam barrier costs $32,000/mi more than the cable barrier to install and the cable barrier costs $2,549/mi/yr more than the beam barrier to maintain. At these rates, the cable and beam expenditures per mile of barrier will be equal at the end of 13 yr. If 60 percent of the damages continue to be recovered by the state, the two expenditures would be equal at the end of 31 yr, with the cost being in favor of the cable barrier for the first 31 yr and in favor of the beam barrier thereafter. Any increase in the rate of recovery of damages could increase the time required to equalize the cost of the two types.

SUMMARY OF FINDINGS

1. Median barriers are effective in preventing cross-median accidents.
2. Fatalities due to cross-median accidents have been practically eliminated where barriers have been installed.
3. Although the barriers themselves, especially the cable barrier, cause an occasional fatality, the total number of fatal accidents (due to all causes) has been reduced at barrier locations by 23 percent.
4. The number of accidents per MVM has increased 32 percent in the case of the cable barrier and 20 percent in the case of the beam barrier.
5. The combined number of injury and fatal accidents per MVM have increased 18 percent at cable barrier locations and 30 percent at beam barrier locations.
6. Accidents involving the median have increased 88 percent at cable barrier locations and 11 percent at beam barrier locations.
7. The rate of accidents involving the median decrease substantially with increasing median width in the case of the beam barrier and decreases slightly with increasing width in the case of the cable barrier.
8. For the median width where data are available (6 to 16 ft), the beam barrier has a substantially lower median accident rate than the cable barrier.
9. In 15 collisions with the cable barrier, persons were ejected and killed when the vehicle spun to a stop. These fatalities might have been prevented if the vehicle occupants had worn seat belts.
10. Cable barriers installed in medians with sawtooth sections (horizontal curves) or containing dikes are being penetrated under the cable or are being overtopped by catapulting vehicles. Further full-scale impact tests are under way in an effort to see if the cable barrier can be modified at sawtooth sections to prevent barrier failures.
11. Cable barriers are very expensive to maintain. If no cost of repair is recovered by the state from the party responsible for the damage, 13 yr are required for the added maintenance costs to counteract its initial lower construction costs. However, since approximately 60 percent of the repair costs are recovered, 31 yr are required for the total costs to balance.

APPENDIX A

Section Number	Type of Barrier	Freeway Name	Location	Length in Miles	Median Width	Before Period: MVM	Total Acc's.	Rate	Injury Acc's.	Rate	Fatal Acc's.	X-Med. Fat. Acc's.	Acc'n. Involv. Med.	Rate	After Period: MVM	Total Acc's.	Rate	Injury Acc's.	Rate	Fatal Acc's.	X-Med. Fat. Acc's.	Acc's. Involv. Med.	Rate
1	Cable	Santa Ana	Buhman Ave. Ped. O.C. to Simmons U.C. (A.T. & S.F.)	3.20	12'	202.8	231	1.14	98	0.48	5	1	46	0.23	236.4	322	1.36	116	0.49	3	1	80	0.34
2	Beam	Santa Ana	Simmons U.P. (A.T. & S.F.) to Long Beach Fwy.	2.58	12'	156.7	137	0.87	48	0.31	3	1	42	0.27	168.6	266	1.58	105	0.62	2	0	46	0.27
3	Guard Rail	Santa Ana	Lorena St. to Soto St.	0.73	10'										95.6	144	1.51	71	0.74	1	0	24	0.25
4	Beam	Santa Ana	Soto St. to San Bernardino Fwy.	1.47	12'	109.8	198	1.80	92	0.84	3	2	43	0.39	99.4	181	1.82	71	0.71	1	0	28	0.28
5	Beam	Santa Ana	San Bernardino Fwy. to Alameda St.	0.70	6-8'	60.9	141	2.31	78	1.28	0	0	11	0.18	63.2	199	3.15	105	1.66	4	0	25	0.40
6	Beam	Hollywood	4-Level Str. to 500' N. of Alvarado St.	1.20	12'	192.3	403	2.10	231	1.20	2	1	52	0.27	212.4	533	2.51	294	1.38	2	0	41	0.19
7	Beam	Hollywood	500' N. of Avarado St. to 1300' N. of Silver Lake Blvd.	1.11	8'	92.9	148	1.59	82	0.88	1	0	8	0.09	88.0	117	1.33	52	0.59	1	0	11	0.13
8	Beam	Hollywood	Melrose Ave. to Highland Ave.	2.96	12'	170.4	287	1.68	148	0.87	2	1	38	0.23	164.2	269	1.64	143	0.87	2	0	34	0.21
9	Cable	Hollywood	Highland Ave. to 500' N. of Barham Blvd.	1.34	22-40'	73.9	239	3.24	121	1.64	2	0	34	0.46	84.6	236	2.79	123	1.45	1	0	62	0.73
10	Cable	Hollywood	1300' N. of Lankershim Blvd. to 700' S. of Riverside Dr.	0.86	22'	46.0	77	1.67	43	0.93	1	0	16	0.35	45.4	80	1.76	42	0.93	0	0	22	0.51
11	Cable	Ventura	Kraft Ave. to Laurel Canyon Rd.	0.91	22'										74.9	122	1.63	62	0.83	0	0	23	0.31
12	Cable	Ventura	Laurel Canyon Rd. to Sepulveda Blvd.	4.27	22'										497.5	599	1.20	313	0.63	4	1	194	0.39
13	Cable	Ventura	Haskell Ave. to Encino Ave	2.36	22'										226.7	267	1.18	211	0.93	3	0	97	0.43
14	Cable	Ventura	Encino Ave. to Reseda Blvd.	1.31	22'										78.1	84	1.08	53	0.68	0	0	36	0.46
15	Cable	Golden State	6th St. to Alleje St.	2.30	22'										222.0	171	0.77	88	3.96	0	0	32	0.14
16	Beam	San Bernardino	Indiana St. to Long Beach Fwy.	1.83	4-6'	117.6	288	2.45	81	0.69	4	1	58	0.49	135.2	344	2.54	171	1.27	2	0	51	0.38
17	Cable	San Bernardino	Baldwin Ave. to Puente Ave	3.20	40'	274.8	290	1.06	105	0.38	1	0	52	0.19	288.3	362	1.26	144	0.50	4	0	128	0.44
18	Cable	San Bernardino	Puente Ave. to Holt Ave.	5.64	16'	212.5	222	1.05	133	0.63	8	3	63	0.30	189.4	338	1.79	123	0.65	1	0	89	0.47
19	Cable	Bayshore	Sierra Pt. O.H. to Blanken Ave.	2.72	36'	84.9	84	0.99	40	0.47	1	1	27	0.32	106.8	104	0.97	43	0.40	1	0	39	0.37
20	Beam	Bayshore	Blanken Ave. to Paul Ave.	0.86	6-12'	41.7	60	1.44	26	0.62	1	0	12	0.29	47.2	121	2.56	56	1.19	1	0	18	0.38
21	Beam	Bayshore	Powhatten Ave. to Army St.	0.61	6'	57.8	89	1.54	34	0.59	1	0	9	0.16	61.7	142	2.30	61	0.99	1	0	16	0.26
22	Guard Rail	Bayshore	Army St. to 17th St.	1.10	6'										174.4	552	3.16	254	1.46	1	0	66	0.38
23	Cable	Nimitz	Washington Ave. to 98th Ave.	3.80	12'	192.5	247	1.28	100	0.52	6	4	44	0.23	222.8	474	2.13	181	0.81	5	0	120	0.54
24	Beam	Nimitz	98th Ave. to High St.	2.90	12'	149.6	233	1.56	58	0.38	3	3	35	0.23	173.8	398	2.29	173	1.00	4		70	0.40
25	Beam	Nimitz	5th Ave. to Adeline St.	1.53	4-16'	61.4	83	1.35	32	0.52	1	0	16	0.26	66.8	111	1.66	48	0.72	0	0	12	0.18
26	Beam	Eastshore	Distribution Structure to El Cerrito O.H.	3.87	12'	154.1	239	1.55	105	0.68	4	3	47	0.30	162.0	269	1.66	117	0.72	3	0	46	0.28
27	Cable	San Diego	Ventura Blvd. to Burbank St.	1.27	Interchange traffic; adjacent area under construction. Data considered unreliable.																		
28	Cable	Harbor	190th St. to 120th St.	4.36	22'										269.0	428	1.59	229	0.85	2	0	169	0.63
29	Beam	Pasadena	U.P.R.R. to Glenarm St.	5.58	6'	237.1	318	1.34	162	0.68	4	0	64	0.27	205.1	330	1.61	167	0.81	4	0	83	0.41
30	Concrete	Santa Monica	Grand Ave. to Naomi	1.35	22'										21.4	16	0.75	9	0.42	0	0	3	0.14
31	Concrete	Santa Monica	Naomi to Los Angeles Riv.	1.13	21'										27.0	30	1.11	18	0.67	0	0	7	0.26
32	Beam	Bayshore	Southern Fwy. to Powhatten Ave.	0.40	6'	31.5	66	2.10	27	0.86	2	1	7	0.22	32.8	88	2.68	31	0.95	0	0	12	0.37
33	Beam	Harbor	7th St. to Santa Monica Fwy.	0.68	16-22'										42.3	80	1.89	49	1.16	0	0	10	0.24
34	Cable	Harbor	Imperial Hwy. to Santa Monica Fwy.	8.51	16-22'										458.8	1048	2.28	625	1.36	9	0	215	0.47
35	Cable	San Bernardino	Holt Ave. to Jct. Rte. 77 (Arroyo Ave.)	3.84	16'	108.2	196	1.81	73	0.67	7	0	26	0.24	104.2	315	3.02	132	1.27	6	0	89	0.85
	Total Before and After Study																						
	Cable			26.60		1195.6	1586	1.32	713	0.60	31	9	308	0.26	1277.9	2231	1.75	904	0.71	21	1	629	0.49
	Beam			27.60		1633.8	2690	1.65	1204	0.74	31	13	443	0.27	1680.4	3330	1.98	1612	0.96	27	0	511	0.30

APPENDIX B

MEDIAN BARRIER FAILURES AND PARTIAL PENETRATIONS 1959 THROUGH 1963

FREEWAY	SEVERITY	VEHICLE	MEDIAN WIDTH	MEDIAN TYPE	BARRIER TYPE	REMARKS
1. Santa Ana	PDO	Chevrolet Flatbed	12'	"B" Curb-Paved	Cable	Truck over cables
2. Ventura	PDO	55 Oldsmobile	22'	Dirt	Cable	Vehicle straddled cables
3. Golden State	PDO	53 Ford	22'	Dirt	Cable	8" berm - 3' from barrier-curve-cable 28" above ground
4. San Bernardino	Injury	58 Lincoln	16'	"C" Curb-Paved	Cable	Veh. over cables-cables did not strip. Cable ht. = 30".
5. Ventura	Injury	62 Chevrolet Pickup	22'	Dirt	Cable	8" berm - 3' from barrier - curve - veh. over cables. Cable ht. = 30" above ground - 17" above berm.
6. Ventura	PDO	62 Pontiac Coupe	22'	Dirt	Cable	6" berm - 3' from barrier - curve. Cable ht. = 33" above ground - 24" above berm.
7. San Diego	PDO	58 Mercury	22'	Dirt & Oleanders	Cable	2" berm - 1½' from barrier - pillbox at point of Impact.
8. Ventura	PDO	52 Pontiac	22'	Dirt	Cable	Pontiac went partially under cables.
9. Golden State	PDO	55 Ford	22'	Dirt	Cable	Ford over cables - cables did not strip.
10. Harbor	PDO	53 Chevrolet	22'	Dirt	Cable	Chevrolet hit barrier and rolled over - cables did not strip.
11. Harbor	Injury	Austin-Healy Sprite	16'	"C" Curb-Paved	Cable	Raised median - Sprite under cables. Cable ht. = 31".
12. Ventura	Injury	59 Ford Sta. Wagon	22'	Paved	Cable	Ford Sta. Wagon went over cables - 6" berm - 3' from barrier. Cable ht. = 30" above ground - 18" above berm.
13. Ventura	PDO	*	22'	Dirt	Cable	Vehicle straddled cables.
14. Ventura	PDO	*	22'	Dirt	Cable	Vehicle over barrier.
15. Golden State	Injury	62 MG Conv.	22'	Dirt	Cable	MG under cables - scene is a superelevation transition.
16. Golden State	Injury	61 Austin-Healy	22'	Dirt	Cable	Vehicle under cables.
17. Ventura	Injury	1 Sedan 2 Trucks	22'	Dirt	Cable	Ford changed lanes and forced the trucks into barrier. All 3 came to rest on top of barrier. Pill box at point of impact.
18. Santa Ana	PDO	61 Ford	12'	"B" Curb-Paved	Cable	Hood of Ford went under cables. Impact ∢ = 30°±.
19. Santa Ana	Injury	63 Oldsmobile	12'	"B" Curb-Paved	Cable	Olds under cable. Cable ht. = 33" above ground.
20. San Bernardino	PDO	55 Buick	16'	"C-2" Curb-Paved	Cable	Buick over cable - mesh acted as a ramp.
21. San Bernardino	Injury	Trac. & Semi.	16'	"C" Curb-Paved	Cable	Truck over cables.
22. San Bernardino	Fatal	60 Corvette	16'	Flat & Paved	Cable	Corvette under cables - driver decapitated.
23. San Bernardino	PDO	57 Ford	16'	"C" Curb-Paved	Cable	Ford over cables.
24. Bayshore	Injury	61 T-Bird	36'	Dirt-Fairly Flat	Cable	Hood of T-Bird under cables.
25. Bayshore	Injury	62 T-Bird	36'	Dirt-Flat	Cable	T-Bird under cables (envelope). Cable ht. = 35"
26. Bayshore	Fatal	55 Corvette	36'	Dirt-Flat	Cable	Corvette under cables (envelope).
27. Bayshore	Injury	57 Buick Hardtop	36'	Dirt	Cable	Buick under cables - top of car torn off.
28. Nimitz	Injury	Alpha-Romeo	12'	"B" Curb-Paved	Cable	Car under cables.
29. Santa Ana	Fatal	Panel-Truck	12'	*	Cable	Truck over barrier (head-on).
30. Harbor	*	Car	22'	Paved	Cable	Car over cables on a curve. Cable ht. < 30".
31. Harbor	Fatal	Car	12'	Curbed	Beam	Car jumped beam.
32. Bayshore	Injury	Austin-Healy	36'	Dirt-Flat	Cable	Car under cables.
33. Ventura	Fatal	60 Cadillac	22'	Paved	Cable	Cad. over cables hit a 1951 Chevrolet head-on.
34. San Bernardino	PDO	60 Ford	16'	"C" Curb-Paved	Cable	Ford got on top of cables and vaulted.
35. San Bernardino	Injury	59 Chevrolet Sta. Wagon	16'	"C-2" Curb-Paved	Cable	Chevrolet station wagon over cables.
36. San Diego	Injury	57 Ford	22'	Dirt	Cable	Ford over cables. Berm - 3' from cables - cable was 36" above ground and 26" above berm.
37. Bayshore	Fatal	62 Pontiac	36'	Dirt	Cable	Cable ht. = 18". Grade had been raised but cable had not. Pontiac hit a Karmen Ghia head-on.
38. Bayshore	Injury	63 Lincoln Conv.	30'	Ice Plant	Cable	Ht. = 31-33". Lincoln went under cables and across opposing lanes. Took the top off. Speed about 75 M.P.H.

* *Not readily available*

APPENDIX C

FATAL ACCIDENTS INVOLVING MEDIAN BARRIERS 1959 THROUGH 1963

FREEWAY	SEVERITY	VEHICLE	MEDIAN WIDTH	MEDIAN TYPE	BARRIER TYPE	REMARKS
1. Harbor	Fatal	1950 Crosley Sta. Wagon	22'	Paved	Cable	Passenger ejected and killed.
2. San Bernardino	Fatal	Buick	16'	'C' Curb-Paved	Cable	Driver ejected and pinned under Buick which rolled 1 1/2 times.
3. Ventura	Fatal	58 Talbot	22'	Paved	Cable	Talbot hit barrier and spun, ejecting driver.
4. Golden State	Fatal	51 Chevrolet	22'	Dirt	Cable	Driver found in back seat with head injury. 6" berm 3' from barrier.
5. Golden State	Fatal	57 Volkswagon	22'	Dirt-Oleanders	Cable	Wheel came off - V.W. hit barrier and spun, ejecting 2 passengers.
6. Bayshore	Fatal	57 Volkswagon	36'	Dirt	Cable	Driver and passengers ejected and killed.
7. Nimitz	Fatal	Sedan	12'	'D' Curb-Paved	Cable	Car struck cable and ejected passenger.
8. Nimitz	Fatal	Motorcycle	12'	Curbed	Cable	Motorcycle struck barrier and ejected driver.
9. San Bernardino	Fatal	Car	16'	'C' Curb-Paved	Cable	Car struck barrier and ejected driver.
10 Nimitz	Fatal	Car	12'	*	Beam	Suicide - Driver left a note - Bounced off beam into bridge rail
11. Nimitz	Fatal	Truck	12'	Curb-Paved	Beam	Truck struck beam and ejected driver.
12. Bayshore	Fatal	52 Plym.	36'	Paved	Beam	Plymouth struck end of beam. No ejections.
13. Ventura	Fatal	61 Falcon	22'	Paved	Cable	Falcon struck barrier - Driver ejected.
14. Santa Ana	Fatal	Ford	6'-8'	Curb-Paved	Beam	Ford struck beam - Passenger ejected.
15. Bayshore	Fatal	Kaiser	36'	Dirt	Cable	Kaiser was knocked into barrier - Driver ejected.
16. San Bernardino	Fatal	Oldsmobile	16'	'C' Curb-Paved	Cable	Olds struck cable rail and spun around - Driver ejected.
17. Harbor	Fatal	50 De Soto	22'	Paved	Cable	De Soto hit barrier and overturned.
18. San Bernardino	Fatal	Pontiac Conv.	16'	'C' Curb-Paved	Cable	Pontiac lost wheel, hit barrier and overturned - Driver ejected.
19. Golden State	Fatal	52 Chrysler	22'	Paved	Cable	Crysler hit barrier and spun - Driver ejected
20. San Bernardino	Fatal	58 T-Bird	16'	'C' Curb-Paved	Cable	T-Bird hit barrier and spun - Driver ejected.
21. San Bernardino	Fatal	55 Buick	16'	'C' Curb-Paved	Cable	Buick hit barrier and rolled 1 1/2 times - Driver and passenger ejected.
22. Santa Ana	Fatal	52 Ford	6'-8'	Curb-Paved	Beam	Ford hit beam - Passenger ejected and run over.

**Not readily available*

Interchange Ramp Color Delineation and Marking Study

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At two study locations, color coding was applied to edgemarking, delineation, and signing; blue was used for advance exit signing. Although white coding was applied to the through roadway and yellow to the entrance ramps, evaluation was made only on the blue coding for the exit ramps. Evaluation was based on observations made before and after color installation, with emphasis on erratic driving practices and lane change movements. Night- and daytime comparisons were made. Driver interviews were conducted to determine public reaction to the general principle of color coding and the specific devices used.

Analysis of the results revealed that channeling of traffic into exiting lanes occurred farther in advance of the exit ramp with a reduction of 30 to 32 percent in erratic driving maneuvers. Public acceptance is indicated by the fact that 90 percent of the motorists interviewed stated they received definite benefit from the color scheme.

•THE ADVENT of the freeway system with its variety of interchange designs and higher travel speeds has created a need for instant communication to provide guidance to motorists at interchange areas. High-speed traffic requires "glance" notification to permit advance positioning for exit maneuvers. This system of communication must result in increased convenience and comfort and reduced confusion, and by so doing, contribute to the overall safety of freeway motorists.

A system of color coding of interchange ramps has been proposed to provide this means of notification, communication, and guidance for the motoring public. This pilot project was conducted to determine its effectiveness.

PURPOSE

The purpose of the pilot project was to evaluate a color coding system, consisting of edgemarking, delineation, and signing, and to determine whether further research into possible general application of the system is warranted.

RELATED RESEARCH

Experimentation with color coding at interchange ramps has been conducted by the Minnesota Department of Highways and the Florida State Road Department. In the Minnesota experiment (conducted in cooperation with the Minnesota Mining and Manufacturing Co. and reported by Mathew J. Huber, Yale Traffic Bureau, 1960), colored paint was applied to the entire surface of the ramps and corresponding delineators were installed. In the Florida experiment (1), only colored edgemarking was applied with corresponding delineators. In both experiments, white color indicated through roadway, yellow was used for on-ramps, and blue for the off-ramps. Both experiments

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reported that the application of color coding provided definite benefits for motorists. There was a decided reduction in confusion for both exiting and through traffic. "Glance" notification in advance of the interchange permitted earlier alignment of exiting traffic.

These experiments generated widespread interest in the color coding of interchange ramps for better notification and guidance to freeway motorists. This project was planned in 1961 and initiated in 1962 with preliminary material investigations Michigan added the factor of color coding to the exit and directional signs, whereas the previous projects were concerned only with edgemarking and delineation. Since then, other states have become interested in similar projects. Ohio has experimented with color edgemarking at interchange ramps on a limited basis. Oregon initiated a project in the summer of 1964 consisting of the application of color coding to five successive interchanges. This project included the exit signs at the ramps in the color system. Vehicle placement and speed measurements will be conducted in the Oregon study.

These latter projects continued the color designations in the color system initiated in Minnesota and used in the Florida and Michigan projects

SELECTION OF COLORS

The selection of colors for this pilot project was based on compatibility and consistency with present highway usage, the colors already selected in the related projects, and a review of colors available for use. This review resulted in the retention of white for the through roadway, blue for the exit ramps, and yellow for the entrance ramps. The white edgemarking and clear delineators are already used to delineate the through roadway. The use of yellow for the entrance ramps is a natural extension of its use as a warning or caution color. Blue for exit ramps provided a distinct contrast to the white and yellow; its subdued characteristic emphasized the white of the through roadway and still provided sufficient differentiation and attraction. In addition, blue is the standard background color for Interstate "Rest Area" and "Gas-Food-Lodging" signs, as well as "State Police" signs in Michigan All of these signs imply an exiting movement from the freeway. The selection of the colors for the Michigan project was also influenced by the Minnesota and Florida projects. The selection by these projects was definitely supported by this review, and their use in the Michigan project indicates complete agreement with their choice.

REVIEW OF MATERIALS

A review of existing materials for edgemarking and delineators was conducted to insure a high level of reflectorization, particularly for the yellow and blue. As a result of this review, it was decided to experiment with the high-intensity edgemarking paint mixes which had recently become available in all three colors.

Review of the delineators was also necessary. The standard white or clear 3-in. delineator presently used on Michigan highways was entirely satisfactory for the through roadway delineation. Further investigation of the yellow and blue delineators was carried on to find an economical and easily applied material with satisfactory reflectance. From inspection of several types of material sizes and shades of colors, the materials which filled these requirements were those with exposed-lens reflectorization of white plastic sealed to yellow or blue plastic plaques. (New types have been developed subsequent to this investigation and will be inspected.) The yellow and blue delineators were 4- by 10-in. plaques using signal sheeting material constructed as above. This material and construction alone provided sufficient reflectance for the yellow and blue delineators.

To complete this evaluation, blue, yellow, and white high-intensity reflectorized edgemarking was placed at the study locations in the fall of 1962 to observe placement and performance. Blue and yellow delineators were also installed for experimental observations. Inspection of this experimental painting after 1 yr revealed that the white edgemarking had retained its effectiveness, the yellow edgemarking had become slightly deteriorated, and the blue edgemarking had deteriorated to the point that it had become almost indiscernible. Further inspection revealed that the blue and yellow edgemarking had been placed on rather new concrete, and surface scaling had caused this condition.

LOCATION OF PROJECT

The testing was conducted on US 27 at two freeway interchanges involving left-hand business route exits into Mount Pleasant and Clare, Mich. The interchange design at

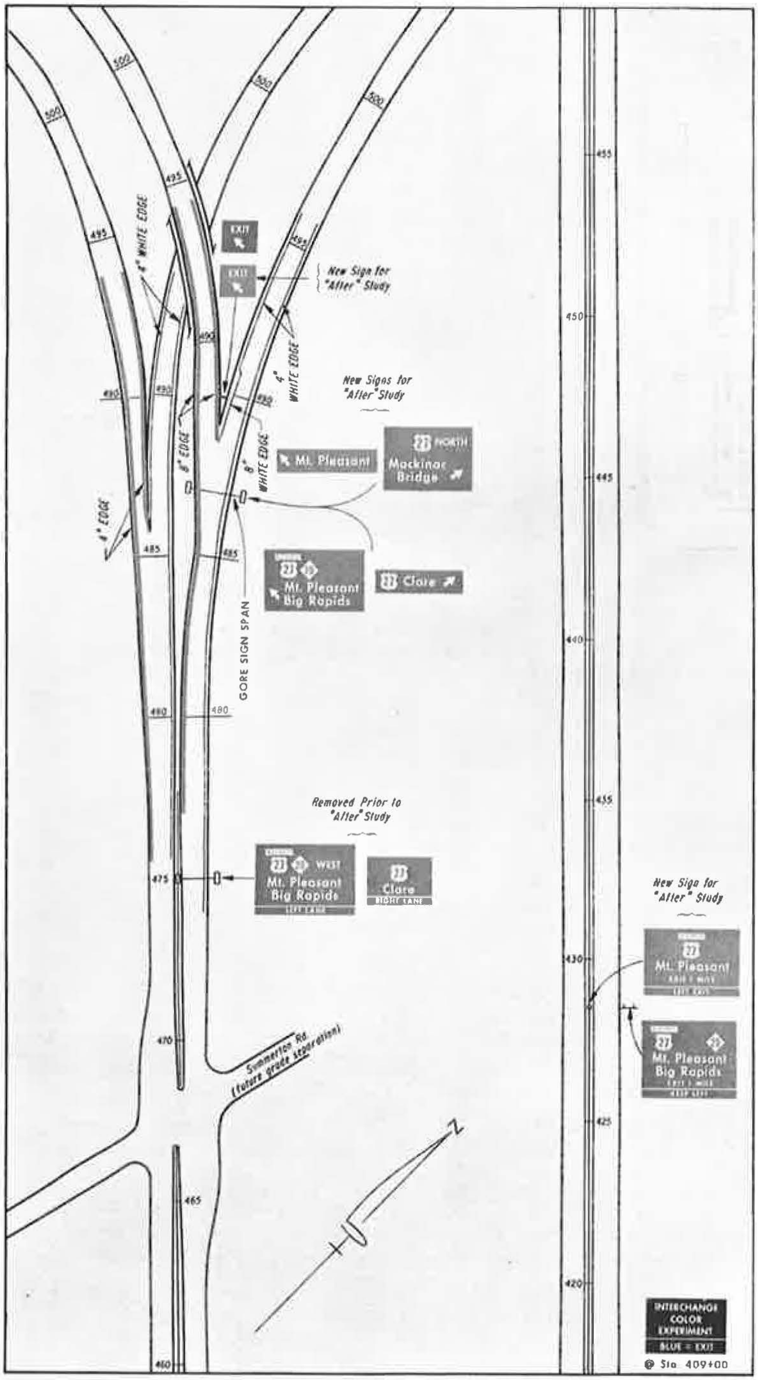

Figure 1. Mount Pleasant interchange.

these locations consists of a 2-lane exit straight ahead and a 2-lane through route with sufficient curvature to conceal its continuation. This design creates difficulty for motorists trying to distinguish the exit ramp from the through roadway. Figures 1 and 2 show the geometric design of these locations and the application of the color system.

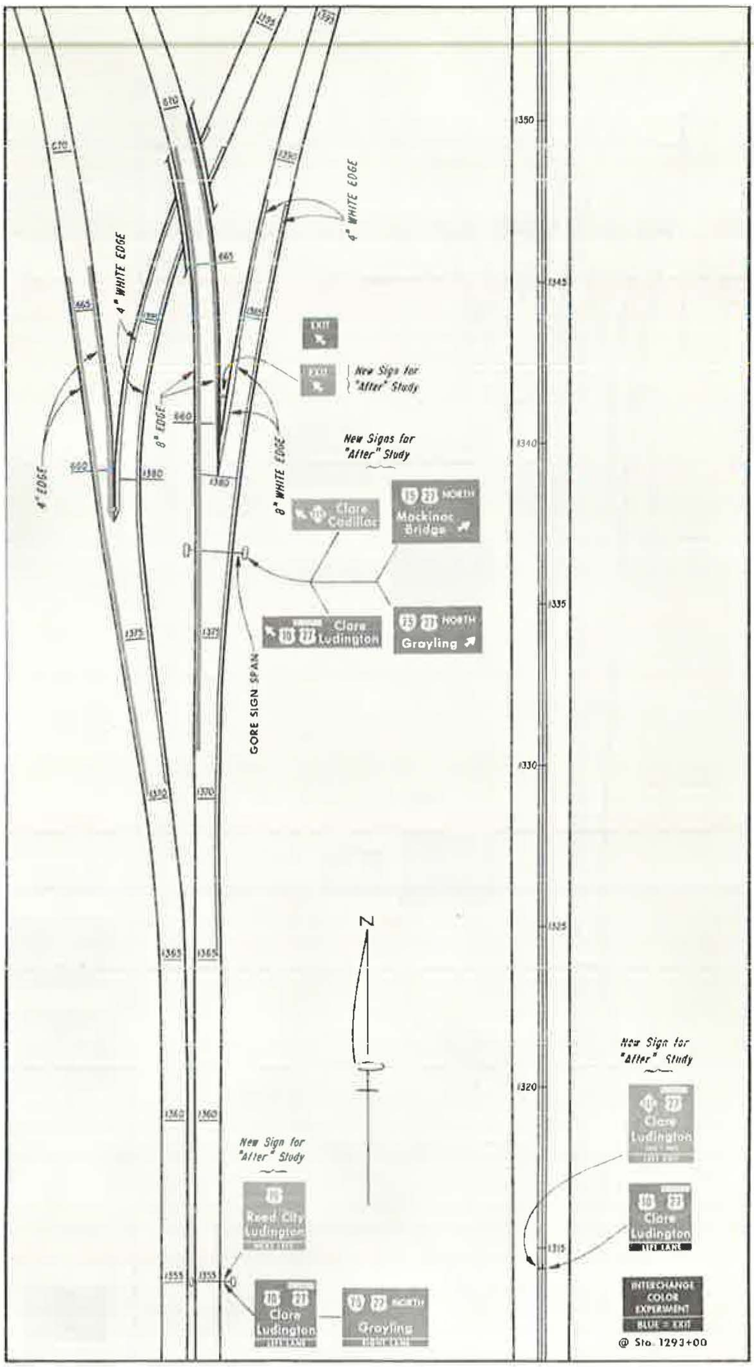

Figure 2. Clare interchange.

In view of the existing difficulty, changes in signing had been contemplated. These interchanges permitted the use of blue background for exit and directional signing as an added feature. The left-hand exits, their unfamiliarity to motorists, and the alignment perspective of the through roadway and the 2-lane ramp provided an extreme test for the color coding system.

COLOR SYSTEM DETAILS

Edgemarking

The edgemarking for the exit ramps consisted of an 8-in. high-intensity blue reflectorized stripe which started about 1,000 ft in advance of the gore and continued along the left side of each exit to approximately 750 ft beyond the gore. On the right side of the ramp, the blue edgemarking was applied from the gore to about 750 ft beyond.

A 4-in. high-intensity white reflectorized edgemarking was applied on the right edge of the through roadway from about 1,500 ft in advance of the gore to 750 ft beyond. On the left side, the white edgemarking was applied for 750 ft beyond the gore.

For the entrance ramps in the southbound direction, a 4-in. high-intensity yellow reflectorized stripe was applied on both sides of the roadway from 750 ft in advance of the gore to the edge of the through roadway on the acceleration lane. The southbound through roadway was edgemarked on both sides with 4-in. high-intensity white for approximately 1,100 ft in advance of the entrance ramp. The right side marking ended at the near side of the entrance ramp. The marking on the left side continued to a point opposite the yellow marking at the end of the entrance-ramp acceleration lane.

Delineators

Delineators of corresponding colors were used as follows: 3-in. white or clear for through roadway and 4- by 10-in. plaques of yellow and blue for the on- and off-ramps, respectively. In addition, the blue and yellow delineator posts were painted with corresponding nonreflectorized paint to assist in daytime delineation.

It should be noted that the experimental delineators had been removed through the assistance of an interested public. Thus, the original conditions were present for the before-study observations.

Signing

The new exit and directional signs at the two study locations were replaced utilizing blue Scotch-Lite background with directly applied signal sheeting legend.

The advance directional signs were installed on the median or left side of the roadway to serve the left exits at both study sites.

Overhead signing with a blue background pertaining to the exit ramps was placed over the left lane. A sign span at Mount Pleasant was in place 1,200 ft in advance of the gore sign during the before phase. However, this span was removed before the after observations because a grade separation to be constructed in 1964 would hide the sign's message from the driver. This sign, as shown in Figure 1, directed left-lane traffic to Business US 27 and M-20 west, Mount Pleasant and Big Rapids and right-lane traffic to US 27, Clare.

Legend changes were also incorporated in the new directional signs. In the before phase at Clare, all three directional signs, including the ½-mi advance sign, showed US 10, Business US 27, Clare, and Ludington as the exit destination. In the after phase, the 1-mi and the gore signs presented the directional information for Clare and Cadillac. At the gore, Mackinac Bridge replaced Grayling as a confirming through message. The ½-mi sign was changed to read: "REED CITY AND LUDINGTON NEXT LEFT." All legend changes are shown in Figures 1 and 2. Signs reading "INTERCHANGE COLOR EXPERIMENT" were installed in advance of the study locations.

EVALUATION OF COLOR SYSTEM

Study Procedure

The evaluation of the color system was limited to the northbound interchange areas including the two left-exit business routes into Mount Pleasant and Clare, respectively. This evaluation was based on a vehicle movement study and on driver interviews.

Vehicle Movement Study. —Vehicle movement observations were made before and after the color installation, with emphasis on the erratic driver maneuvers and lane changes. These vehicle movements were recorded on a field sheet similar to that shown in Figure 3, which presents the study section in advance of the bifurcation and is

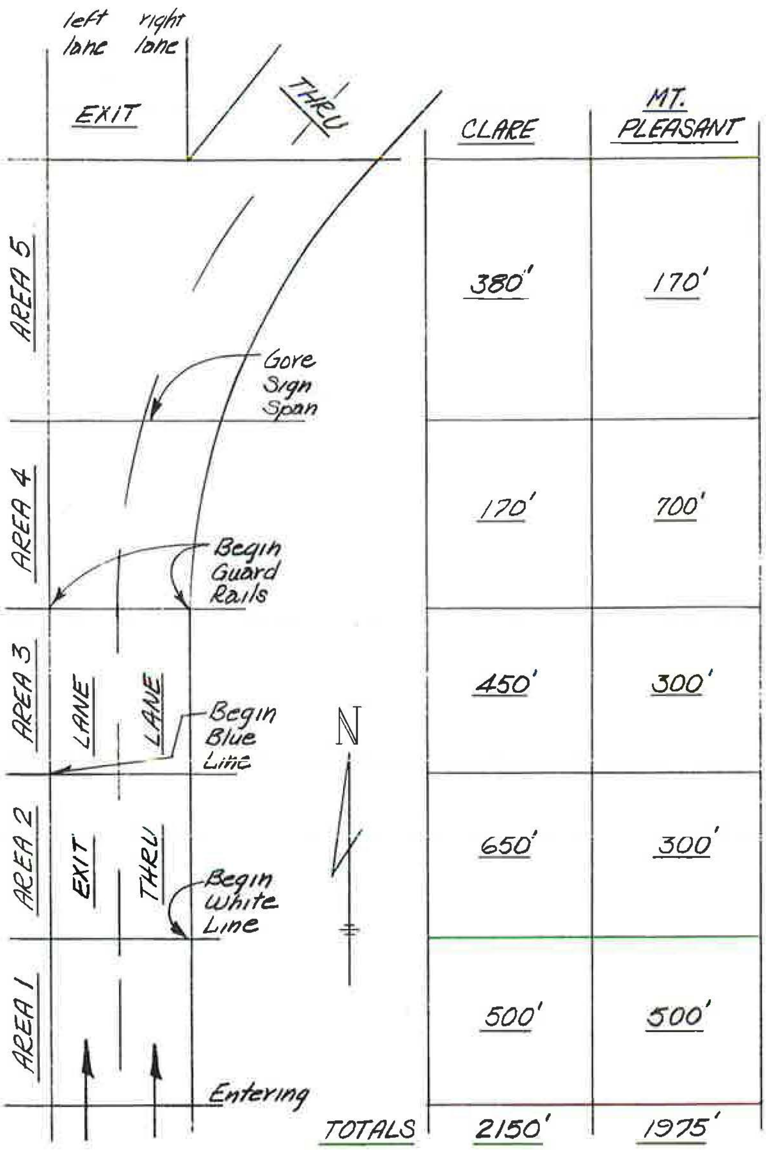

Figure 3. Vehicle placement study field sheet.

broken down into Areas 1 through 5. The movements of vehicles as they entered the study section were traced through the five areas. Vehicle movements were observed during the day and at night. Vehicles obviously making a passing maneuver were not recorded. Vehicle movements through the area to the through roadway or the exit ramp that did not involve a lane change were also recorded.

Extreme erratic driving maneuvers were recorded separately. To avoid any question of judgment regarding what constituted an erratic maneuver, it was decided that unless it was an obvious movement, any vehicle that made two lane changes within the study section would be so classified. Within the length of the study sections, two lane changes would realistically constitute an erratic maneuver. This classification, therefore, included any extreme movements such as stopping and backing up from either the exit ramp or through roadway, radical movements across the gore, and vehicles stopping on the freeway proper and then proceeding. It is easily apparent that difficulty would arise in judging as an erratic maneuver a vehicle movement that appeared to be hesitant, moved laterally within a lane, or reduced speed. These could have resulted from other causes. This classification could not detect this sort of maneuver or the confused or lost driver who may have appeared to an observer to be fully aware of his direction of travel. This erratic maneuver classification was based on an objective indication as much as possible.

Traffic volumes were obtained during vehicle movement observations before and after to provide a control for comparison. The vehicle movement observations before and after were taken in July and October 1963, respectively. This resulted in a difference in traffic volumes since the after vehicle movement observations were not taken during the summer tourist traffic. The time required for the application of the color coding system caused this scheduling. Since the reduction in traffic volume of the after phase may have influenced vehicle movements, the movements were calculated and compared as a rate of movement per 1,000 veh of the total traffic. The vehicle movements were observed during four daytime hours (9:00 a.m. to 11:00 a.m. and 2:00 p.m. to 4:00 p.m.) and three nighttime hours (9:00 p.m. to midnight) for 2 days each before and after the color system was installed. These observations covered a total period of 1 wk.

Driver Interviews. —Driver interviews were conducted to determine public reaction to the general principle of color coding interchange ramps. Interviews were conducted day and night over a 1-wk period (third week of September 1963) following the installation of the color. Interviews were separated by driver's knowledge of the area. Familiar drivers were classified as those drivers who had driven the area 5 times or more, and unfamiliar drivers were those who had driven the area 4 times or less. Figure 4 is the interview form used.

Study Results

Vehicle Movement Study. —Vehicle movements for Mount Pleasant and Clare were considered separately since the geometric characteristics are quite different. Also, for purposes of analysis, erratic maneuvers were considered independently of the total vehicle movements.

Table 1 gives a comparison of the total erratic maneuvers observed at Mount Pleasant and Clare, respectively. The day and night erratic maneuvers are combined due to the limited nighttime data. The indicated reductions in total erratic maneuvers are highly significant. In addition, no extreme vehicle maneuvers, such as a vehicle stopping on the freeway and backing up, occurred in the after phase. It should be noted again that vehicle movements involving two or more lane changes, stopping and backing up on the freeway, etc., were classified as erratic maneuvers.

Table 2 summarizes vehicle movements comprising lane changes by areas for Mount Pleasant and Clare. The vehicle movements consist of those vehicles moving to the median or exit lane and proceeding to the exit ramp, and are recorded by the area in which the movement was made. The rates of this vehicle movement per 1,000 veh for each study section can be seen to increase. These increases in total vehicle movements, as classified, were significant. Thus, with the color system, more drivers were apparently positioning themselves earlier for the exit movement. By individual

Date	Recorder	Interview #
Location: Mt. Pleasant (Thru ___ (Exit ___; Clare (Thru ___ (Exit ___	Vehicle Type: Car ___ Truck ___	License: Local ___ State ___ Out of State ___

1. Have you travelled this route before?	No ___ 1-5 ___ 5-10 ___ (omit question #2) Often ___ (omit question #2)
2. Did you have any difficulty in determining your desired direction of travel?	Yes ___ (ask A B C) No ___ (ask A B D)
(A) What was the desired direction of travel?	Thru ___ Exit ___
(B) Did you know that blue signing and painting directed you to the exit?	Yes ___ No ___
(C) What confused the driver?	
(D) Was the colored signing and painting a benefit to you in determining your direction of travel?	Yes ___ No ___
What was of a definite assistance? (color, legend, etc.)	
3. What is your opinion of using a color scheme at all interchanges? Such as blue at exits, yellow entrance, white silver thru.	

Figure 4. Interview field sheet.

TABLE 1

RATE OF ERRATIC MANEUVERS[a]

Interchange	Before			After			Decrease (%)
	Total Veh	No. Erratic Veh	Rate (per 1,000 veh)	Total Veh	No. Erratic Veh	Rate (per 1,000 veh)	
Mt. Pleasant	2,365	49	20.7	1,708	22	12.8	38.2
Clare	2,085	46	22.1	1,420	21	14.8	33.5

[a]Classified by two or more lane changes.

areas, the rate increases for this movement were particularly evident in Areas 3 and 4. This proved true for daytime and particularly for nighttime traffic. It should be noted that the "blue" color coding for the exit ramp begins with Area 3. This is where an increase in vehicle movements to the exit lane would be expected.

TABLE 2

VEHICLE MOVEMENT SUMMARY[a]

Movement	Interchange	Area	Day					Night					Total				
			Before		After		Rate Change (%)	Before		After		Rate Change (%)	Before		After		Rate Change (%)
			No.	Rate	No.	Rate		No.	Rate	No.	Rate		No.	Rate	No.	Rate	
To exit ramp	Mt. Pleasant[b]	1	32	13.5	21	12.3	–	0	0	0	0	–	32	13.5	21	12.3	–
		2	66	27.9	53	31.0	–	7	3.0	4	2.3	–	73	30.9	57	33.4	–
		3	80	33.8	87	50.9	–	22	9.3	26	15.2	–	102	43.1	113	66.2	–
		4	104	44.0	94	55.0	–	40	16.9	39	22.8	–	144	60.9	133	77.9	–
		5	38	16.1	30	17.6	–	20	8.5	12	7.0	–	58	24.5	42	24.6	–
		Total	320	135.3	285	166.9	+23.4	89	37.6	81	47.4	+26.1	409	172.9	366	214.3	+23.9
	Clare[c]	1	48	23.0	25	17.6	–	2	1.0	2	1.4	–	50	24.0	27	19.0	–
		2	84	40.3	47	33.1	–	31	14.9	15	10.6	–	115	55.2	62	43.7	–
		3	122	58.5	128	90.1	–	30	14.4	18	12.7	–	152	72.9	146	102.8	–
		4	92	44.1	113	79.6	–	14	6.7	26	18.3	–	106	50.8	139	97.9	–
		5	34	16.3	36	25.4	–	8	3.8	20	14.1	–	42	20.1	56	39.4	–
		Total	380	182.3	349	245.8	+34.8	85	40.8	81	57.0	+39.7	465	223.0	430	302.8	+35.8
To through roadway	Mt. Pleasant[b]	Total[d]	47	19.9	44	25.8	+29.6	9	3.8	4	2.3	-6.1	56	23.7	48	28.1	+18.6
	Clare[c]	Total[c]	31	14.9	9	6.3	-4.2	3	1.4	1	0.7	-60.0	34	16.3	10	7.0	-42.9

[a]Per 1,000 veh.
[b]Traffic volume: before, 2,365 veh; after, 1,708 veh (28 percent reduction).
[c]Traffic volume: before 2,085 veh; after, 1,420 veh (32 percent reduction).
[d]Number of vehicle movements to through roadway small, so area totals combined.

Total vehicle movements to the through route are also given in Table 2 for information only, since the total sample for all areas proved inadequate to reveal any conclusive effects on these vehicle movements.

Figures 5 and 6 show the vehicle movements to the exit ramps by the area in which the vehicle made its movement to the exit lane. These figures indicate the shift in location of the vehicle movements through the study section. Erratic maneuvers are also shown in this manner.

Table 3 gives the vehicle movements to the exit ramp according to the lane of the exit ramp used for exiting, including exiting traffic that did not make any lane change through the study sections but exited from the freeway. It can be seen that use of the

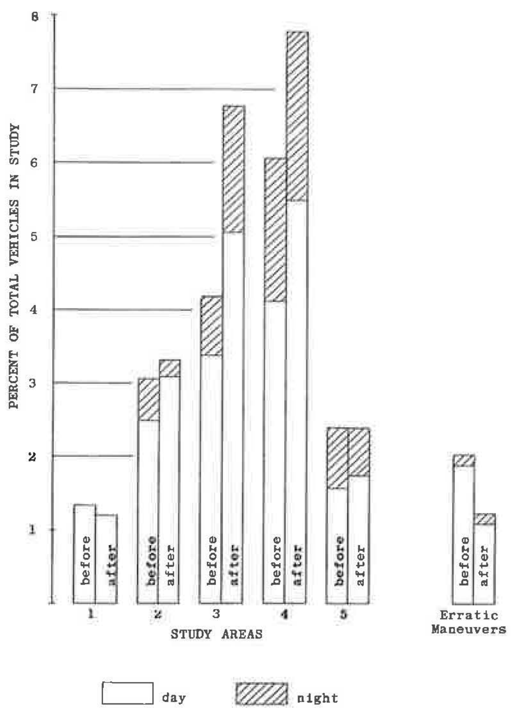

Figure 5. Vehicle movements to exit ramp and erratic maneuvers at Mount Pleasant.

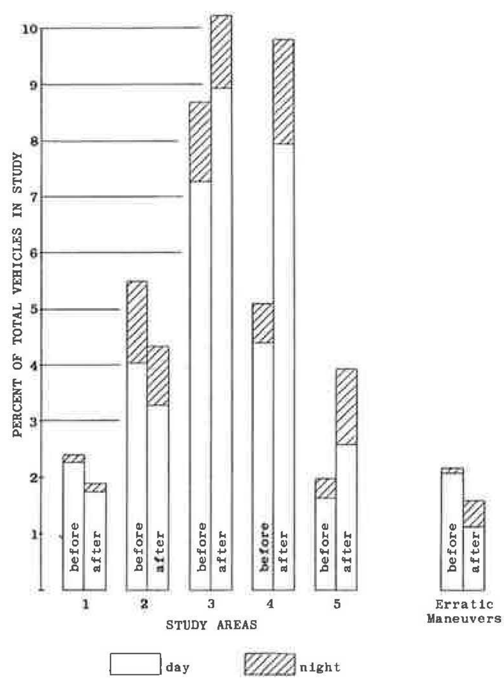

Figure 6. Vehicle movements to exit ramp and erratic maneuvers at Clare.

TABLE 3

EXITING VEHICLE MOVEMENTS[a]

Movement	Interchange	Area	Time	Right Lane Exit					Left Lane Exit					Exit Total				
				Before		After		Rate Change (%)	Before		After		Rate Change (%)	Before		After		Rate Change (%)
				No.	Rate	No.	Rate		No.	Rate	No.	Rate		No.	Rate	No.	Rate	
To exit ramp	Mt. Pleasant	1	Day	16	21	3	5	—	16	21	18	28	—	32	42	21	33	—
			Night	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		2	Day	33	43	12	19	—	33	43	41	63	—	66	86	53	82	—
			Night	3	4	2	3	—	4	5	2	3	—	7	9	4	6	—
		3	Day	49	64	35	54	—	31	41	52	81	—	80	105	87	135	—
			Night	42	16	17	26	—	10	13	9	14	—	22	29	26	40	—
		4	Day	80	105	64	99	—	24	31	30	47	—	104	136	94	146	—
			Night	25	33	19	29	—	15	20	20	31	—	40	53	39	60	—
		5	Day	38	50	28	43	—	—	—	2	3	—	38	50	30	46	—
			Night	20	26	11	17	—	—	—	1	2	—	20	26	12	19	—
			Total	276	361	191	296	-18.0	133	174	175	271	+55.7	409	535	366	567	+6.0
	Clare	1	Day	34	36	10	14	—	14	15	15	20	—	48	51	25	34	—
			Night	2	2	2	3	—	—	—	—	—	—	2	2	2	3	—
		2	Day	70	74	27	37	—	14	15	20	27	—	84	89	47	64	—
			Night	29	31	15	20	—	2	2	—	—	—	31	33	15	20	—
		3	Day	108	114	103	139	—	14	15	25	34	—	122	129	128	173	—
			Night	23	24	14	19	—	7	7	4	5	—	30	31	18	24	—
		4	Day	83	88	101	137	—	9	9	12	16	—	92	97	113	153	—
			Night	14	15	24	32	—	—	—	2	3	—	14	15	26	35	—
		5	Day	34	36	36	49	—	—	—	—	—	—	34	36	36	49	—
			Night	8	8	20	27	—	—	—	—	—	—	8	8	20	27	—
			Total	405	428	352	476	+11.2	60	63	78	106	+68.3	465	491	430	582	+18.5
From exit lane, no lane change	Mt. Pleasant	All	Day	67	88	31	48	—	245	320	190	295	—	312	408	221	343	—
			Night	15	20	12	19	—	28	36	46	71	—	43	56	58	90	—
			Total	82	107	43	67	-37.4	273	357	236	366	+2.5	355	464	279	433	-6.[illegible]
	Clare	All	Day	201	212	58	78	—	230	243	204	276	—	431	455	262	355	—
			Night	27	29	16	22	—	24	25	31	42	—	51	54	47	64	—
			Total	228	241	74	100	-58.5	254	268	235	318	+18.7	482	509	309	418	-17.9
Total	Mt. Pleasant	—	—	358	469	234	363	-22.6	406	531	411	637	+20.0	764	1,000	645	1,000	—
	Clare	—	—	633	668	426	576	-13.8	314	332	313	424	+27.7	947	1,000	739	1,000	—

[a]Per 1,000 exiting veh.

left lane of the exit ramp increased with the color system. The exit lane (left, in this case) on the freeway which proceeds to the exit ramp is, of course, color coded blue. A higher percentage of the exiting traffic in the exit lane, which made no lane change in the study section, utilized the left lane of the exit ramp with the color system.

The exiting vehicle data in Area 5 (Table 3) requires some clarification. Almost all of these movements to the exit, before and after, day and night, utilized the right lane of the ramp at both Mount Pleasant and Clare. Area 5 is 175 ft and 380 ft in advance of the gore at Mount Pleasant and at Clare, respectively. At Clare, there was an increase in this movement in Area 5. The difference in length of area may have some bearing on this movement. However, these movements to the exit were made by vehicles that proceeded in a continuous smooth movement in the through lane of the freeway to the right lane of the exit ramp. Rather than lane changes, these movements were actually lane crossings. Field data verified that these vehicles exited without altering their path. Considering the geometric design of both locations, this movement becomes natural and can be made with ease. It would be assumed that a motorist, well aware of the exiting facilities, would make this movement. If any unknowing drivers were among this group, it was impossible to detect them by their travel characteristics.

The nighttime observations for the vehicle movement study were very limited. The data indicate definite trends which show the favorable effects of the color coding system on vehicle movements, but are not sufficient to measure the system's full benefits.

Driver Interviews. —Table 4 summarizes the driver interviews conducted at the study locations at Mount Pleasant and Clare, with opinions classified according to the drivers' knowledge of the area. As indicated, 86 percent of the total drivers interviewed reported that the color scheme is of definite value to them. This result is further emphasized by the day and night drivers: 83 percent of the day drivers and 91 percent of the night drivers reported a benefit. The driver opinions at each study location revealed the consistent overall advantage of the color system.

Based on knowledge of the area, of the familiar drivers interviewed, 86.2 percent of daytime drivers and 93.5 percent of nighttime drivers reported that the color system was beneficial to them. Of the unfamiliar drivers interviewed, 82.5 percent daytime and 90.6 percent nighttime reported a definite benefit from the color system.

TABLE 4

DRIVERS' OPINIONS OF COLOR SYSTEM

Opinion	Knowledge of Area[a]	Mount Pleasant						Clare						Both Interchanges					
		Day		Night		Total		Day		Night		Total		Day		Night		Total	
		No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Benefit	Familiar	338	80.7	104	93.0	442	83.2	444	91.0	99	94.3	543	91.6	782	86.2	203	93.5	985	87.6
	Unfamiliar	295	81.1	91	89.2	386	82.8	305	84.0	93	92.1	398	85.8	600	82.5	184	90.6	784	84.3
	Total	633	80.8	195	91.1	828	83.1	749	88.0	192	93.2	941	89.0	1,382	84.6	387	92.2	1,769	86.1
No benefit	Familiar	40	9.5	4	3.5	44	8.3	20	4.1	2	1.9	22	3.7	60	6.6	6	2.8	66	5.9
	Unfamiliar	27	7.4	8	7.8	35	7.5	36	9.9	5	4.9	41	8.8	63	8.7	13	6.4	76	8.2
	Total	67	8.6	12	5.6	79	7.9	55	6.6	7	3.4	63	6.0	123	7.5	19	4.5	142	6.9
None	Familiar	41	9.8	4	3.5	45	0.5	24	4.9	4	3.0	28	4.7	65	7.2	8	3.7	73	6.5
	Unfamiliar	42	11.5	3	3.0	45	9.7	22	6.1	3	3.0	25	5.4	64	8.8	6	3.0	70	7.5
	Total	83	10.6	7	3.3	90	9.0	46	5.4	7	3.4	53	5.0	129	7.9	14	3.3	143	7.0
Total	Familiar	419	—	112	—	531	—	488	—	105	—	593	—	907	—	217	—	1,124	—
	Unfamiliar	364	—	102	—	466	—	363	—	101	—	464	—	727	—	203	—	930	—
	Total	783	—	214	—	997	—	651	—	206	—	1,057	—	1,634	—	420	—	2,054	—

[a] Familiar drivers considered, in this study, those who had driven area 5 or more times.

Some drivers who have explicit knowledge of the interchange areas and ramps, perhaps through their clear perception of the area, would feel no need for the color system. However, the foregoing results show that the system is profitable to the familiar driver as well.

Aside from the purpose of obtaining the general public's reaction to the color system, the interviews were designed to reveal whether or not the color system (particularly the blue) would, without prior knowledge, be understandable to the motorists. Also, it was desirable to determine the nature and extent of any difficulty experienced with the color system. It was felt that motorists unfamiliar with the interchange areas would more appropriately reveal this information. Therefore, these drivers were asked specifically (a) whether or not they knew that blue meant exit and (b) whether any difficulty was experienced. Table 5 indicates that out of 930 unfamiliar drivers interviewed, 91 percent were aware that the "blue" meant exit. Also, out of this group, 39 drivers reported difficulty of some degree. It was reasonable to assume that all familiar drivers having passed through the interchange areas at least five times would be aware of what the blue meant. It also could be assumed that familiar drivers would experience much less difficulty than unfamiliar drivers. However, it is possible that some familiar drivers did experience great difficulty.

Several drivers reported that they experienced difficulty but could not state exactly the cause. As could be expected, the alignment or geometrics of the roadway was the factor most frequently listed as the source of difficulty. Lack of understanding of sign legend was reported by a few motorists (e.g., "LEFT EXIT" and "NEXT EXIT" referring to same exit). Lack of acquaintance with color system was reported by some. The small percentage of unfamiliar drivers who reported difficulty and the large percentage who recognized the significance of the blue color without prior exposure are indicative of the general success and understanding of the color system.

CONCLUSIONS AND RECOMMENDATIONS

From the results of this pilot project, the effectiveness of the color system as a means of communication and guidance to freeway motorists can be evaluated. The vehicle movement study indicated positively that the color coding system was, and can be, successful in communicating its intent to motorists and in obtaining the desired

TABLE 5

RESULTS OF INTERVIEWS OF UNFAMILIAR DRIVERS

Driver	Mount Pleasant						Clare						Both Interchanges					
	Day		Night		Total		Day		Night		Total		Day		Night		Total	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Total interviewed	364	—	102	—	466	—	363	—	101	—	464	—	727	—	203	—	930	—
Aware blue meant exit	334	92	93	91	427	91.5	328	91	95	94	423	91.5	662	91.5	188	93	850	91
Reported difficulty	8	2.2	5	4.9	13	2.8	22	6.1	4	4.0	26	5.6	30	4.1	9	4.4	39	4.2

reaction. The significant reduction in erratic driving maneuvers specifically showed the lessening of confusion at the exit ramps under study.

The color system can also provide the motorists with increased convenience in performing exiting maneuvers. The advance notification permits earlier positioning for these maneuvers. This factor is illustrated by the increase in the rate of vehicular movements which occurred in certain areas in advance of the exits. The change in these movements indicates the effect of the color system on traffic behavior for both day and night traffic. It is reasonable to conclude that providing the freeway motorist with advance notification permitting earlier positioning for exiting can result in greater convenience and safety.

The driver interviews revealed a general public acceptance of the color system. These interviews showed that 85 to 90 percent of the day and night drivers believed the color system was definitely beneficial. Only a small percentage of drivers reported any degree of travel difficulty at the two study locations following the installation of the color system. It is apparent that at interchanges of this design, some confusion to drivers is inescapable.

Public reaction to the color system was also clearly expressed by the many voluntary letters received by the Highway Department which were in favor of its use at the study locations and stated desire for its expanded use on a general basis.

The results of the pilot project clearly show that the color system was a successful means of communication and guidance to freeway motorists at the interchange areas under study. However, as a pilot project, several aspects of the research on this system remain to be explored.

The study sites are located on US 27, a rural freeway carrying an annual daily average traffic volume of 6,500 veh approaching Mount Pleasant and 5,100 veh approaching Clare. Although the traffic is higher during the summer tourist period, it would not be considered an extremely high-volume roadway. The total vehicle movement data were sufficient to illustrate the effects of the color system, but the nighttime data were rather limited. It would be desirable to conduct further research to gain experience under higher volumes and to supplement the nighttime observations. Research of this system under urban freeway traffic would also be of interest.

The study sites consisted of two isolated locations which were left-hand exits. Certainly, based on this pilot project, similar benefits from the color system could be anticipated at exit ramps of other types or design. Even greater benefits could be anticipated if the color system were applied to a series of ramps on a continuous length of roadway. Acclimatization of motorists to general use of the color system could result in greater benefit. Research along these lines is certainly warranted and recommended.

The pilot project was conducted applying a total system of color coding. Very little, if any, evaluation was possible of the independent effect and benefit of the elements of edgemarking, delineators, and signing. Comments obtained during driver interviews provided a limited insight in this matter. Some question remains as to the length of edgemarking on the exit approaches, the length of edgemarking extending beyond the gore, and the extent of the color code for advance directional and exit signing.

From the results of this pilot project, a continuation of this research project is proposed to investigate the general application of the color system to a length of freeway and satisfy the need for study in the specific areas cited in the foregoing discussion.

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