Safety Considerations in Median Design

JOHN W. HUTCHINSON and THOMAS W. KENNEDY
Respectively, Associate Professor of Civil Engineering, University of Kentucky, and Assistant Professor of Civil Engineering, University of Texas

The frequency, nature and causes of vehicle encroachments on medians of divided highways were investigated to obtain information needed in establishing traffic safety criteria for median width and cross section design. The effects of median width and cross section, traffic volume, roadway alignment, weather, roadside signs, grade separation structures and other features of the highway and driving environment were considered. Relationships between traffic volume and the frequency and nature of vehicle encroachments on medians are presented. The recommendations include minimum design requirements for safe stopping or control of vehicles in the median.

•THIS IS the final report on a six-year study of the frequency, nature and causes of vehicle encroachments on medians of divided highways. It covers one phase of a research project conducted by the University of Illinois Engineering Experiment Station as a part of the Illinois Cooperative Highway Research Program. Other phases of this work have been reported previously (1-4, 7).

The objective of this study was to determine the frequency and nature of vehicle encroachments on certain types of medians under selected field conditions, in order to evaluate the median's potential as a stopping or recovery space for erratically moving vehicles. Because the importance of designing the median as a stopping or recovery space varies with the extent to which the frequency and nature of encroachments can be controlled, particular attention was also devoted to factors causing or influencing encroachments.

STUDY METHOD

In planning the study it was assumed that conventional accident records would be of little value in determining either the frequency or nature of vehicle encroachments on medians. A subsequent comparison of accident records and project data supported this assumption (2).

The argument against the use of accident records as the primary source of data was that they gave little indication of the extent to which medians are successful as a stopping or recovery space for vehicles.

Accident records could provide measurements of the failure of the median to serve as a vehicle stopping or recovery space. However, the limited amount of police surveillance allows some undetected cross-median vehicle movements and many unreported minor collisions of vehicles with fixed objects in the median.

The study consisted of analyzing the evidence at the site of each encroachment on highway medians. This required carefully planned, frequent coverage of the entire length of the selected highway segments to locate and evaluate evidence of encroachments.

Surveillance was provided by two-man teams who patrolled the highway in specially marked slow-moving vehicles. Each encroachment record included a sketch of the

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vehicle path with dimensions, highway cross-section dimensions, type of median cover, approximate time of occurrence, and other pertinent data. A visual record of each encroachment was compiled through the use of colored and black-and-white pictures. To avoid duplicate reporting during the 3½-year study on I74, each encroachment was assigned a number which was painted on the pavement at the site.

Encroachment frequency was determined from records of every incident involving vehicle travel in the median during a chosen time interval. Intentional turns across the median and encroachments resulting from maintenance activities were not used in these calculations.

The nature of encroachments was determined from data collected at the sites, and from additional information in available accident reports. Because of the necessary accuracy and detail of the needed data, some observed locations had to be excluded from this part of the study for lack of sufficient evidence for analysis.

Factors causing or influencing encroachments were given considerable attention throughout the study. An analysis of conditions at several points of high encroachment frequency on US 66 was reported previously (3). A similar analysis of 24.6 mi of I74 is included herein.

ENCROACHMENT FREQUENCY

Because of limitations of time, money and personnel, only four-lane highways were considered in this study. Of primary concern was the development of relationships between the frequency and/or rate of encroachment and traffic volume. No attempt was made to obtain the great quantity of data necessary for development of a critical comparison of these relationships for six- and eight-lane highways.

Data for this phase of the study were obtained from I74 (from US 150 Spur, Urbana, to the US 150 Junction, Danville) and a portion of Kingery Expressway (from Calumet Expressway to the Illinois-Indiana state line, Chicago). Both of these highway segments have dual 24-ft roadways, complete control of access and essentially tangent alignment. The widths and cross sections of the medians are different; I74 has a forty-ft median, depressed about 3 ft, whereas the Kingery Expressway median is 18 ft in width and is depressed about 6 in. However, from the standpoint of factors affecting frequency, the most significant difference in the design features of these two highways is the extent to which roadway delineation has been provided (3). I74 has reflective delineators; Kingery Expressway does not. Some roadway delineation is provided by wooden cable-barrier posts in the Kingery Expressway median, but the general level of delineation is undoubtedly lower than on I74.

Traffic volumes increased from about 1,700 to 6,000 veh/day on I74 and from 18,000 to 31,000 veh/day on Kingery Expressway during the periods for which data were compiled.

Encroachment and traffic volume data for the 3-mi Kingery Expressway study section were obtained from the Illinois Division of Highways, and were for four-month periods extending from December 1 through March 31 of 1957-58, 1958-59 and 1959-60. Data for the 24.6-mi I74 study section were recorded by project personnel from October 4, 1960 through April 6, 1964. Traffic volume and encroachment data are presented in Table 1 and Figure 1.

Figures 2 and 3 show the relationship between traffic volume and the recorded encroachments. The curves in these figures have been constructed through the weighted average of I74 data points associated with traffic volumes of approximately 4200 and 5800 veh/day. This was done to decrease the effects of seasonal variations in number of encroachments for periods with approximately equal traffic volumes. The basic character of the relationships (Figs. 5 and 6) is not changed by averaging the data points (Figs. 2 and 3). Observed seasonal variations are shown in Figure 4.

Figure 2 indicates that encroachment frequency on I74 increased with traffic volume until an ADT volume of about 4,000 veh/day occurred. At higher traffic volumes the frequency decreased until a minimum was reached at about 6,000 veh/day.

The dashed line (Fig. 2) connecting the data points for I74 and Kingery Expressway shows the general nature of the change in encroachment frequency expected on I74 at

TABLE 1

ENCROACHMENT FREQUENCY AND RATE DATA

Period of Observation	Days of Observation	Traffic Volume (ADT), Veh/Day	Vehicle-Miles of Travel	Observed Encroachment	Encroachment Frequency, Enc/Mi/Yr	Encroachment Rate, Enc/100 × 10^6 Veh Mi
(a) I74 (24.6 mi)						
Oct. 4, 1960-Dec. 22, 1960	79	1,900	3,693,000	16	3.0	433
Dec. 22, 1960-March 29, 1961	97	3,000	7,159,000	31	4.7	433
March 29, 1961-July 12, 1961	105	4,000	10,332,000	58	8.2	561
July 12, 1961-Dec. 2, 1961	143	4,150	14,599,000	30	3.1	205
Dec. 2, 1961-March 31, 1962	119	4,350	12,734,000	32	4.0	251
March 31, 1962-June 26, 1962	87	5,250	11,236,000	17	2.9	151
June 26, 1962-Oct. 13, 1962	109	5,750	15,418,000	16	2.2	104
Oct. 13, 1962-April 16, 1963	185	5,950	27,078,000	50	4.0	185
April 16, 1963-June 27, 1963	72	5,950	10,539,000	5	1.0	47
June 27, 1963-April 6, 1964	284	5,700	39,822,000	47	2.4	118
(b) Kingery Expressway (3.0 mi)						
Dec. 1, 1957-March 31, 1958	120	18,195	6,550,000	7[a]	7.1	107
Dec. 1, 1958-March 31, 1959	120	20,490	7,376,000	9	9.1	122
Dec. 1, 1959-March 31, 1960	121	31,253	11,345,000	14	14.1	123

[a]Incomplete record.

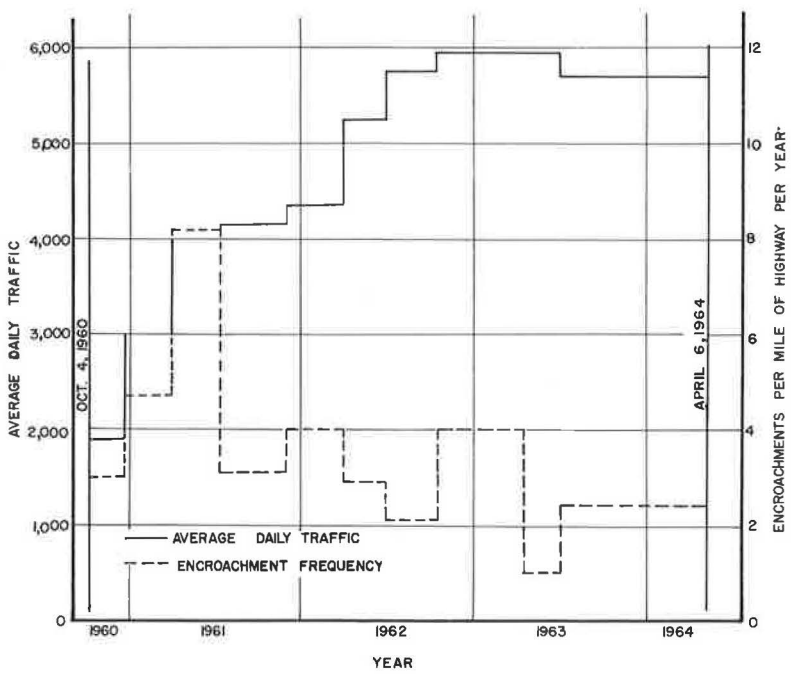


Figure 1. Comparison of variations in traffic volume and encroachment frequency for I74.

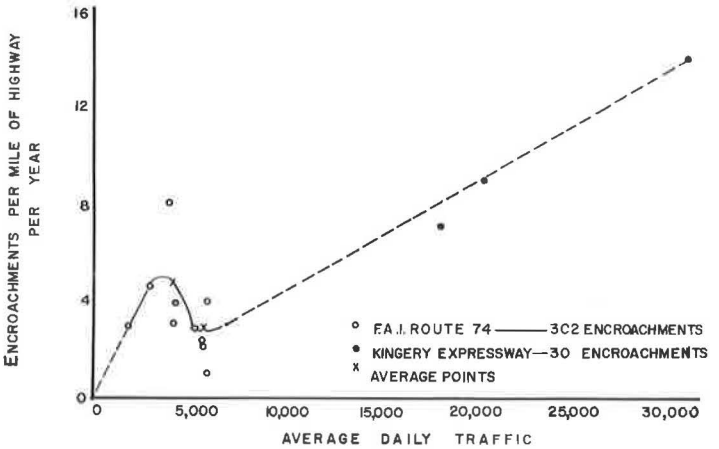


Figure 2. Encroachment frequency for 174 and Kingery Expressway.

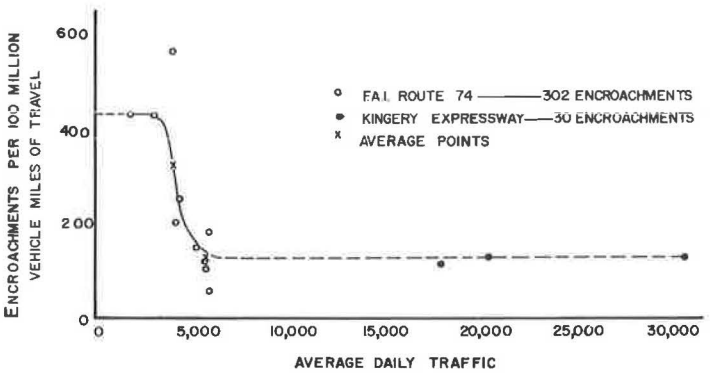


Figure 3. Encroachment rate for 174 and Kingery Expressway.

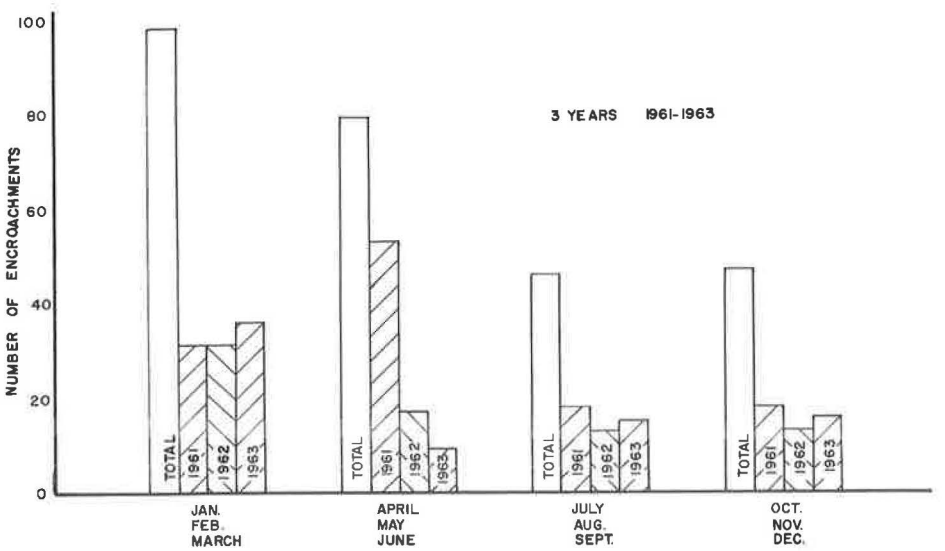


Figure 4. Seasonal variation in number of vehicle encroachments on median of 174.

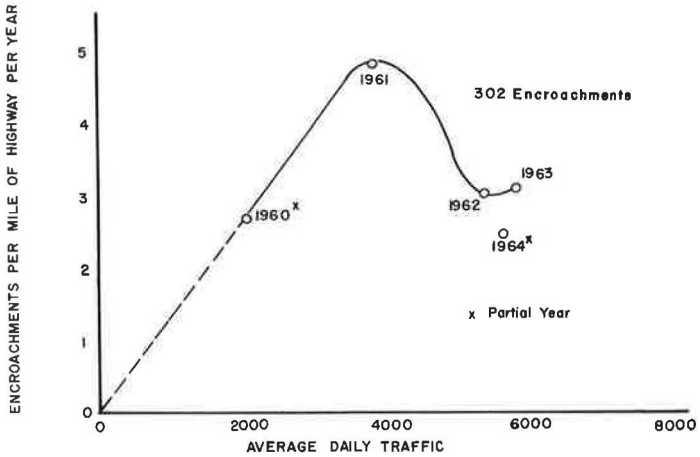


Figure 5. Yearly encroachment frequency for I74.

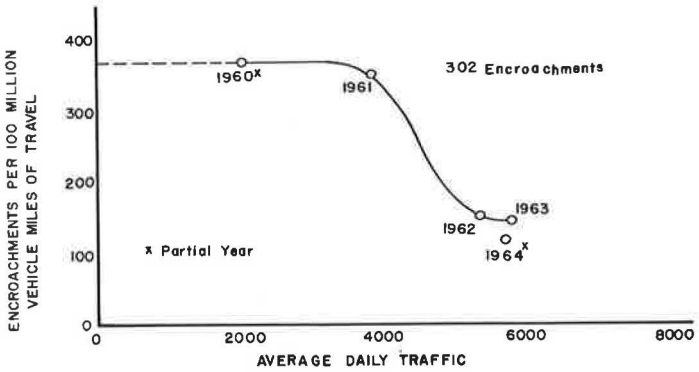


Figure 6. Yearly encroachment rate for I74.

volumes greater than 6,000 veh/day. It does not represent an extrapolation of data under the assumption that the relationship between frequency and traffic volume is not affected by differences in the design features of these highways. Previously reported findings indicate that such an assumption is not valid (4). The better roadway delineation on I74 should result in somewhat lower encroachment frequencies than are represented by the dashed line. Furthermore, the observed frequencies of encroachment on Kingery Expressway are probably high due to seasonal influences; all the data from Kingery Expressway were collected during winter months. Therefore, the dashed line in the interval from 6, 000 to 20,000 veh/day is only an indication of the general shape and direction of the future volume-frequency relationship predicted for I74.

The point representing Kingery Expressway data for the winter of 1957-58 (approximately 18,000 veh/day) does not fall on the curve. This is because an incomplete record was obtained during the first winter of study on Kingery Expressway. Failure to properly coordinate field activities with the occurrence of snow storms resulted in the loss of some evidence. The data point for this period falls below the constructed curve, thus indicating a proper relative position of the portion of the curve representing Kingery Expressway data.

Encroachment rate (Fig. 3) is a function of the slope of the encroachment frequency curve. At a traffic volume of 3,000 to 4,000 veh/day the rate on I74 began to decrease rapidly with increasing traffic volume. As the traffic volume approached 6,000 veh/day the rate became relatively constant at a value less than one third of the original value. The trend of the curve at about 6,000 veh/day suggests a more or less constant rate, equal to or less than the rate for Kingery Expressway, at traffic volumes above 6,000 veh/day.

The proposed explanation of these changes in rate and frequency is based on the differences in driving environment associated with changes in traffic volume.

Drivers act more or less independently at low traffic volumes; there is extensive freedom of movement with restrictions imposed only by the physical features of the roadway. Furthermore, modern high-speed highways are designed to relieve the driver of many operational judgments and decisions associated with older two-lane highways. This environment leads to inattentiveness and reduced alertness which increase the probability of an inadvertent median encroachment. Since drivers operating at low traffic volumes can be considered as isolated units, it appears logical to assume that the probability of encroachment is constant for each vehicle and independent of the behavior of other vehicles.

Another important consideration is the reduced roadway delineation which occurs at low traffic volumes. In the absence of other vehicles the driver must orient his vehicle with respect to the physical features of the roadway which may or may not provide adequate delineation. If, however, other vehicles are present there is a tendency to caravan, with each driver consciously or subconciously following the vehicle ahead. Vehicles do, in a sense, delineate roadway alignment and provide a reference point for lateral positioning of vehicles further back in the traffic stream.

As traffic volume increases, driver-vehicle behavior is influenced to a greater and greater extent by the presence of other vehicles. The decreased spacing between vehicles should increase driver alertness and roadway delineation with a resulting reduced probability of an inadvertent encroachment. At the same time the probability of encroachment due to evasive action or actual physical contact between vehicles should increase.

Considering Figure 2, it is reasoned that, in the interval between zero and

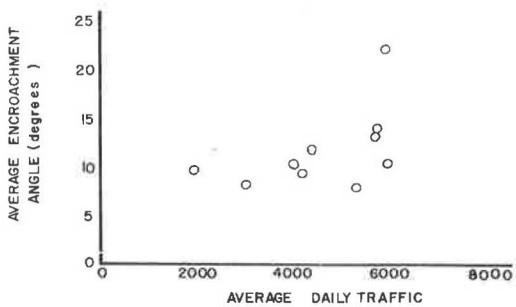


Figure 7. Relationship between traffic volume and angle of encroachment for I74.

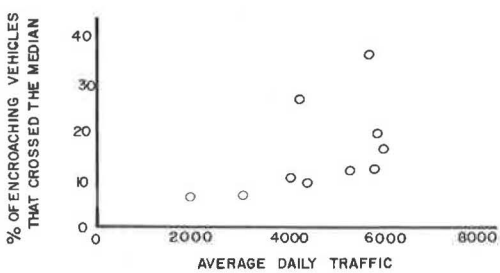


Figure 8. Relationship between traffic volume and percent of encroaching vehicles that crossed the median of I74.

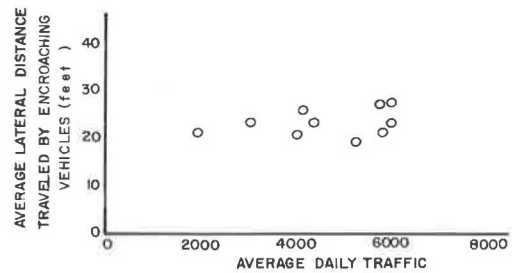


Figure 9. Relationship between traffic volume and average maximum lateral movement of encroaching vehicles for I74.

2,000 veh/day (extrapolated), the driver is operating independently of other vehicles and the probability of median encroachment is constant for each unit. Thus, the number of encroachments is primarily dependent on the number of vehicles subject to the chance of encroachment and a linear relationship should exist between frequency and traffic volume. As traffic volume increases (above 2,000 veh/day), the effect of improved roadway delineation and driver alertness is illustrated by the decreasing slope of the volume-frequency relationship; the probability of an inadvertent median encroachment is reduced and the frequency increases at a decreasing rate.

At about 4,000 veh/day the frequency of encroachment begins to decrease with increasing traffic volume; the effect of greater numbers of vehicles subject to the chance of encroachment has been more than offset by the gradual improvement in roadway delineation and the rising level of driver alertness.

However, as volume increases, there is also increasing friction and conflict between vehicles. The driver must devote an increasing share of attention to the maneuvers and positioning of other vehicles. Friction and conflict between vehicles is reflected in the more severe encroachments resulting from evasive action and/or physical contact between vehicles. The average angle of encroachment increases in the interval from 4,000 to 6,000 veh/day (Fig. 7). There is also an increase in the percentage of encroaching vehicles that cross the median (Fig. 8).

Concurrently with this increase in severity of the average encroachment, there is greater variety in the types of encroachments occurring. This is illustrated by an increasing scatter of data points in the interval from 4,000 to 6,000 veh/day (Figs. 7 and 9). The greater variety in types is a result of changes in the relative importance of many volume-related factors affecting the frequency and nature of encroachments. Most important among these factors in the increasing contrast between the types of driving environment found at different periods of the day. Inadvertent encroachments, associated with low traffic volumes, are still represented because the conditions that produce them are still prevalent during low volume periods. However, new reasons for inadvertent encroachments become evident during high volume periods of the day; the driver must often devote more attention to the relative position of nearby vehicles than to the alignment of the roadway and the lateral placement of his own vehicle. The driving task steadily becomes more complex as the traffic volume increases.

The trend of the volume-frequency curve (Fig. 2) in the interval from 5,000 to 6,000 veh/day reflects the growing complexity of the driving task and the resulting increase in encroachments that can be expected at higher traffic volumes. The dashed portion of the curve, in the interval from about 6,000 to 20,000 veh/day, shows a somewhat more rapid frequency increase than will probably be experienced on I74, but it is indicative of the anticipated linear increase.

TABLE 2

ENCROACHMENT RATES[a]

Highway	Rate
Calumet Expressway ADT = 12,000	58
Edens Expressway ADT = 26,000	61
Santa Ana Freeway Approximate ADT = 95,000	54
Nimitz Freeway Approximate ADT = 95,000	68

[a]Encroachments/100 x 10^6 vehicle miles.

Evidence points toward a linear increase in frequency with higher traffic volumes. This can best be illustrated in connection with encroachment rate. All the rates in Table 2 are of the same general magnitude even though a wide range of traffic volumes is represented. This suggests a more or less constant encroachment rate and a linear increase in encroachment frequency at higher traffic volumes.

The encroachment rates for Calumet and Edens Expressways were calculated from data collected in 1960 with evergreen trees installed in the medians of both expressways (4). The evergreen trees are assumed to have provided slightly better roadway delineation than is provided by the reflective delineators on I74. Therefore, the given rates for Calumet and Edens Expressways are assumed to be

slightly lower than can be expected on I74 at equivalent traffic volumes. The rate for higher traffic volumes on I74 is expected to be somewhere between the Kingery Expressway rate (Fig. 3) and the given rates for Calumet and Edens Expressways, i.e., between 60 and 120 encroachments per 100 million vehicle miles of travel.

Rates for the Santa Ana and Nimitz Freeways were calculated from the number of cable-chain-link fence barrier repairs reported by Moskowitz and Shaefer in connection with the study of median barrier performance on California freeways (5). It is doubtful that many vehicles were able to recover within the 6-ft half-width of the curbed medians on these freeways without damaging the barrier.

Edens Expressway and the Santa Ana and Nimitz Freeways are six-lane facilities and therefore cannot be expected to have the same traffic stream characteristics as four-lane facilities like I74 and Kingery Expressway. However, the differences in traffic stream characteristics do not appear to affect significantly the rate under the conditions of reduced vehicle headway associated with high traffic volumes. The average vehicle headway below which the encroachment rate is apparently no longer affected by increases in traffic volume is about 15 sec for I74 (8). The gap equivalent to this average headway can serve as the basis for a rough estimate of the volume above which the rate may be expected to remain relatively constant.

This gap, based on the observed 50th percentile speed of 62 mph at an ADT volume of 6,000 veh/day on I74, is about ¼ mi. The ADT volume producing an average headway equivalent to a ¼-mi gap is therefore the volume above which the rate appears to become relatively constant. In the absence of more complete data, this gap can serve as the basis for a rough estimate of the minimum ADT volume at which the rate may be expected to become relatively constant on a multilane divided highway with complete control of access. A comparison of the relatively constant rates for highways carrying equal or greater ADT volumes should provide a measure of the relative safety of the driving environment provided by different design features. The previously reported experiment with evergreen trees in the medians of Calumet and Edens Expressways was based on such a comparison of rates (4).

Data necessary for such comparisons will become more readily available in the form of median barrier repair records as the growing traffic volumes on many of our present multilane highways exceed the minimum volumes suggested as warrants for the installation of median barriers (6).

NATURE OF MEDIAN ENCROACHMENTS

One of the primary functions of the median (1) is to serve as a suitable stopping or recovery space for encroaching vehicles and yet, except for the study of median barrier performance, there has been little previous effort to determine the effects of median width and cross section on the behavior of encroaching vehicles.

Information on the lateral extent of encroachments can be used as an indication of the median width required to provide an appropriate stopping and recovery space. It can also be used as a measure of the effectiveness of the median cross section in controlling the lateral extent of vehicle movement. The length of vehicle travel during encroachment is an indication of the extent to which the median should be free of obstacles which cannot be traversed safely at normal highway operating speeds.

This analysis of the nature of encroachments concerns rural I74 and I57 and is limited to data from unintentional encroachments with lateral movements in excess of 3 ft. During the periods of study, 302 and 26 encroachments of this type were detected and recorded for I74 and I57 respectively.

In the analysis of physical parameters associated with encroachment patterns, data from less than the total number of encroachments are generally used. This procedure results because certain parameters could not be measured in all encroachments. In addition, only selected portions of the data are considered in certain portions of the analysis. The reasons for this selectiveness are explained in the discussion.

The physical characteristics of the encroachments which generally could be determined from an analysis of field evidence were the basic movement patterns (8), the angles of encroachment, and the lateral and longitudinal distances of vehicle travel.

All measurements were made with reference to the path of the left front wheel of the vehicle. The encroachment angle is defined as the angle between the pavement edge and the path of the left front tire of the vehicle as it departed from the pavement. The lateral extent of movement is defined as the perpendicular distance from the pavement edge to the path of the left front tire of the vehicle at some specified point in the encroachment pattern. The length of travel is the distance from the point at which the vehicle departed from the roadway to some specified point in the pattern as measured along the left front tire path. Table 3 summarizes the more significant vehicle movements and events associated with the encroachments.

TABLE 3

SUMMARY OF SIGNIFICANT MOVEMENTS AND EVENTS ASSOCIATED WITH VEHICLE ENCROACHMENTS

Category	Highway	
	I74	I57
1. Total number of detected vehicle encroachments with sufficient evidence for analysis (lateral movements more than 3 ft into median)	293	25
2. Crossed median (lateral extent of movement greater than 40 ft)	52(17.7%)	0
a. Hit obstacle in median prior to crossing	3	0
b. Recovery-to-right[a] prior to crossing	5	0
c. Would have hit obstacle if recovery-to-right had been attempted	7	0
d. Ran off pavement to the right prior to crossing	2	0
e. Entered roadway from interchange entrance ramp just prior to crossing	4	0
3. Hit major obstacle in median[b]	35(11.9%)	4(16%)
4. Recovery-to-right during encroachment	185(63.1%)	18(72%)
a. Crossed median prior to recovery [a]	3	0
b. Crossed median after striking obstacle subsequent to recovery	2	0
c. Crossed original lanes of travel after recovery	13	1
d. Crossed original lanes of travel after striking obstacle subsequent to recovery	1	0
5. Ran off pavement to the right prior to median encroachment	9(3.1%)	3(12%)
6. Entered roadway from interchange entrance ramp just prior to encroachment	9(3.1%)	0(0%)

[a]"Recovery-to-right" (recovery) is defined as the point in an encroachment pattern at which the lateral velocity component of vehicle movement changes sign due to driver steering through a horizontal recovery curve to the right.

[b]Crossover embankment, culvert headwall, drop inlet structure or earth berm (ditch check).

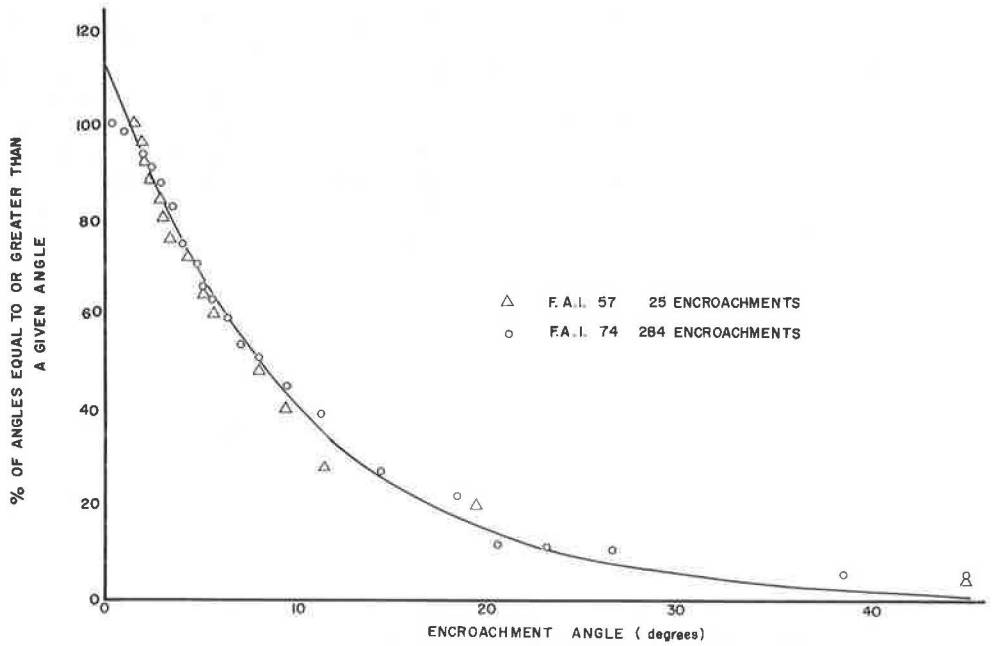


Figure 10. Distribution of encroachment angles for I57 and I74.

The distribution of angles is shown in Figure 10, which includes the combined data from I74 and 57. This figure represents the angles for all unintentional encroachments occurring during the periods of study and having lateral movements greater than 3 ft. The equation approximating the distribution is

$$\beta = 10^{(-0.044\theta + 2.057)}$$

where

β = percentage of θ's greater than or equal to a given θ, and
θ = encroachment angle, degrees.

The observed data deviate from the above expression at low angles (less than about 2 deg) and at high angles (greater then about 25 deg). The deviation at low values of θ is attributed to the failure to record shallow encroachments. The deviation at high values of θ is probably due to the circumstances normally associated with encroachment at large angles. It is doubtful that a vehicle could encroach upon the median at an angle greater than about 25 deg unless it was traveling at low velocity, was involved in a relatively severe collision, or was involved in initial movements resulting in running off the pavement to the right. Available data did not allow an appropriate consideration of the first two possibilities. In Table 3, however, it may be noted that 9 encroachments involved vehicles running off the pavement to the right prior to the actual median encroachment and that 9 others involved vehicles entering the roadway from an interchange ramp. The elimination of these encroachment types greatly reduces the deviation from the distribution relationship at high angles (Fig. 11).

Figure 11 was used to estimate the number of shallow encroachments which occurred on I74. The adjusted distribution curve in Figure 11 suggests that 45 shallow encroachments occurred on I74 during the period of study (17 percent of 266 encroachments).

A summary of the basic statistical parameters associated with encroachment angles in given in Table 4.

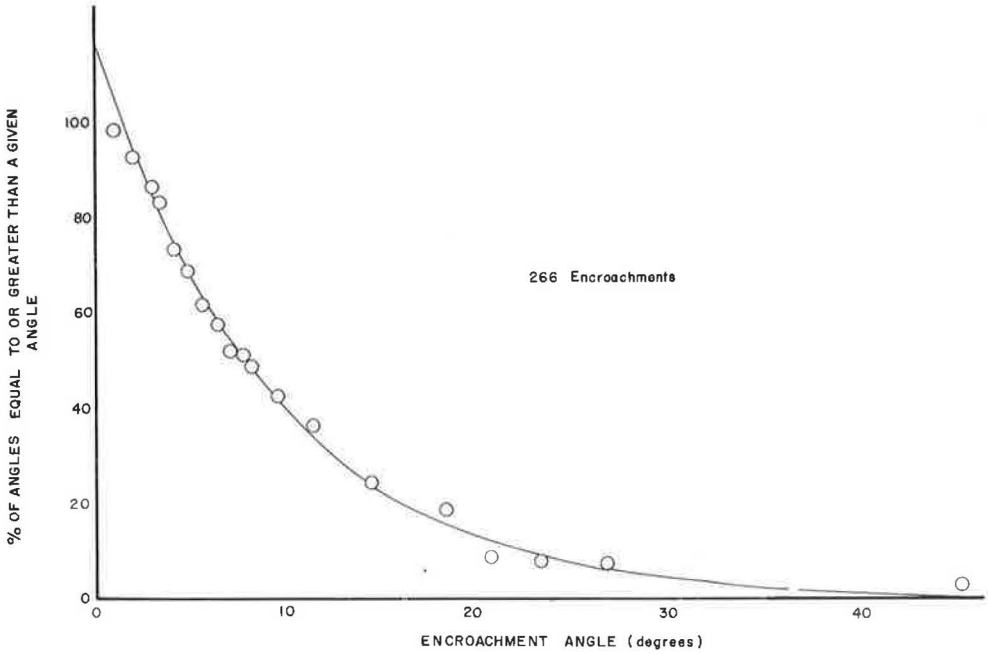


Figure 11. Distribution of encroachment angles for I74 (adjusted).

TABLE 4

BASIC STATISTICAL PARAMETERS ASSOCIATED WITH THE NATURE OF ENCROACHMENTS

Parameters	Number[a]			Average			Standard Deviation			Confidency Interval Coef of Confidence = 0.96		
	I57	I74	I57 and I74	I57	I74	I57 and I74	I57	I74	I57 and I74	I57	I74	I57 and I74
Encroachment angle (deg)	25	289	314	10.2	11.0	10.9	9.6	11.1	11.0	6.2 to 14.1	9.7 to 12.2	9.7 to 12.1
Length of travel (ft)	25	290	315	292	291	291	202	217	216	209 to 376	266 to 316	267 to 315
Lateral extent of travel (ft)	25	296	321	23	23	23	10	11	11	19 to 27	22 to 24	22 to 24

[a]The 3 basic parameters could not be measured for all detected encroachments.

The distribution of travel lengths during encroachment for I74 and I57 are shown in Figure 12. Since there appears to be no significant difference between the mean lengths of travel for the two highways (Table 4), data for both highways have been combined into a single distribution curve in Figure 13.

The distribution in Figure 13 closely approximates a normal distribution except at very low values (L less than about 60 ft) and very high (L greater than about 550). This deviation at high values may be due to the fact that it was impossible in many instances to determine whether a vehicle was not under control or whether the driver was merely operating his vehicle in the median area.

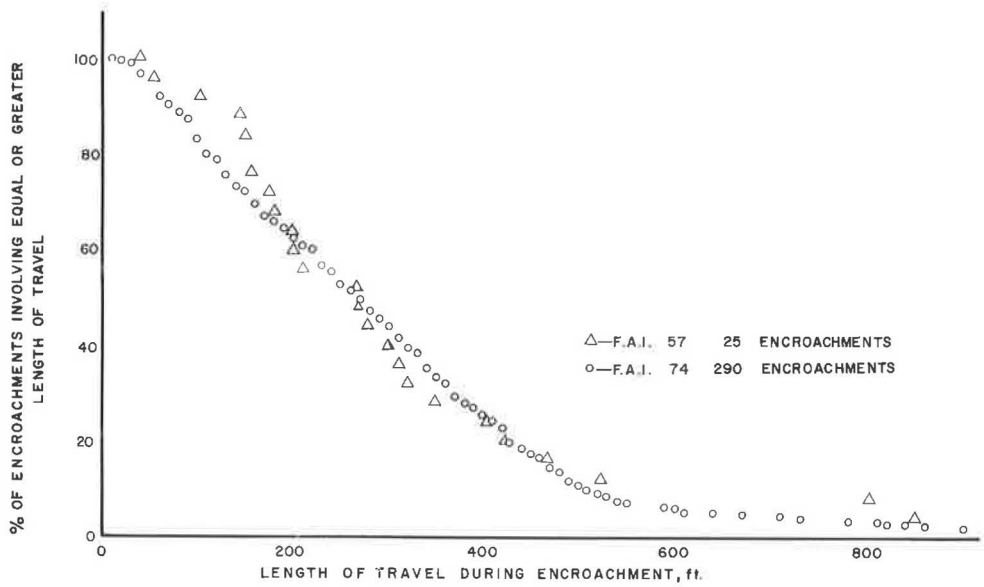


Figure 12. Distribution of lengths of vehicle travel during encroachment for 157 and 174.

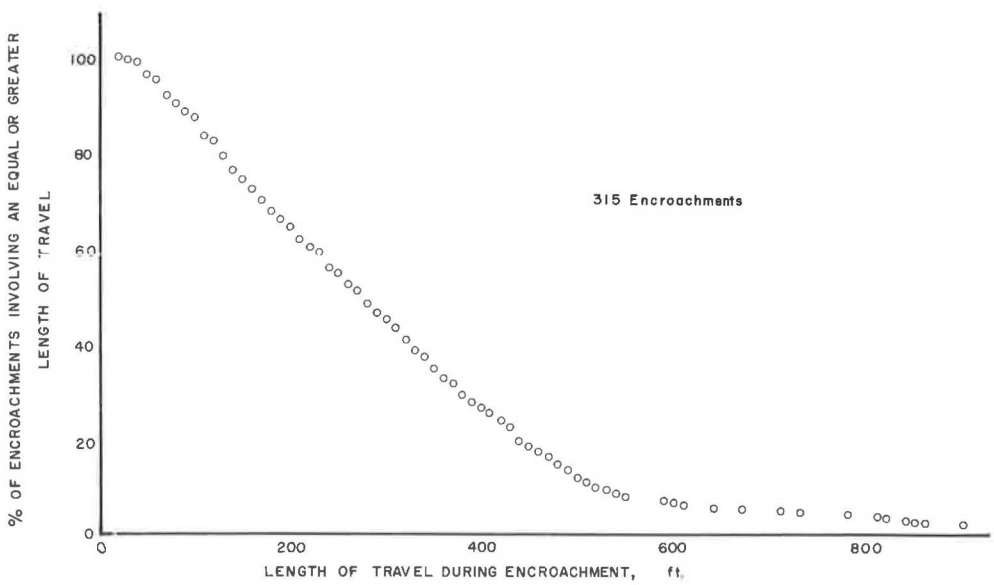


Figure 13. Distribution of lengths of vehicle travel during encroachment for 157 and 174, combined.

The mean values of L for 174 and 157 are 293 ft and 292 ft respectively. Other statistical parameters are summarized in Table 4.

The length of travel during encroachment is an indication of the reasonable extent to which the median should be free of obstacles which cannot be traversed safely at normal highway operating speeds. The greater the length of travel the greater the prob-

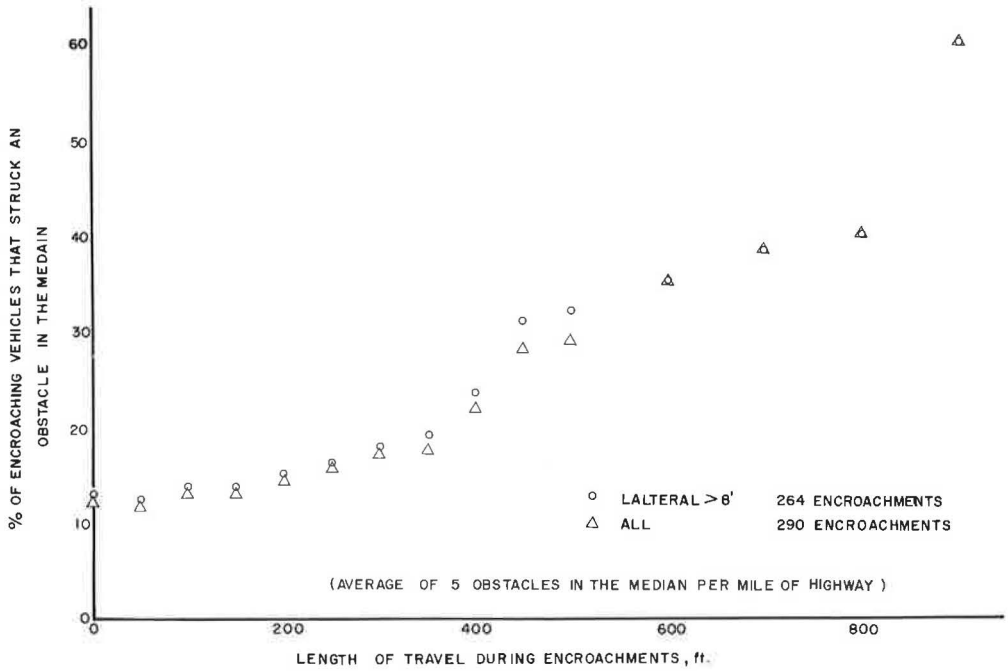


Figure 14. Frequency of vehicle collision with obstacles as related to length of travel during encroachment for I74.

ability that the vehicle will strike a median obstacle such as a culvert headwall, a drop inlet, or a ditch check. On I74 there is an average of five such obstacles per mile of median. Figure 14 indicates the percentage of vehicles that struck obstacles in the median. Figure 14 includes only those encroachments with lateral movements greater than 8 ft since there are no obstacles on the shoulder.

During the 3½-year study on I74, 11.9 percent of all encroaching vehicles struck obstacles in the median. Many other vehicles either straddled or passed between culvert headwalls or passed smoothly over headwalls with only the tires making actual contact with the obstacle. With possibly as many as 14 encroachments per mile per year at higher traffic volumes (Fig. 2), the above findings indicate that an average of more than 1.6 veh/mi per year could eventually be expected to strike obstacles in the median of I74.

The significance of obstacles in the median is even greater than would be indicated by an estimate of the accident cost and injury resulting directly from collisions with these obstacles. Many vehicles that crossed the median on I74 apparently did so as a result of the driver's attempt to dodge obstacles. Such encroachments are usually characterized by the lack of evidence of any driver attempt to recover-to-the-right; very few of the cross-median encroachments involved an actual collision with an obstacle in the median. Only three (5.8 percent) of the 52 cross-median encroachments involved vehicles striking obstacles (Table 3). All but 5 of the cross-median encroachments occurred without a recover-to-the-right. The dodging of obstacles in the median is an important factor in cross-median movements.

The distribution of maximum lateral movements during encroachment is shown in Figures 15 and 16. Figure 15 contains the separate distribution curves for I74 and I57 and Figure 16 contains the distribution curve for I74 and I57 combined. Since the median of I74 has essentially the same cross section as the first 40 ft of the 80-ft I57 median and since none of the encroachments on I57 had lateral movements greater than 40 ft, this combination of data appears to be justified. Basic statistical parameters associated with the lateral extents of movement for both highways are contained in Table 4.

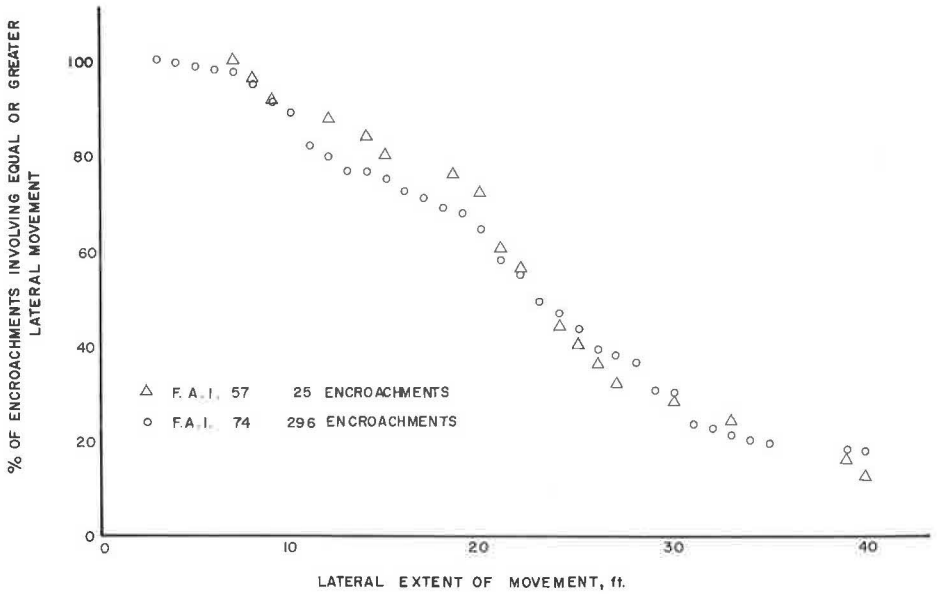


Figure 15. Distribution of lateral movements of vehicles during encroachments for 157 and 174.

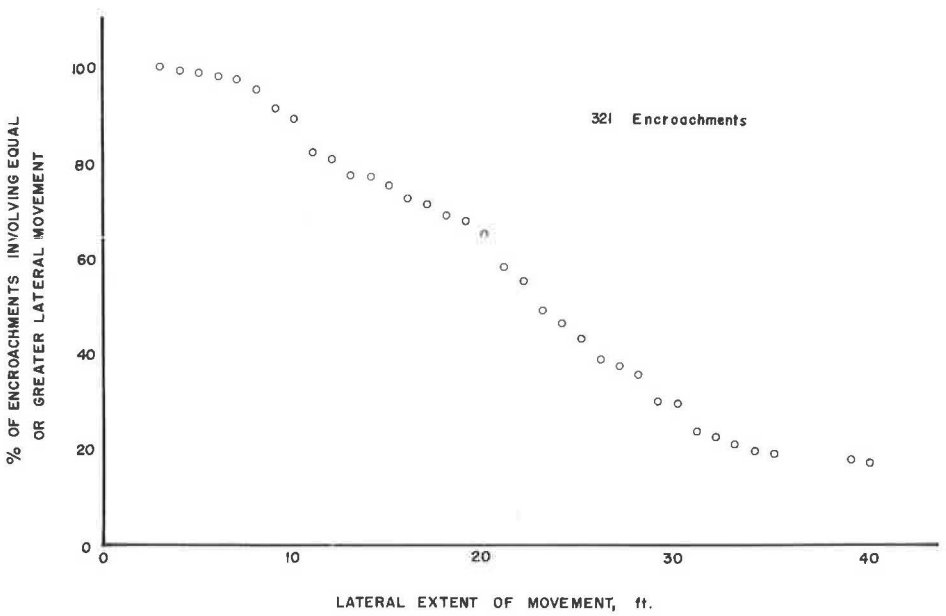


Figure 16. Distribution of lateral movements of vehicles during encroachments for 157 and 174, combined.

The important aspect of these relationships is the apparent influence of median cross section slopes; changes in the slope of the distribution curves occur at approximately the same lateral distances as do the changes in median cross section slope.

When a vehicle is moving at an angle to the left of its intended path of travel it is brought under control by steering it through a horizontal curve to the right. The slope of the median for the first 20 ft of lateral movement is negative superelevation (24:1 on the shoulder, 4:1 on the side slope) on the recovery curve traversed by the vehicle.

Figure 16 shows that, in the interval from 3 to 8 ft of lateral movement (shoulder area), the distribution curve is practically horizontal, indicating that very few vehicles are brought under control in this area. Few drivers are able to regain control of their vehicle on the shoulder once the left front wheel of the vehicle leaves the 3-ft stabilized portion of the shoulder. In the interval from 8 to 11 ft (rounded transition from shoulder to back-slope) a much greater percentage of vehicles is brought under control despite the change from a mild negative slope (24:1) to a severe negative slope (4:1). The relatively large number of recoveries occurring near the shoulder edge is attributed to the reaction time of the driver and vehicle. The vehicle could traverse the shoulder width in the time that it takes for perception by the driver and response by the vehicle to the driver's natural reaction to correct to the right. Assuming a vehicle speed of 60 mph, an average encroachment angle of 7.5 deg[1], and a 1-sec interval between driver perception and vehicle response, the vehicle would travel approximately 11.4 ft laterally.

In the interval from 11 to 20 ft the slope of the distribution curve is relatively flat, indicating that few vehicles are brought under control on the greater negative superelevation (4:1) of the median ditch side-slope. At about 20 ft of lateral movement the distribution curve steepens as a result of the positive superelevation provided by the back-slope of the median ditch. Beyond this, at a lateral distance greater than about 32 ft, the slope of the distribution curve becomes flatter again as the slope of the shoulder on the opposing roadway provides less positive superelevation on the vehicle recovery curve.

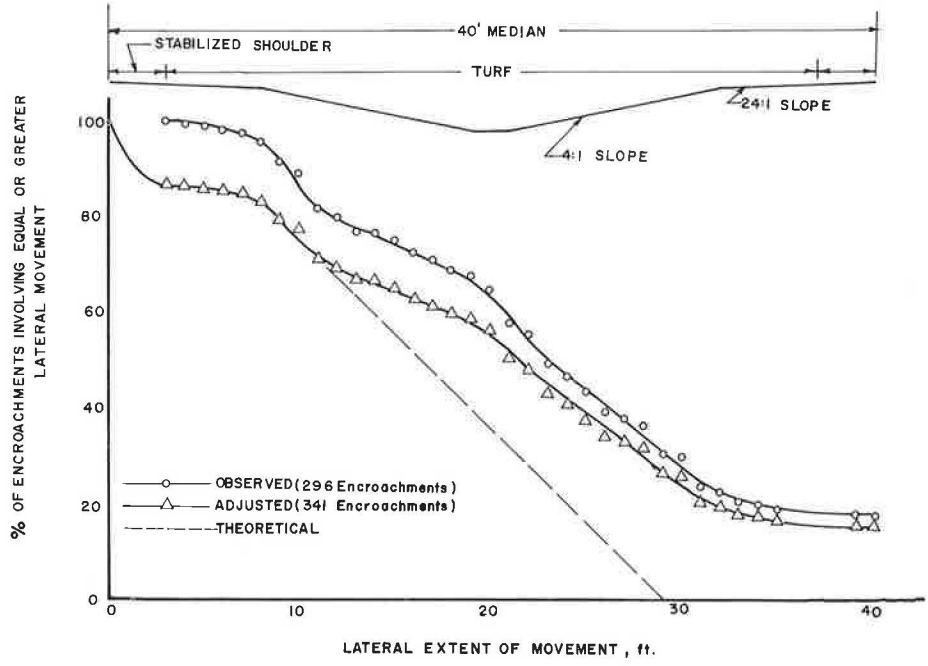


Figure 17. Distribution of lateral distances for 174.

[1]The average encroachment angle for vehicles recovering in the interval from 8 to 11 ft of lateral movement.

The interesting implication is the possibility of maintaining a steep slope of the distribution curve across the entire width of the median by providing a small negative superelevation such as the 24:1 slope used on the shoulders of I74.

Figure 17 shows the actual, adjusted, and theoretical distributions of maximum lateral movements for I74. The adjusted curve includes the estimated number (45) of shallow encroachments. This estimate indicates a relatively large number of encroachments occurring within the 3-ft width of stabilized shoulder. This portion of the distribution curve is substantiated to a certain extent by previous findings on US 66 (3). The theoretical curve is an estimate of the distribution of maximum lateral movements that would be obtained if the 24:1 shoulder slope were extended. It was constructed by extending the slope of the adjusted distribution relationship that occurs in the interval from 9 to 11 ft of lateral distance. This estimate is conservative because an even larger percentage of the drivers would probably have regained control of their vehicles in the interval from 8 to 11 ft of lateral movement if the vehicle had not been in an area of high negative superelevation (4:1) on the recovery curve. The one major limitation of this estimate is that, although the percentage of vehicles reaching the centerline of the median would be reduced, the effect of the decreased positive superelevation provided by the median ditch back-slope cannot be evaluated.

Considering this theoretical curve, it appears that practically all of the encroaching vehicles would have been brought under control within a lateral distance of about 29 or 30 ft. In view of the present trend toward wider medians to reduce headlight glare, the possibility of reducing median cross section slopes should be considered and investigated.

Another major benefit resulting from the use of flatter median cross slopes could be an increased driver calmness resulting in a higher probability of safe recovery. On the presently used 4:1 side-slope the driver's natural reaction is to turn sharply to the right while the median cross slope is causing the vehicle to be pulled violently to the left. This probably causes many drivers to overcorrect to the right. Table 3 shows that 13 vehicles (7.0 percent of those recovering to the right) were overcorrected to the right, across their former lanes of travel.

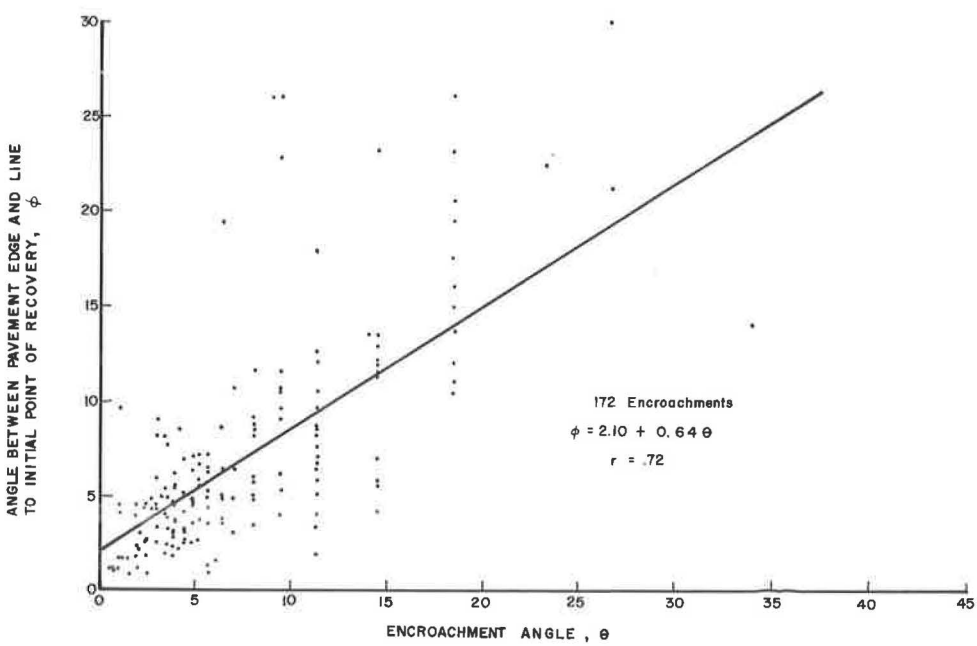


Figure 18. Relationship between encroachment angle and initial point of recovery for I74.

Attempts to determine significant relationships among the three basic parameters (angle of encroachment and lateral and longitudinal encroachment travel distances) were not successful; this was probably due to the large number of variables (vehicle speed, extent of braking, etc.) which could not be measured. Of particular interest, however, was the observation that in the case of 185 (63.1 percent of the 293 encroachments on I74), the drivers made a recovery-to-the-right.

Because of the relatively large number of drivers who made a recovery-to-the-right, an attempt was made to determine the relationship between the three basic parameters at the point of initial recovery-to-the-right. A significant relationship of this type would provide valuable guidance in the design and placement of highway guardrails.

The lateral extent of movement at the point of initial recovery-to-the-right is termed the initial lateral extent of movement, X', and the length of travel to this point is termed the initial length of encroachment travel, L'. Figure 18 shows the relationship between θ and Φ. The equation approximating this relationship is

$$\Phi = 2.10 + 0.64\,\theta$$

where

Φ = angle between pavement edge and the line connecting the initial point of recovery with the point of beginning of the encroachment, and
θ = encroachment angle.

A second form of the equation is

$$\frac{X'}{L'} = \sin\,(2.10 + 0.64\,\theta)$$

where

X' = initial lateral extent of movement, and
L' = initial length of encroachment travel.

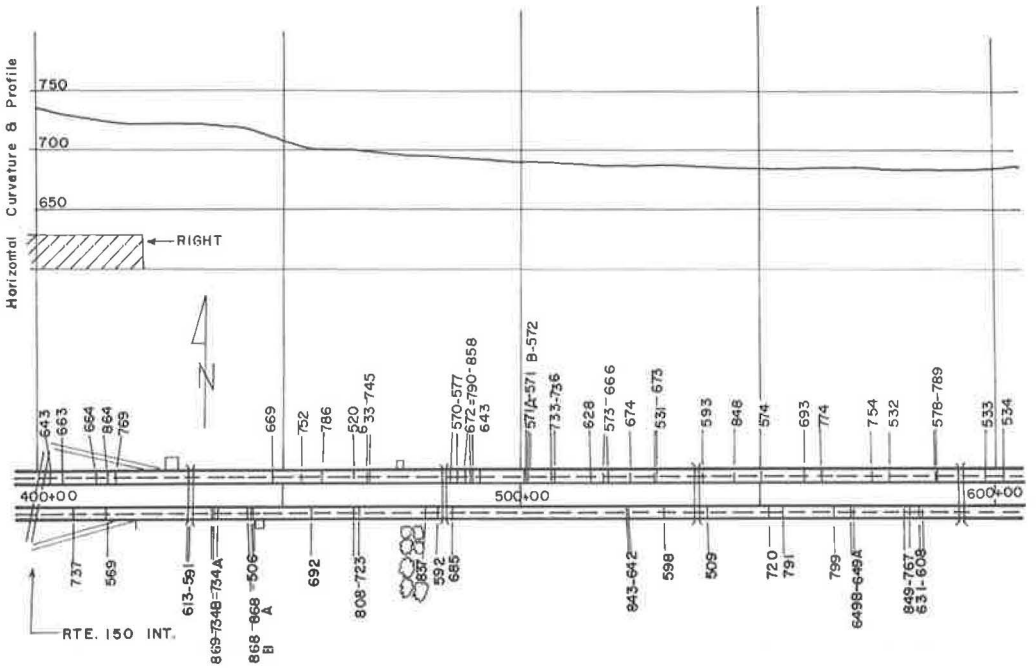
Although the above regression line is highly significant, the correlation coefficient indicates a large amount of deviation from the regression line. Thus, a definite relationship between θ and Φ appears to exist but it cannot be used to obtain a highly reliable prediction of the area of vehicle recovery. For any given encroachment angle, a wide range of lateral and longitudinal travel distances may be expected. This range appears to increase with traffic volume as discussed in connection with Figures 7, 8 and 9.

CAUSES OF ENCROACHMENTS

Over six million vehicle trips were made on this segment of I74 during the 3½-year study; less than five thousandths of one percent of these trips involved a vehicle encroachment upon the median. The individual driver, vehicle and highway factors involved in the encroachments are normally so subtle that they may seriously affect only one trip in ten thousand.

The driver is the ultimate variable because he is the conscious and subconscious sensor of landscape, vehicles, roadway alignment, weather, fatigue, light conditions, pavement surface conditions and most other factors involved in erratic vehicle movements. Because of the number of encroachments observed in this study, it was possible to recognize certain factors that had rather consistent overriding effects. Among these are light conditions, fatigue, roadway alignment, weather, roadside signs, grade separation structures and terrain features.

Unfortunately, the average number of encroachments observed per unit of length of highway is quite small when only 500 or 1000 ft of highway are being considered in connection with a curve, roadside sign or interchange ramp. If all observed encroachments during the 3½ years of study are considered, there is an average of only 2.325 encroachments per 1000 ft of highway. With such a small average there is no appropriate



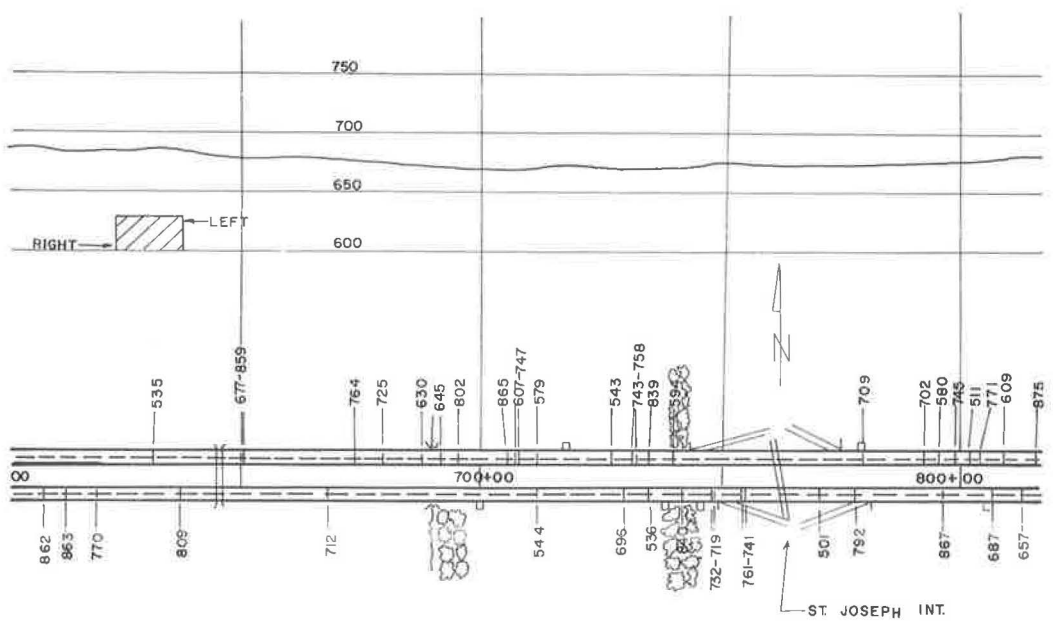
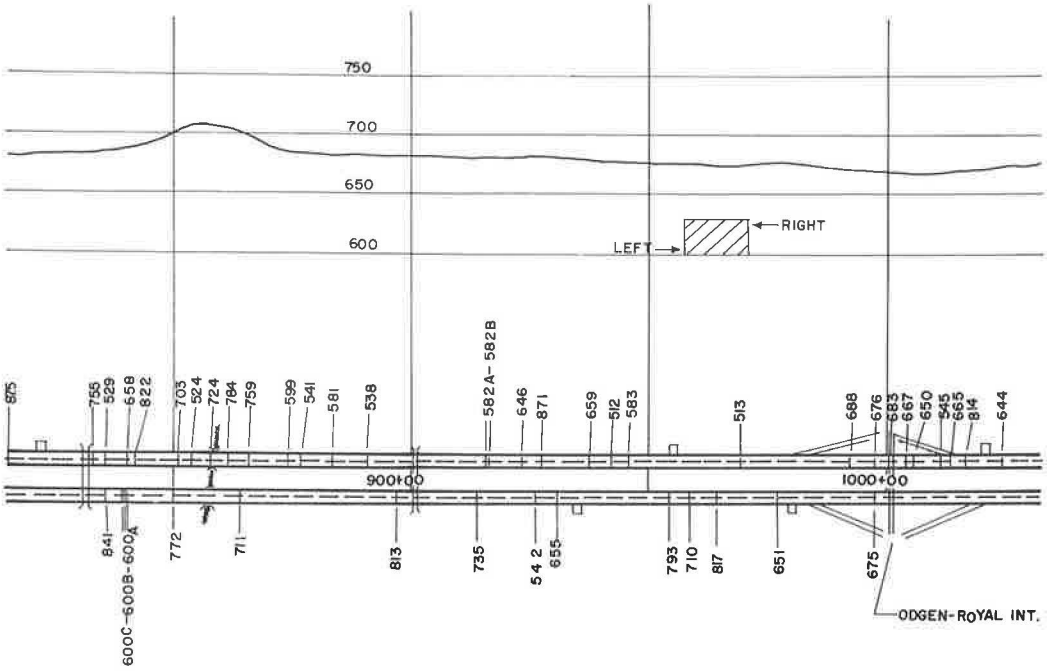


Figure 19. Strip map of 174.



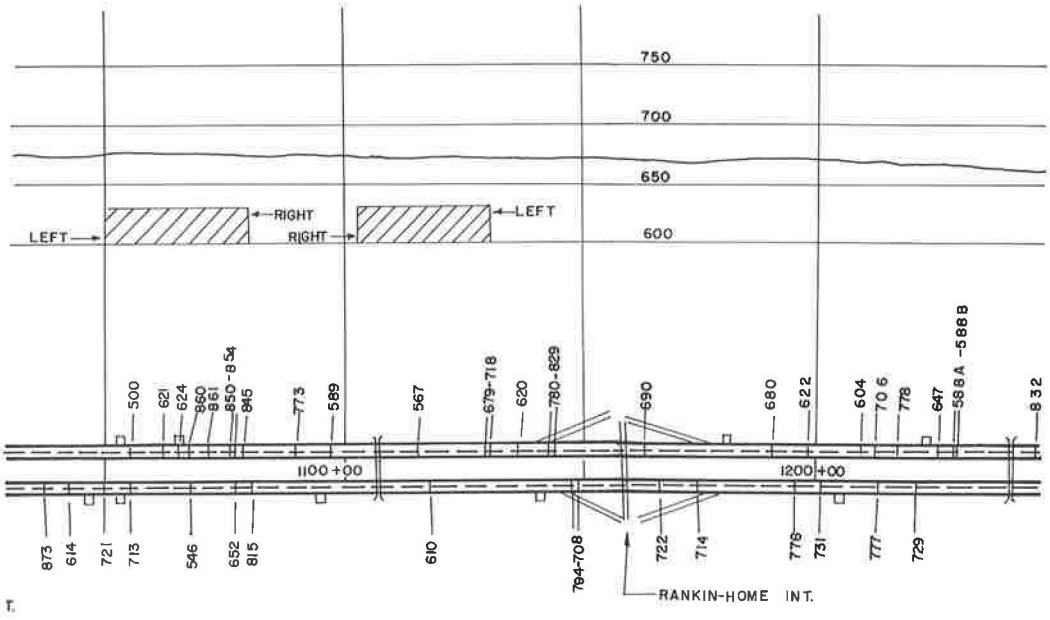
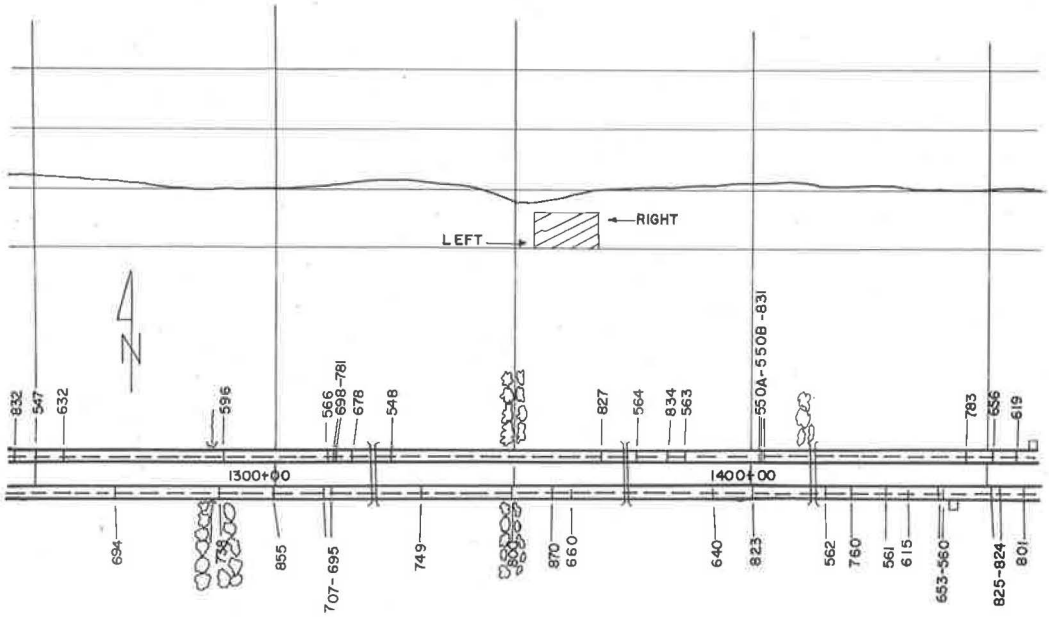
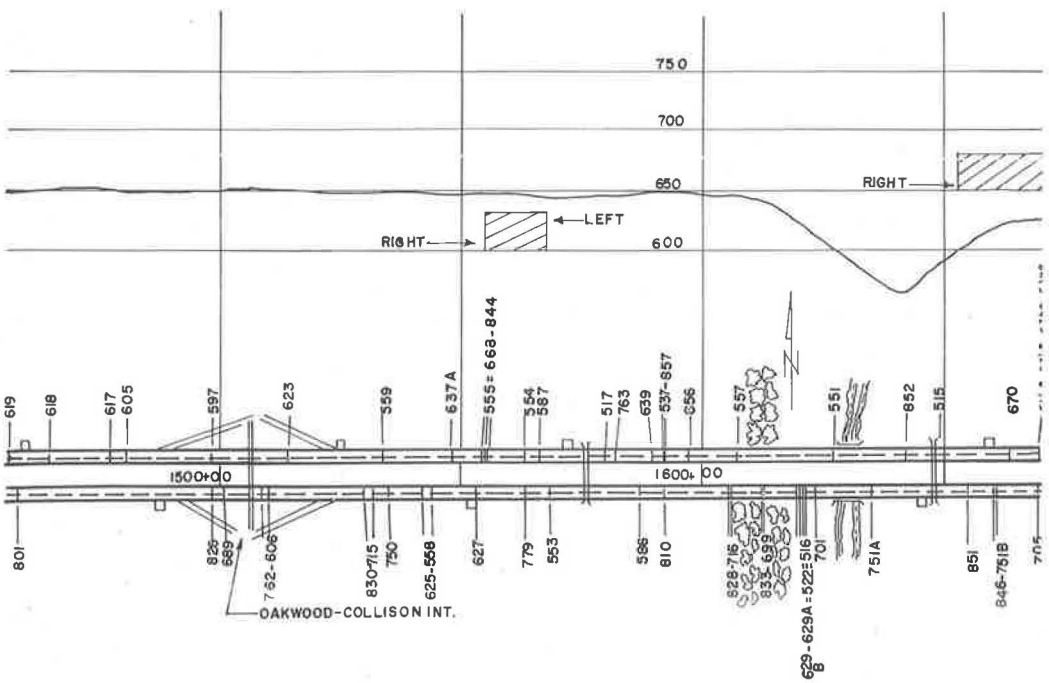


Figure 19. (Continued)





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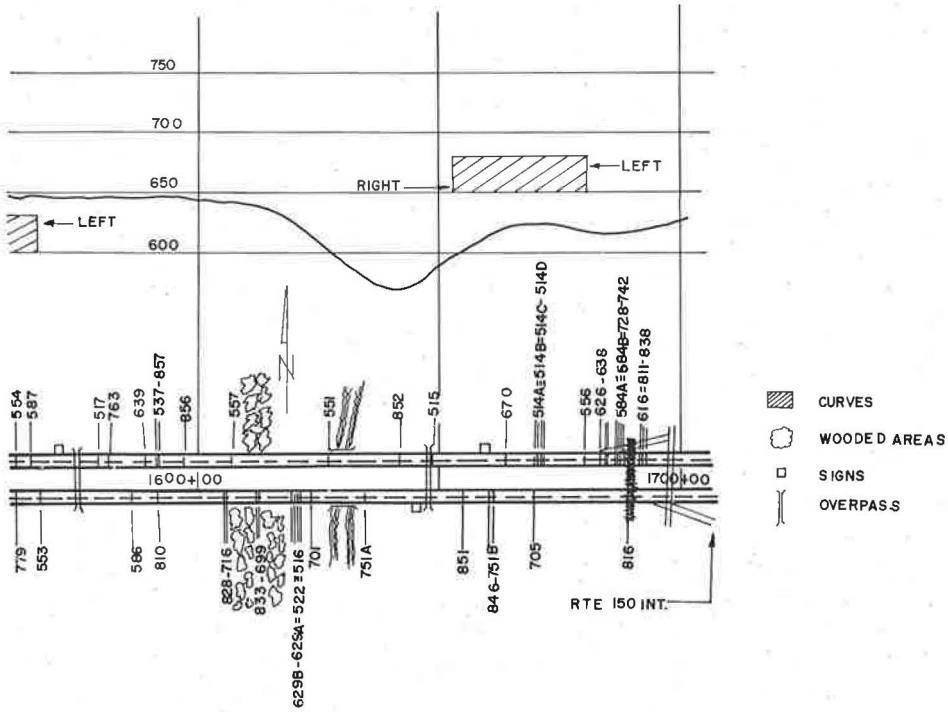

Figure 19. (Continued)

statistical test of the significance of 3, 4 or even 10 encroachments within any given 1,000-ft length of highway. Therefore, statistical tests were applied only in the case of factors affecting the entire length of study section.

Light Conditions and Fatigue

Figure 19 is a strip map of the 24.6-mi study section showing roadway features, pavement station numbers and the exact location of each of the 302 observed encroachments.

The identification number for each encroachment is located next to the roadway from which the encroachment originated. Cursory examination of the strip map reveals that a majority of the encroachments originated from the westbound traffic stream. Actually, 58 percent of the vehicles were westbound. Chi-square testing of this deviation from the expected even distribution by directions (151 eastbound and 151 westbound) shows that this difference is significant (99 percent level).

Drivers in the westbound traffic stream are facing the sun in the afternoon when they are most likely to be fatigued from the day's activities, whereas eastbound drivers face the morning sun at the beginning of the day when they are most likely to be refreshed. If these circumstances are an explanation of the observed difference in number of encroachments originating from the two directions of travel, then the previous conclusions with regard to vehicle caravaning would suggest that these differences in number should decrease as the volume increases. The gradually increasing number of vehicles in the westbound traffic stream should provide progressively better roadway delineation to help offset the effects of driving into the afternoon sun.

This reasoning is supported by the encroachment data. Figure 20 shows how the separate encroachment rates for the two directions of travel varied with traffic volume. The westbound rate, originally much higher than the eastbound rate, decreased rapidly in the volume range from 4,000 to 5,000 veh/day and finally became nearly equal to the

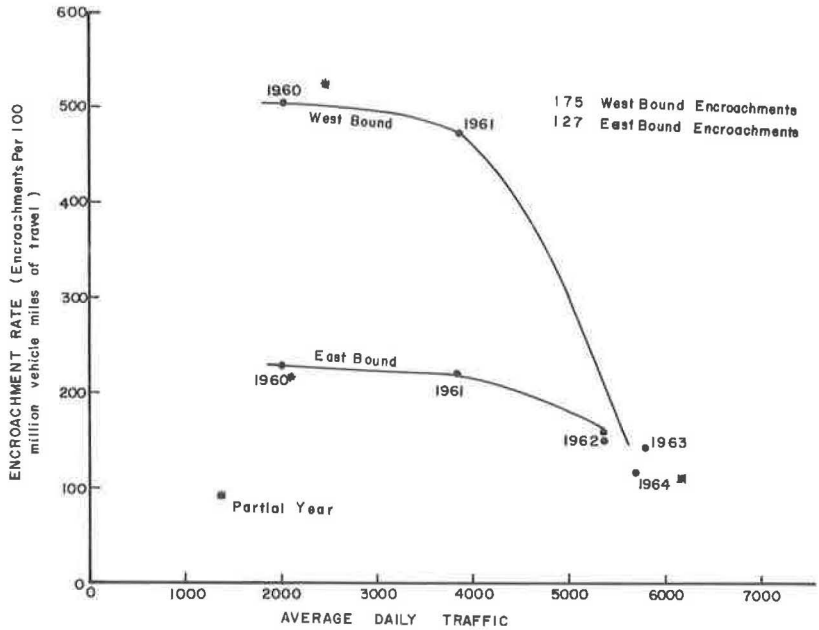

Figure 20. Yearly encroachment rates by direction of travel for I74.

eastbound rate. Apparently, the increasing number of vehicles in the traffic stream eventually provided enough roadway delineation to offset the effect of driving into the afternoon sun.

Another possible effect of fatigue is indicated by the distribution of encroachments along the study section. A relatively high percentage of encroachments occurred near the west end of the study section for the westbound traffic stream and near the east end for the eastbound traffic stream. Slightly over 22.5 percent of all encroachments originating from each traffic stream occurred on the last 4 mi (16.25 percent of mileage) at the downstream end. This includes consideration of those encroachments (10 eastbound and 10 westbound) resulting from entrance ramp friction at the upstream end for each direction of travel. If those encroachments are not considered, the percentage occurring on the last 4 mi in each direction of travel becomes 24 percent. Many different fatigue-related factors such as decreased alertness, velocitation and lowered visual acuity are undoubtedly involved in this downstream distortion of encroachment distribution.

Weather

Weather is partially responsible for the differences in observed numbers of encroachments in the two directions of travel. The prevailing wind and source of storms is from the westerly direction in central Illinois. Westbound vehicles are normally subjected to much higher wind velocities (travel speed plus wind speed) than are eastbound vehicles (travel speed minus wind speed). This difference in wind velocities magnifies the effect of windbreaks (overpass abutments, roadside groves of trees, etc.) on westbound vehicles. The hardest driven rain and snow storms are also from the west. Westbound vehicles are, therefore, subjected to more rapid accumulations of snow and rain on the windshield with resulting poorer driver visibility.

Some of the variation shown in Figure 4 is due to weather changes. As indicated, the number of encroachments during April, May and June varied greatly during 1961, 1962, and 1963. In 1961, this three-month period was marked by temperatures averaging 4.4 deg below normal and precipitation averaging 1.81 in. above normal. During

this cold, wet weather in the spring of 1961 there were nearly three times more encroachments than were observed during the same three-month period in 1962 when the temperature averaged 2.1 deg above normal and the precipitation averaged 0.78 in. below normal. The same three-month period in 1963 brought even less precipitation (2.31 in. below normal) accompanied by a further decrease in encroachments.

Weather differences and traffic volume increases are both partially responsible for the rapid decrease in encroachment rate during 1962. The relative effects of each cannot be accurately judged. Nevertheless, the continued low rate after the spring of 1963, in the absence of any other significantly abnormal weather conditions, suggests that increasing traffic volumes would have eventually brought about the same reduction in rate even without improved spring weather. Therefore, traffic volume increases are assumed to have produced most of the rate reduction which occurred in 1962.

This assumption has no important effect on Figures 2 and 3. An adjustment of the volume-frequency relationship to account for the effects of spring weather would merely broaden the apex of the curve in Figure 2 and steepen the sharp downward slope of the curve in Figure 3.

Interchanges

There were 6 interchanges involved in the study section: 4 diamond interchanges within the study section and a trumpet interchange at each end. The number of encroachments at each interchange and in the vicinity of each interchange ramp was compared with the average number of encroachments per equivalent unit length of highway.

There was no significant variation that could be attributed to any of the interchanges as a whole, regardless of the length of highway considered to be within the area of influence. For an assumed area of influence extending 500 ft beyond the entrance and exit ramps, the interchanges represent 16 percent of the length of the highway within which only 13.8 percent of the median encroachments occurred.

If each interchange ramp is considered separately, there appear to be three locations with significant concentrations of encroachments: (a) the entrance ramp for eastbound vehicles at the west end of the study section (station 420 + 00), with 10 encroachments; (b) the exit ramp for westbound vehicles at Ogden, Illinois (station 1017 + 50), with nine encroachments; and (c) the entrance ramp for westbound vehicles at the east end of the study section (station 1685 + 00) with ten encroachments.

The reasons for the concentration of encroachments near the Ogden exit ramp were never apparent. Eight of these encroachments occurred during the first 1½ yr of surveillance and only one occurred during the remaining 2 yr.

The concentration of encroachments near the entrance ramp at the east end of the study section (station 1685 + 00) was a result of excessive vehicle entry speeds. Only two encroachments have occurred there since an advisory speed sign was installed on the ramp in November 1962 (Fig. 21).

Excessive vehicle entry speeds were only partially responsible for the ten encroachments near the entrance ramp at the west end of the study section (station 420 + 00). The overpass structure (station 431 + 00) and roadside sign (station 445 + 00) immediately downstream from the ramp are believed to be equally important, if not controlling factors at this location. Consequently, no special effort has been made to control vehicle speeds on this entrance ramp.

Grade Separation Structures

Within the 24.6-mi study section there are 18 grade separation structures which carry state highways and local roads over I74. Four of these are at the diamond interchanges. These 18 structures serve as windbreaks, the effects of which can be seen in the encroachment distribution (Fig. 19).

For an assumed area of influence extending 800 ft upstream from each structure, the combined length of influence area for all 18 grade separation structures is 11.1 percent of the length of the study section. This area of influence contains 16.2 percent of the encroachments originating from the westbound traffic stream and only 8.7 percent of the encroachments originating from the eastbound traffic stream. This is evidence of the effect of prevailing west wind as discussed in connection with weather.

Figure 21. Westbound entrance ramp to 174 near Danville, Illinois.

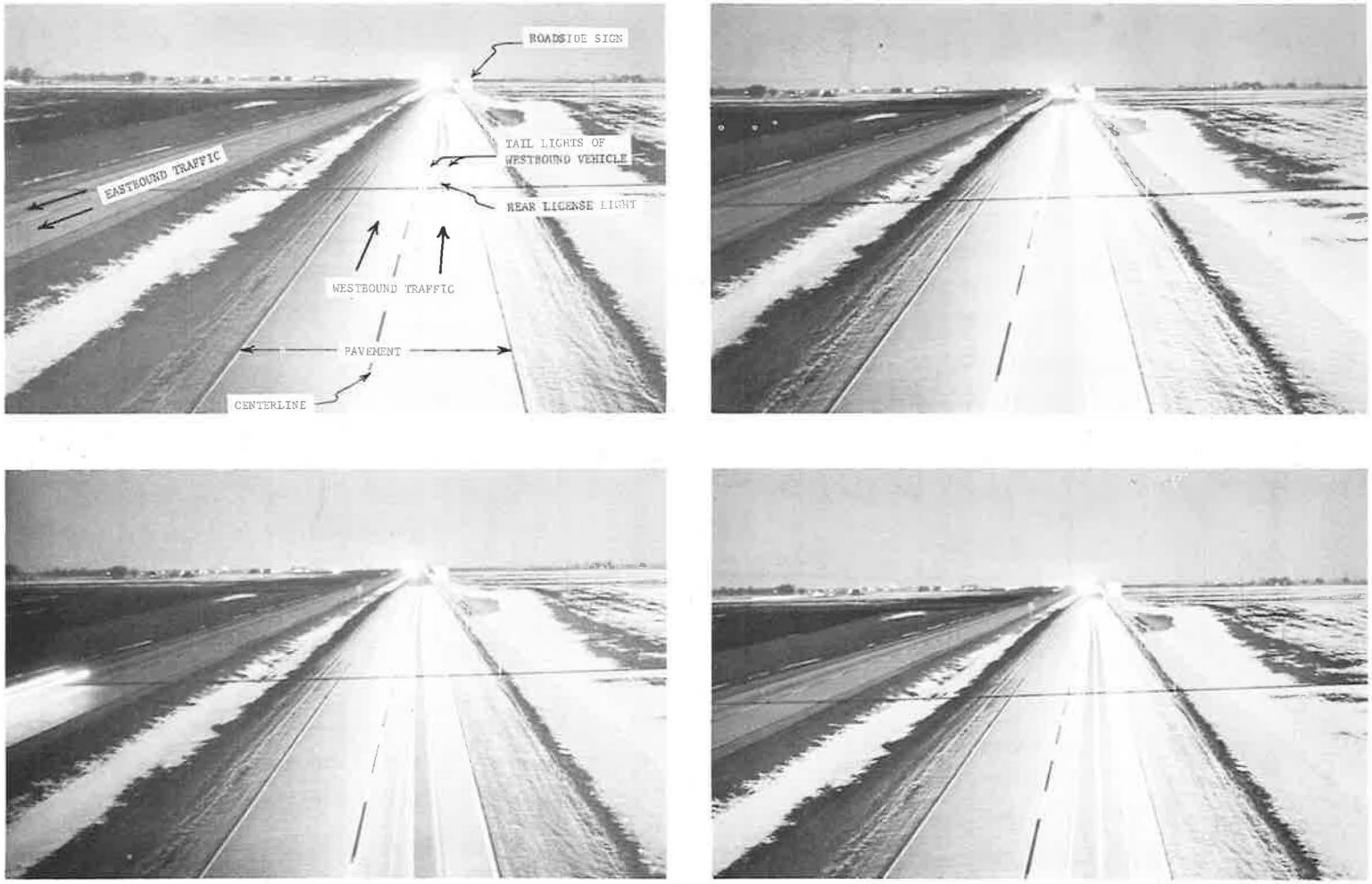

Figure 22. Time exposure of tall lights of individual westbound cars immediately west of grade separation structure at station 1241 + 00, showing how drivers veer away from large roadside sign in background.

TABLE 5

OBSERVATIONS OF VEHICLE BEHAVIOR AT ROADSIDE SIGN

Date	Method	Number of Vehicles Observed	Number Shifting to Left	Percent
11/9/63	Manual observer	50	13	26
2/7/64	Photographic	10	5	50
2/22/64	Photographic	32	10	31
	Total	92	28	30

If this same analysis is made for 800 ft downwind (from the prevailing west wind) areas of influence at each grade separation structure, the distribution becomes more nearly the same for both directions of travel. The combined influence areas contain 16.2 percent of encroachments originating from the westbound traffic stream and 13.4 percent of encroachments originating from the eastbound traffic stream.

Grade separation structures serve as windbreaks which cause erratic vehicle movements on the pavement downwind from the structures. Encroachments result only when these erratic vehicle movements occur in combination with other conditions such as driver inattentiveness, poor visibility and wet, icy or snow-covered pavement surface. The combinations of conditions necessary for encroachments rarely occur, but erratic vehicle movements can be observed downwind from the structures on any windy day.

Roadside Signs

Erratic vehicle movements on the pavement were also observed in the vicinity of large roadside signs. Vehicles apparently veer away from the signs as illustrated in Figure 22. The sign in Figure 22 faces westbound traffic and serves as a small windbreak for vehicles heading into the prevailing west wind. The absence of a heavy accumulation of snow on the roadside immediately downwind from the sign indicates the area of greatest air turbulence. The beginning of most erratic vehicle movements coincides with the downwind limits of this area of high air turbulence.

Three series of observations were made at the location shown in Figure 22. The results (Table 5) show that slightly over 30 percent of the vehicles shifted to the left in the vicinity of the sign. Lateral movements normally ranged from 2 to 4 ft, with the maximum lateral movement usually occurring about 500 ft upstream from the sign. However, some vehicles changed lanes, from right to left, in the vicinity of the sign and subsequently returned to the right-hand lane. Others shifted to the left at a considerably greater distance upstream from the sign, beyond the limits of the area affected by high air turbulence.

Six encroachments in the vicinity of this sign (station 1225 + 00) were probably influenced by such erratic vehicle movements on the pavement. Many other small concentrations of encroachments are associated with roadside signs throughout the length of the study section for both directions of travel. However, the greatest effect occurs where a roadside sign is located about 1,500 ft downstream from a grade separation structure.

One such location, immediately downstream from the entrance ramp at the west end of the study section, was discussed in connection with the effects of interchange ramps. Six of the first nine encroachments downstream from this entrance ramp were probably influenced by the roadside sign at station 445 + 00. A grade separation structure occurs just upstream from this sign, but it is far enough upstream that its effect as a wind-break could not have been responsible for encroachments near the sign. The abutment of the structure hides the sign from the driver's view until he is within about

2,500 ft of the sign. Then, as the sign begins to appear within the landscape viewed by the driver, it gives a subtle impression of having moved out toward the roadway from behind the abutment. This does not seem to make a conscious impression on the driver; all test drivers who were rightfully accused of having shifted to the left either emphatically denied it or claimed that they were not aware of having done so in the vicinity of the sign. Some were unsuspecting members of the research project staff who were aware of this phenomenon, but who were driving over the study section for other reasons.

Current practice with regard to placement of roadside signs should be reviewed in the light of these observations. Large roadside signs should be located as far downstream from overpass structures as is practical. Smaller signs, such as the ones giving distances to various cities, appear to have considerably less effect on driver-vehicle behavior.

Curves

Of the seven horizontal curves wholly within the study section, so many are accompanied by large roadside signs that the effects of the curves and signs cannot be separated.

Nevertheless, roadside signs appear to have some effect on the frequency of encroachment in the vicinity of horizontal curves. If the two long curves near station 1100 + 00 are compared, it can be seen that about 2½ times more encroachments occurred at the curve accompanied by large roadside signs.

A similar difference in numbers of encroachments is noted when the relatively short curve, with a large sign, at station 1560 + 00 is compared with the other three curves of similar length that are not accompanied by large roadside signs, stations 630 + 00, 960 + 00 and 1360 + 00. Curves and the approaches to curves should be avoided as locations for large roadside signs.

Curves, per se, do not appear to have been important factors affecting encroachment frequency. For an assumed area of influence extending from the beginning of each curve to a point 500 ft downstream from the end of each curve, the combined length of influence area for all curves represents 15.1 percent of the mileage of the test section, within which 15.1 percent of the encroachments occurred. Without the effects of roadside signs, the curves might possibly have been the safest sections of roadway.

Curves without roadside signs appear to be in areas where encroachments are thinly scattered, especially the areas from station 600 + 00 through 685 + 00 and from station 1330 + 00 through 1375 + 00.

Terrain Features

Several of the other areas with thinly scattered encroachments are upstream from groves of trees that serve as dominant terrain features and delineate roadway alignment. Two examples, in connection with the eastbound traffic stream, are the areas from station 650 + 00 through 775 + 00 and from station 1250 + 00 through 1350 + 00. The areas from station 1450 + 00 through 1410 + 00 and from station 790 + 00 through 740 + 00 are similar examples for the westbound traffic stream.

Roadside clumps of trees seem to be beneficial as roadway delineators. However, the concentrations of encroachments downstream from some of these locations must not be overlooked.

When particularly thick clumps of tall trees are encountered, such as at stations 740 + 00 and 1610 + 00, the downstream windbreak effect largely offsets the upstream delineation benefits and there is not net reduction in encroachments. Consideration should be given to the need for thinning and/or pruning trees outside the limits of the highway right-of-way. Particular attention should also be given to landscaping grade separation structures with types of plantings that will not accentuate the windbreak effects of the structures.

In view of the many different highway, driver and vehicle variables that may be assumed to cause or inhibit encroachments, it is not possible to assign a specific cause of any given concentration of encroachments. The foregoing discussion merely emphasizes those features of the driving environment which were most often associated

with encroachments. In some cases it appears as though an adjustment of features would be both desirable and practicable.

CONCLUSIONS AND RECOMMENDATIONS

Curves, the approaches to curves and the areas immediately downstream from grade separation structures should be avoided as locations for large roadside signs; the safety benefits that might accrue from the use of overhead signs in lieu of roadside signs should be thoroughly investigated.

More emphasis should be placed on landscape planting to improve delineation of roadway alignment; attention should be given to control of the windbreak effects of all roadside plantings, both inside and outside the right-of-way limits.

The windbreak effects of grade separation structures should be considered in connection with the other factors controlling the number and location of such structures; landscape planting, structure modifications and other possible means of controlling these windbreak effects should be thoroughly investigated.

Because of the wide range of lateral and longitudinal travel distances components of vehicles must be taken into account in the design of median barriers to achieve safe vehicle deceleration rates. Angles do not provide a reliable basis for prediction of lateral velocity components of vehicles at any appreciable distance from the pavement edge.

Consideration should be given to the design of flatter median cross slopes as a means of (a) decreasing the maximum lateral extent of movement of encroaching vehicles, and (b) decreasing the frequency of erratic vehicle reentry to the traffic stream.

Obstacles commonly built into the median, in the form of culvert headwalls, drainage inlet structures, earthen ditch checks and crossover embankments, place a serious limitation on the value of the median as a safe vehicle stopping or recovery space. The median appurtenances represented by these obstacles should be decreased to the smallest practical number and designed so as to present the least possible hazard to the passage of vehicles encroaching upon the median at normal highway operating speeds.

A 30-ft width of obstacle-free median with mild cross slopes (24:1 for a 30-ft median width and steeper allowable slopes for greater median widths) appears to be the absolute minimum requirement for safe stopping or control of vehicles encroaching on medians at rural highway operating speeds. This provides no more than a minimum reasonable chance for escape from the median, under control, without crossing into the opposing traffic stream.

This minimum width should always be exceeded in the design of new rural highway facilities because, as indicated in Figures 7 and 8, the average severity of vehicle encroachment increases with traffic volume. Consideration must also be given to the additional median width needed for economical highway drainage design and for the plantings, glare screens or horizontal separation of roadways that will reduce headlight glare to tolerable levels. A desirable median width of more than twice the 30-ft minimum is therefore not unreasonable.

When, for reasons of economy, the above absolute minimum median width cannot be provided, the installation of suitable median barriers, on the basis of suggested traffic volume warrants (6), should be considered.

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