DRIVER BEHAVIOR AND ITS RELATION TO FREEWAY ENTRANCE RAMP DESIGN

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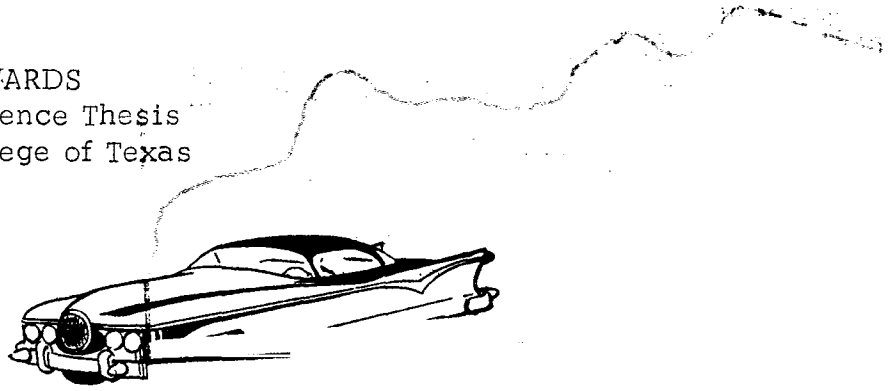
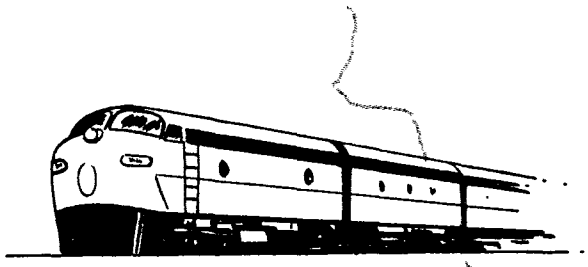
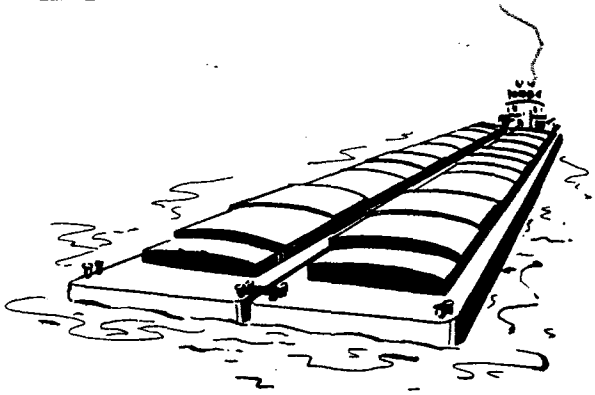


Research Results from a Portion of
Texas Transportation Institute
Research Project RP-16





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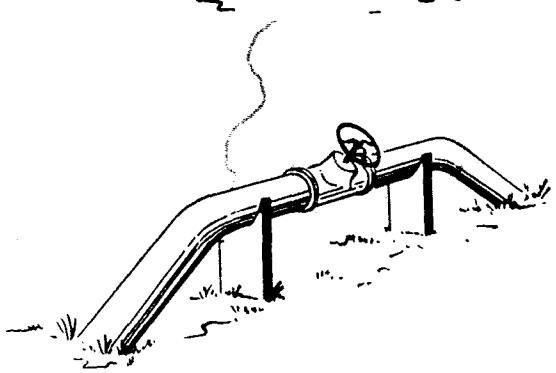

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SYNOPSIS

The study of freeway entrance design has received considerable attention during the past few years. In attempting to provide some of the answers to the problem of freeway entrance ramp operation, research studies have been focused primarily toward the study of vehicle maneuvers. This research, though providing much needed data, has indicated how the facility is being utilized through vehicle maneuvers and has failed to reflect the actual behavior of the driver. Preliminary investigations have indicated that many of the operational problems encountered at freeway entrances are the direct result of undesirable behavior on the part of the entering driver, and deviations from the intended use of the facility.

This paper presents a portion of the results of a research project "Ramps and Interchanges" which was conducted by the Texas Transportation Institute for the Texas Highway Department. This phase of the project was designed to investigate driver behavior on freeway entrance ramps under operational conditions.

The field data were gathered through the use of motion picture studies which utilized a dual camera technique. One 16 mm camera, equipped with a six inch telephoto lens, was positioned on an elevated vantage point across the freeway from the ramp being studied and was

used to record the actions of the individual drivers as they entered the freeway. The second 16 mm camera, mounted on an elevated vantage point in advance of the ramp, was used to record data on the overall operation of the freeway and entrance ramp. Two separate studies were conducted, one at an entrance ramp location on the Gulf Freeway in Houston, Texas, and the other at an entrance ramp location on a freeway in San Antonio, Texas. Both peak and off-peak conditions were recorded.

The analysis of the data revealed some significant results which point out the increasing need for freeway designers to consider driver behavior in the design of freeway entrances.

INTRODUCTION

Entering a high speed, high volume freeway is a very difficult and complex driving maneuver requiring of the driver a series of rapid decisions. As he approaches and enters the freeway the ramp driver must evaluate the traffic stream, select or reject a gap in that traffic stream, and then adjust his speed accordingly. At the same time he must devote his attention to vehicles both in front of him and behind him on the ramp approach. Thus, through the nature of its use, entrance ramp design is one of the most complex problems facing freeway designers.

It has been stated that more time has been spent in designing access facilities to freeways than any other single item (1). Today, however, serious operational difficulties are being encountered on many entrance ramps. Preliminary observations have indicated that many of these operational difficulties are the result of undesirable behavior on the part of the entering drivers. This improper operation, reflected by entrance speeds, paths of entry, accidents, and ramp stoppages, indicates the need for improving entrance ramp efficiency.

Each designer provides for and assumes a certain type of operation in each of his designs. This assumption, however, in no way assures the designer that the drivers will use the facility as intended. For example, in the modern concepts of design, acceleration lanes are provided

1. All references will be found in the Bibliography.

as an integral part of many freeway entrance ramps. It has been observed however, that many of the drivers, rather than turn onto the acceleration lane and move into the freeway traffic stream, as intended by the designer, stop at the freeway entrance and wait for a large enough gap in the freeway traffic stream to permit a direct entry. This type of behavior on the part of the entering driver results in undesirable operation. As a result, highway designers must recognize the fact that there is often a distinct difference between operation assumed in design and the manner in which traffic actually performs on a facility.

In attempting to provide some of the answers to the problem of freeway entrance ramp operation, research studies in the past have been directed primarily toward the study of vehicle behavior. This research, though providing much needed data, has indicated how the facility is being utilized through vehicle maneuvers and has failed to reflect the actual behavior of the driver. A thorough search of literature yielded no previously reported research specifically aimed at the study of the driver and his actions on freeway entrance ramps under operational conditions.

PREVIOUS INVESTIGATIONS

The subject of driver behavior and its importance in efficient highway operation is not new. The late Thomas H. McDonald, Commissioner United States Public Roads Administration, recognized the importance of driver behavior a number of years ago. In an address before the Washington, D. C. Section of the Society of Automotive Engineers in 1948, Mr. McDonald stated, "We have reached the point in our knowledge of the manner in which highways are used by the mass of traffic to co-ordinate driver behavior under prevailing traffic conditions, and the geometric details of highway design. The degree to which the criteria so determined are accepted and intelligently applied in practice will determine the degree of safe efficiency of our future highways" (2).

In recent years this fact has again been brought to light with its possible application to freeway entrance ramp evaluation.

A number of investigations have pointed out the need and the possibility of improving entrance ramp operation. Terry J. Owens, Urban Highway Engineer with the Automotive Safety Foundation, stated that, "Experience to date would seem to indicate that little can be added to the safety and efficiency of freeways by basic design changes. Future gains must come from operational improvements. To be sure, some gain may be expected from refinement in design of roadways and ramps" (3). This need for operational improvements is reflected not only in ramp

operation but in freeway operation as well. As reported by Keese, Pinnell, and McCasland in "A Study of Freeway Traffic Operation," "The interference of ramp traffic caused reductions in speed, momentary stoppages, and stop-and-go operation during peak flow periods of both studies. Traffic flow during the studies made with the ramp closed was quite smooth and uniform with slightly higher speeds" (4). They further reported, "Many operational difficulties on the freeways studied were found to be directly associated with the entrance ramps."

Studies of accidents at freeway entrances also verify the need for operational improvements. Studies on the North Central Expressway (freeway) in Dallas showed 21.5 per cent of the total accidents on the expressway involved entering vehicles (5). Studies in California also indicated that ramp connections on high-volume freeways were a source of a substantial portion of the total accidents (6).

Considering the above, it appears that some refinement in our present entrance ramp design practices to insure proper operation is not only possible but extremely desirable. It is believed that this need for refinement is created by the lack of information regarding actual driver behavior under operational conditions.

In a published summary of current research and the apparent trend which has been established for future investigations, it was noted that studies of driver behavior are being translated to design criteria to produce highway features which fit the apparent behavior and desires of

the drivers, reflecting ease, comfort and safety of operation (7). When the results of driver behavior studies are available, highway designers will be able to make a more critical evaluation of present design practices and possibly improve entrance ramp efficiency by incorporating some of the findings of these studies.

OBJECTIVES

In view of the apparent fact that no research had previously been undertaken in this specific area, the objectives of the driver behavior research were two-fold:

1. Develop a method for studying driver behavior on freeway entrance ramps.
2. Correlate driver behavior with vehicle maneuvers and entrance ramp design.

It was realized at the outset of the study that it would be impossible, within the limitations of the study, to fully evaluate the second objective; however, it was believed that by applying the study technique to two ramps, the feasibility of this approach to design evaluation could be demonstrated.

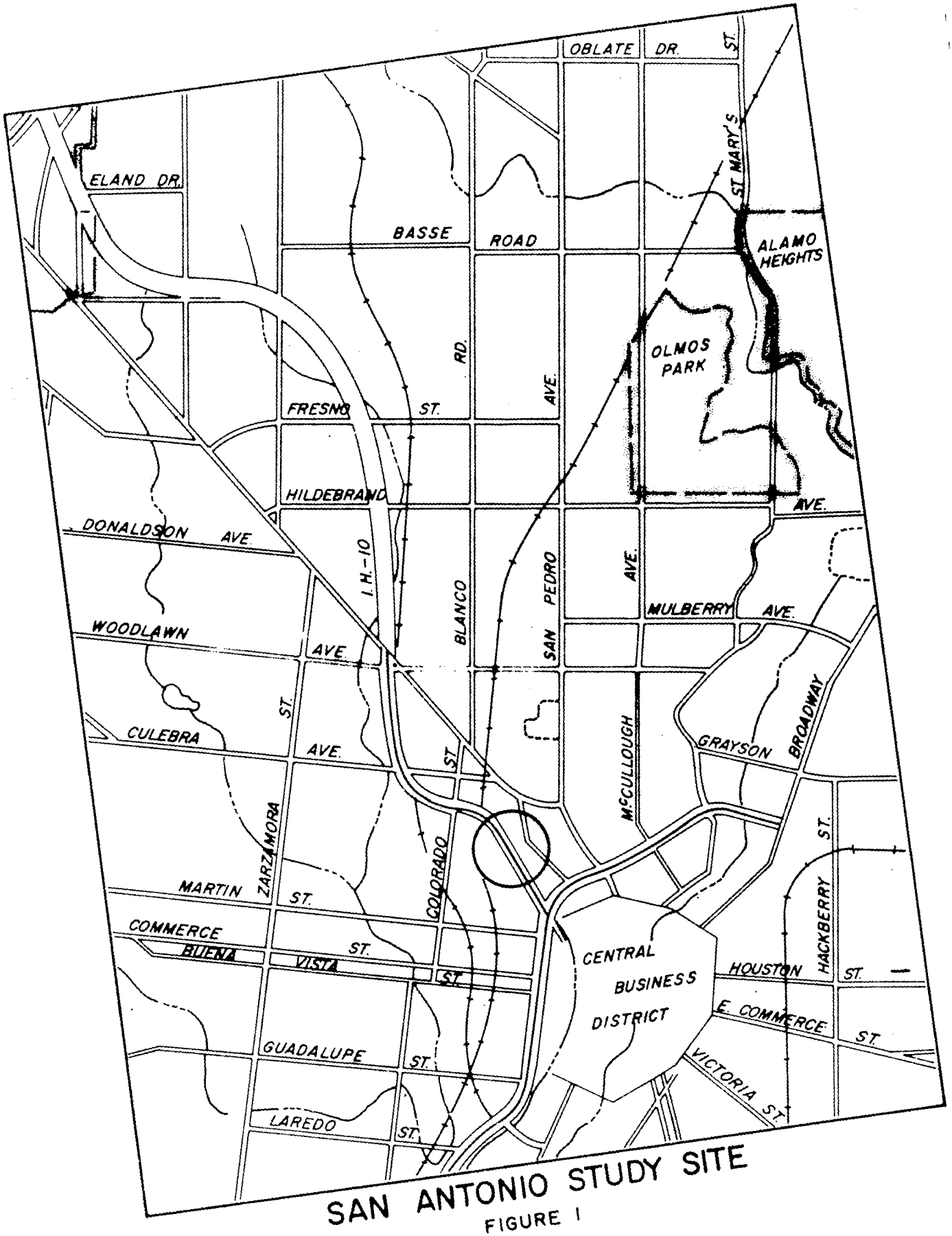
DESCRIPTION OF STUDY SITES

Two different study sites were selected to provide comparison of operation on two ramps of generally similar design. These two ramps one in San Antonio and one in Houston, were selected primarily because they provided about the same sight distance characteristics.

San Antonio Ramp Site

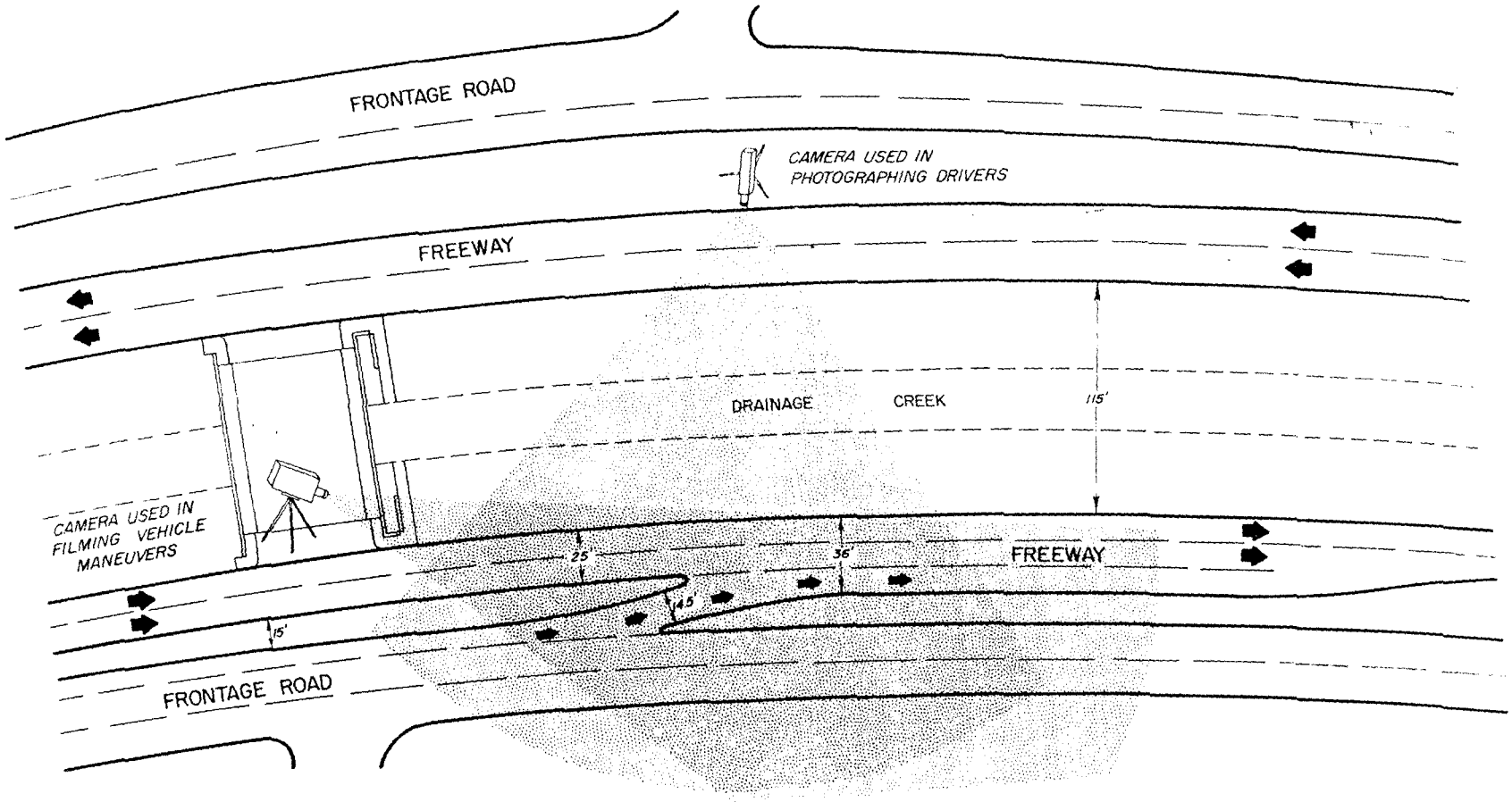
The Marshall Street entrance ramp (outbound) on Interstate Highway 10 was located approximately one mile northwest of the San Antonio Central Business District. The location of the study site is shown in Figure 1. The study section, shown in detail in Figure 2, had the following geometric features:

1. Two 12 foot through lanes in each direction.
2. A 115 foot depressed, barrier-type median.
3. One-way frontage road, 33 feet in width.
4. A 15 foot separation between the freeway traffic lanes and the frontage roads.
5. A short "slip" ramp 25 feet long and 14.5 feet wide, followed by a full width acceleration lane 450 feet in length.
6. Unrestricted sight distance for the ramp drivers for a distance of approximately 650 feet preceding the freeway entrance.
7. Freeway grade line approximately level with the frontage road at the same level.



SAN ANTONIO STUDY SITE

FIGURE 1



DETAIL LAYOUT OF
SAN ANTONIO STUDY LOCATION

FIGURE 2

Houston Ramp Site

The second ramp selected for study was the out-bound Griggs Road entrance ramp south of Houston. This ramp is located approximately one mile south of the central business district on U. S. 75 or the Gulf Freeway (Figure 3).

The study section, shown in Figure 4, had the following geometric features:

1. Three 12 foot through lanes in each direction.
2. A four foot paved barrier median.
3. One-way frontage roads, 32 feet in width.
4. A 50-foot separation between the freeway traffic lanes and the frontage roads.
5. An entrance ramp 13.5 feet wide and 205 feet in length, followed by a full width acceleration lane 560 feet in length.
6. Unrestricted sight distance for the ramp drivers for a distance of approximately 1400 feet preceding the freeway entrance.
7. Freeway grade line approximately level with the frontage road at the same level.

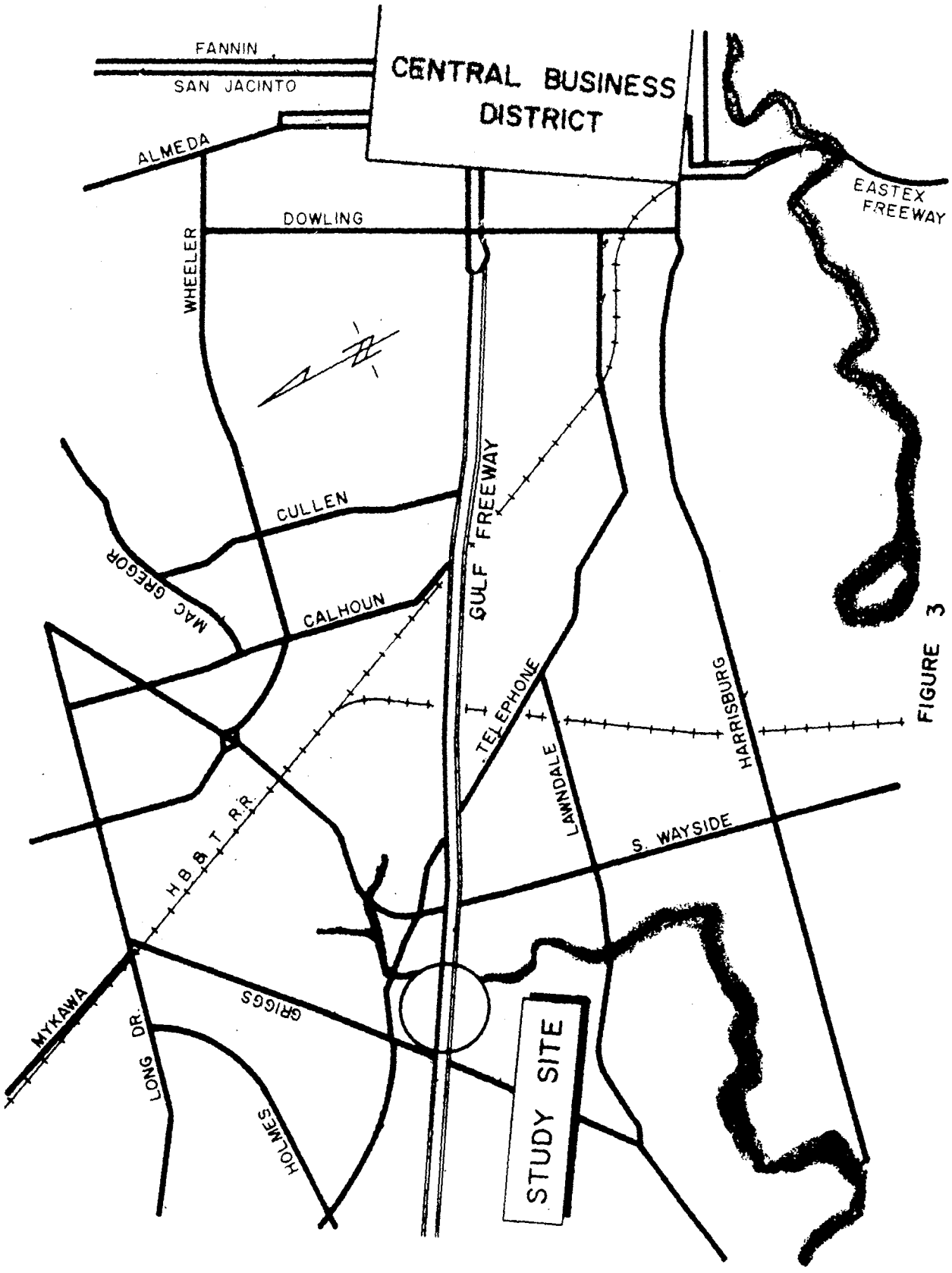
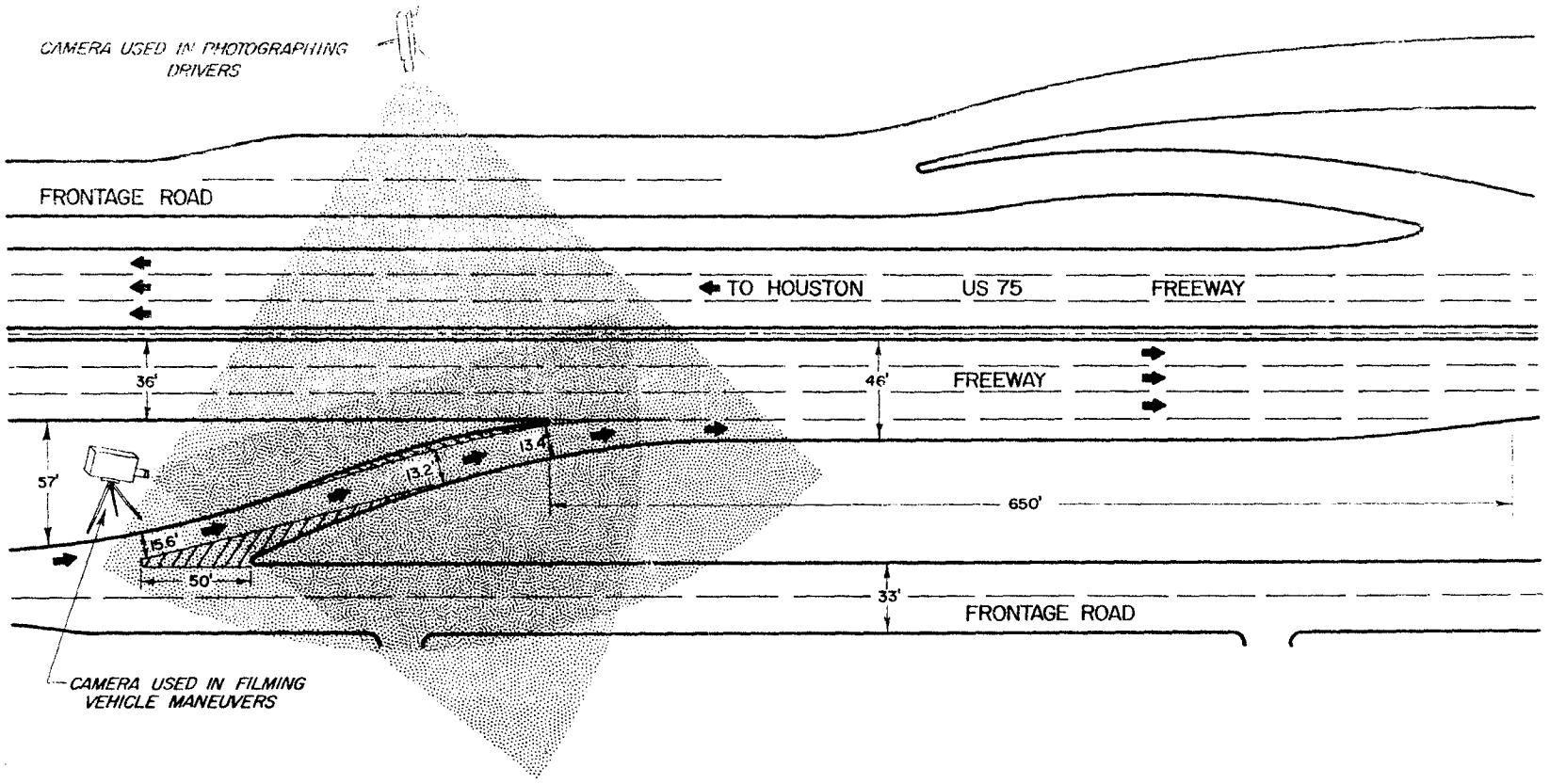

FANNIN
SAN JACINTO
CENTRAL BUSINESS DISTRICT
ALMEDA
EASTEX FREEWAY
DOWLING
WHEELER
GULF FREEWAY
CULLEN
MAC GREGOR
CALHOUN
TELEPHONE
HARRISBURG
LAWNDALE
S. WAYSIDE
H B & T R.R.
MYKAWA
LONG DR.
GRIGGS
HOLMES
STUDY SITE

FIGURE 3



DETAIL LAYOUT OF
HOUSTON STUDY LOCATION

FIGURE 4

STUDY PROCEDURE

It has been found in previous research that because of two complex factors - traffic maneuvers and the inter-relationship between various design features and traffic maneuvers - it was impossible to gather sufficient data for analysis from on-the-spot observation and manual tabulations (8). After consideration of various methods of obtaining data on the operational characteristics of freeway ramp traffic, the motion picture method of study was selected as the best for providing the simultaneous evaluation of the complex operational characteristics of traffic within the study area. In addition, the motion pictures provided the possibility of re-study of specific traffic conditions recorded on film.

In order to record the driver's actions as well as vehicle maneuvers, two cameras were positioned within the study area. One camera was positioned on a vantage point across the freeway in such a manner as to record the actions of the ramp driver as he approached and entered the freeway. The second camera was positioned above and in advance of the entrance ramp in such a position that traffic operation on both the ramp and the freeway were recorded. By this dual camera procedure it was possible to study simultaneously the actions of the driver and the maneuvers of his vehicle as he entered the freeway. Studies included both peak and off-peak conditions for the average weekday.

Driver Behavior

In the study of the driver's actions and behavior, the primary objective was to determine the manner and the location on the ramp at which the drivers were evaluating freeway traffic conditions. The camera used to record the actions of the drivers was equipped with a six inch telescopic lens and was located in such a position to provide continuous filming of the ramp driver throughout the course of the ramp maneuver. The location of the camera and the field of view are shown in Figures 2 and 4. A sequence of pictures reproduced from these movies is shown in Figures 5 and 6.

The filming of the entering drivers was done from a vantage point of approximately 35 feet in height, at a distance of approximately 225 feet from the ramp. It was necessary to film from this distance to minimize any distraction to the drivers caused by the camera set-up. A careful study of the drivers' actions indicated that distractions due to the filming operation were negligible.

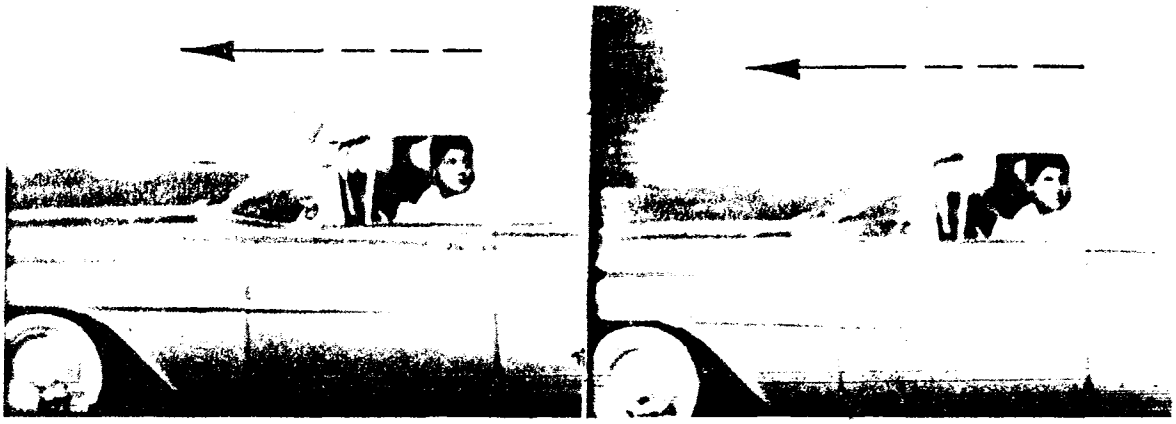
The driver behavior movies were taken at a speed of 24 frames per second using a 16 mm camera. The camera was equipped with a 400 foot magazine and was driven by a constant speed motor (Figure 7). The six inch f4.6 lens used in the filming gave the desired view of the driver and at the same time provided a large enough field of view to positively identify the vehicle.

5-A 5-B

5-C 5-D

TYPICAL BEHAVIOR OF DRIVER
CLASSIFIED AS "NON-OBSERVER"

FIGURE 5

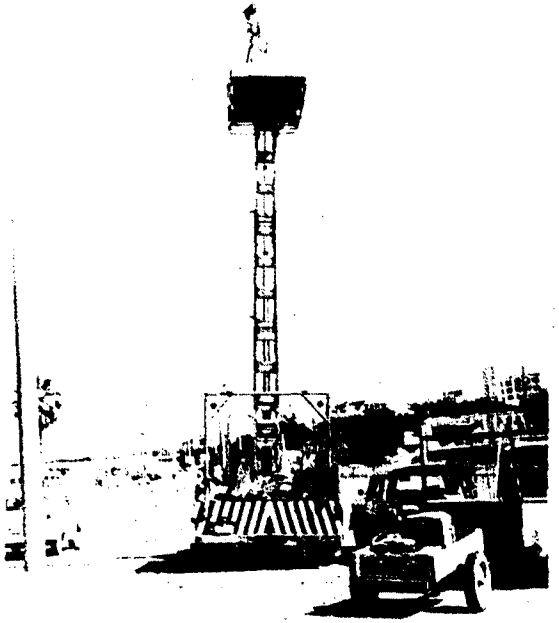


6-A 6-B

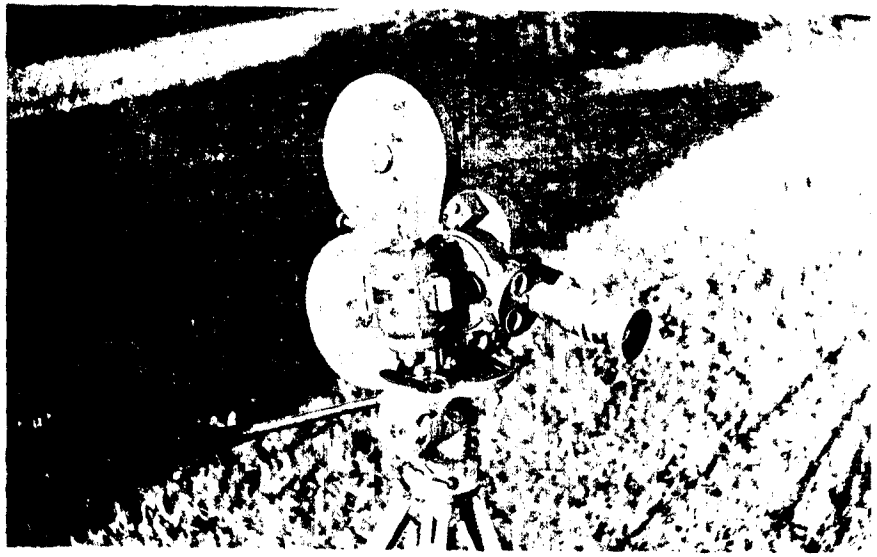
6-C 6-D

TYPICAL BEHAVIOR OF DRIVER
CLASSIFIED AS "AN OBSERVER"

FIGURE 6



PLATFORM TRUCK USED IN
DRIVER BEHAVIOR STUDY



CAMERA USED IN DRIVER
BEHAVIOR STUDY

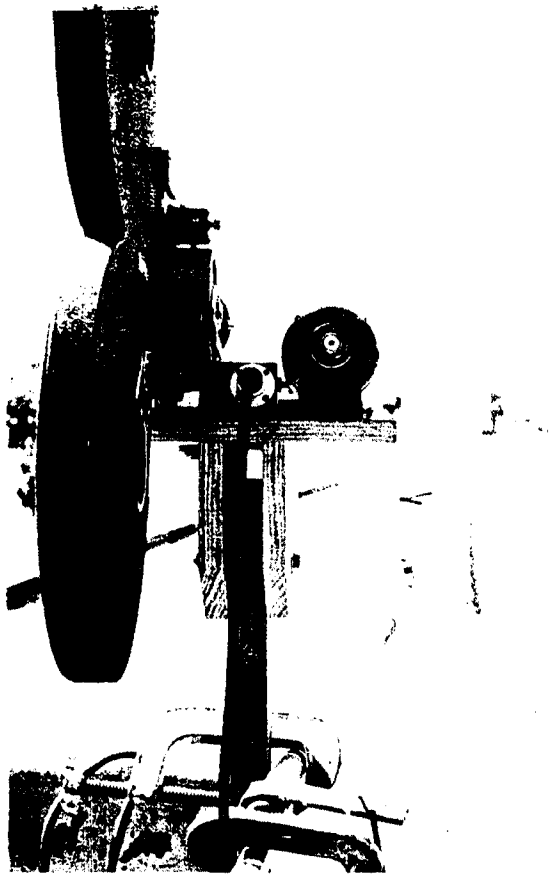
FIGURE 7

In order to determine the locations on the ramp at which the drivers were evaluating freeway traffic conditions, the entrance ramp was divided into a number of sections. This was accomplished by white posts, approximately five feet in height with black horizontal stripes; positioned along the far side of the ramp. By this method it was possible to fix the driver's position on the ramp at any time.

Because of the differential in light conditions between the interior and the exterior of the vehicle, considerable difficulty was experienced in filming the driver. The problem was intensified due to the fact that with air conditioned vehicles light is reflected on the raised window. After a number of tests, in which various camera speeds, coupled with various filters were used, an acceptable filming method was devised. By carefully selecting the location for the camera and exposing for outside light conditions, pictures of the desired quality were obtained.

Vehicle Maneuvers

The second camera used to photograph the study vehicle as it approached and entered the freeway was positioned on a vantage point above and in advance of the entrance ramp. The field of view as shown in Figures 2 and 4 provided an overall view of the study area including both the ramp and freeway. This permitted a continuous elevation of freeway traffic conditions as the ramp driver approached and entered the freeway. This 16 mm camera, shown in Figure 8, was driven by a constant speed motor at a speed of ten frames per second.



BACK-UP CAMERA
(A)

LIFT TRUCK USED FOR
BACK-UP CAMERA
(B)

FIGURE 8

The determination of the vehicle characteristics (paths of entry and entry speeds) was made possible by positioning reference markers at predetermined locations on the entrance ramp and the acceleration lane. These reference markers were placed on the pavement prior to the study using cloth strips approximately two feet in width and twelve feet in length. With these reference markers in place, a few feet of film were taken and the cloth strips then removed. This procedure eliminated any added distraction to the entering drivers during the study and at the same time provided a means whereby a clear plastic template could be made to overlay the special time-motion projector screen used in the analysis of the film.

A 12-inch electric clock with a sweep second hand was so mounted as to be visible in the unused portion of each frame of the film. The clock was driven by the same power source used to drive the camera motor. By timing the clock with a stop watch an excellent check of the camera speed was obtained. In addition, the clock was used in coordinating volume-time relations.

FILM ANALYSIS

In extracting the needed data from the study film, use was made of the special time-motion projector shown in Figure 9. This projector was capable of still or single frame viewing as well as increased speeds to simulate actual traffic conditions. The projector was equipped with a frame counter and finger tip controls (forward and reverse) which permitted manipulation of the individual frames of the film for such specific vehicle data as speeds and paths of entry. Film warping due to lantern heat was controlled by an internal fan and glass plates which fixed the film in place for accurate viewing.

The data were divided into two sections, driver behavior and vehicle maneuvers. These sections included detailed studies of driver classification, freeway evaluation area, paths of entry, freeway entrance speeds and ramp stoppages. In obtaining these data, the following information was tabulated for each driver:

1. Driver Classification.

   Each driver was classified as either "an observer" or "a non-observer. These classifications were based on the movement of the driver's head as he or she entered the freeway. If the driver turned his head less than 90 degrees in evaluating freeway traffic conditions he was classified as a "non-observer" (Figure 5). If the driver turned his head 90 degrees or more in

TIME MOTION STUDY PROJECTOR USED
IN ANALYSIS OF MOTION PICTURES

FIGURE 9

evaluating freeway traffic conditions, he was classified as "an observer (Figure 6). This classification presented no problem as it was observed that if the driver turned his head to evaluate freeway traffic conditions the movement of the head was usually in excess of 90 degrees.

2. Vehicle Identification

This involved recording the make and model of each vehicle studied. This information was necessary in order to provide a positive means of identifying the vehicle when correlating vehicle maneuvers with driver behavior.

3. Freeway Evaluation Area

As previously stated, the entrance ramp was divided into a number of sections by the use of position markers. This provided a means whereby it was possible to fix the driver's position on the ramp at all times. The freeway evaluation area was considered to be the area in which the driver's head was first turned 90 degrees in evaluating freeway conditions. If after such an evaluation the driver resumed a normal driving position and in order to re-evaluate freeway conditions he again turned his head 90 degrees or more, both evaluations were recorded.

4. Condition of Entry

The manner in which a driver enters a freeway is, of course, influenced by the presence of other vehicles on the ramp approach.

It was therefore necessary to classify each vehicle being studied as to the conditions under which it entered the freeway. Three major classifications were used: alone, leading and trailing. In addition, it was decided to further classify the vehicles as to the type of entry. This classification was based on whether the driver stopped prior to entering the freeway.

5. Vehicle Entry Speeds and Paths of Entry

It was believed in the early stages of the study that the area in which a driver evaluated freeway traffic conditions would be reflected in both his speed of entry and his path of entry onto the freeway. Therefore, the entry speed and the path of entry for each study vehicle were computed. The entry speed was considered to be the vehicle's average speed as it entered the freeway. The path of entry was based on the entry of the vehicle's left front wheel and the right rear wheel onto the freeway.

ANALYSIS OF DATA

The analysis of the data taken from the study film was divided into two parts corresponding to the two study locations. The data was further separated for each study location as to driver classification, freeway evaluation area, vehicle entry paths, entry speeds and ramp stoppages.

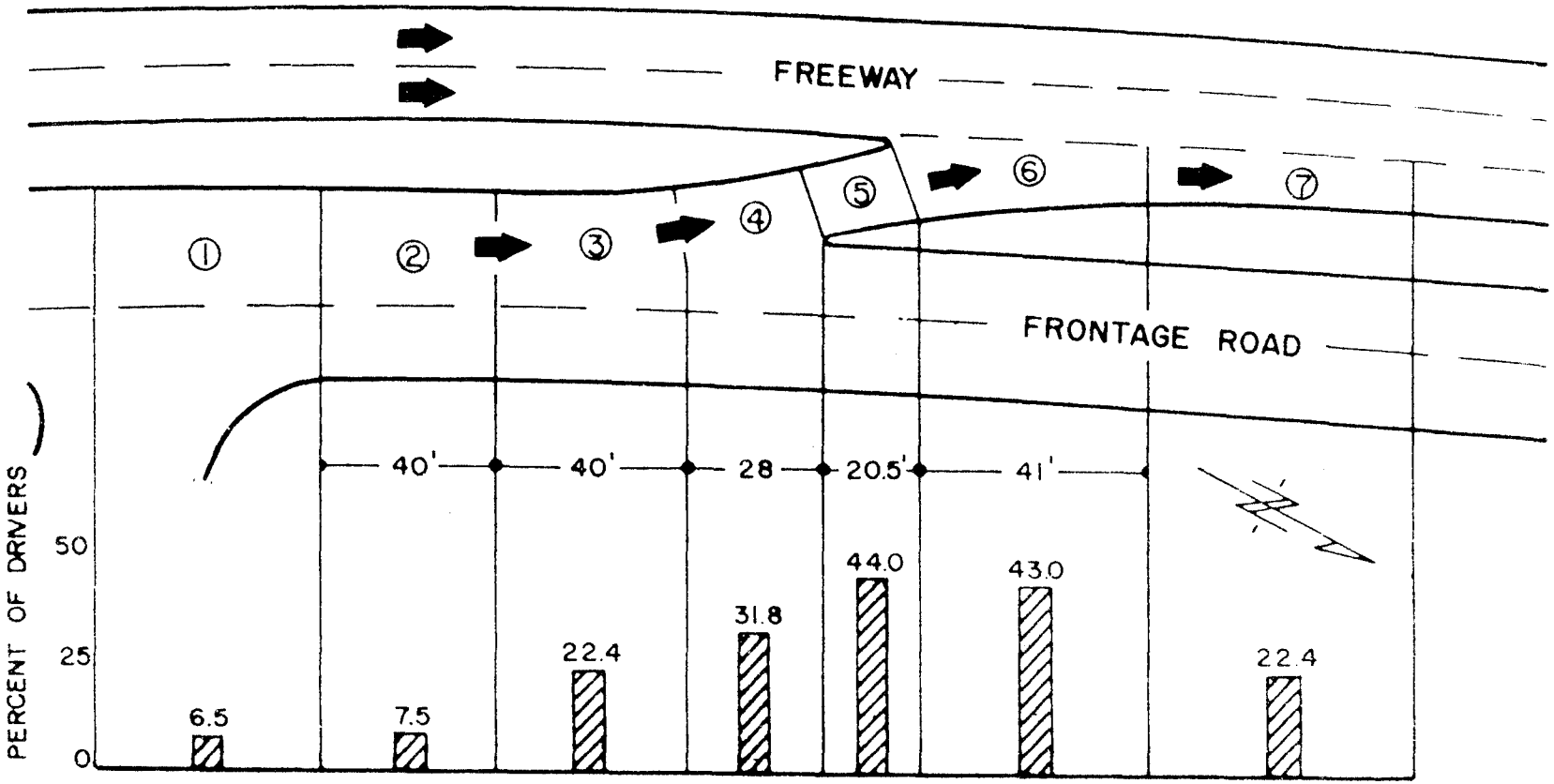
San Antonio Study

Driver Classification

In the San Antonio study, the actions of 180 drivers were recorded on film. Seventy-three of these drivers either entered the freeway by the use of a rear-view mirror or made freeway evaluation prior to entering the study area. These drivers were classified as "non-observers." The remaining 107 drivers, or 59.5 per cent of those studied, turned his or her head in excess of 90 degrees one or more times prior to entering the freeway. These 107 drivers were classified as "observers."

Freeway Evaluation Area

A summary of the areas in which the entering drivers observed freeway traffic conditions is shown in Figure 10. It was found that a large percentage of the drivers made more than one evaluation of the freeway prior to entering. It was also found that in making these freeway evaluations a driver often moved a considerable distance forward while his head was turned 90 degrees or more. The percentages shown in Figure 10 represent the percentage of the 107 drivers who turned to evaluate freeway



COMBINED OBSERVATIONS
SAN ANTONIO STUDY - 107 DRIVERS

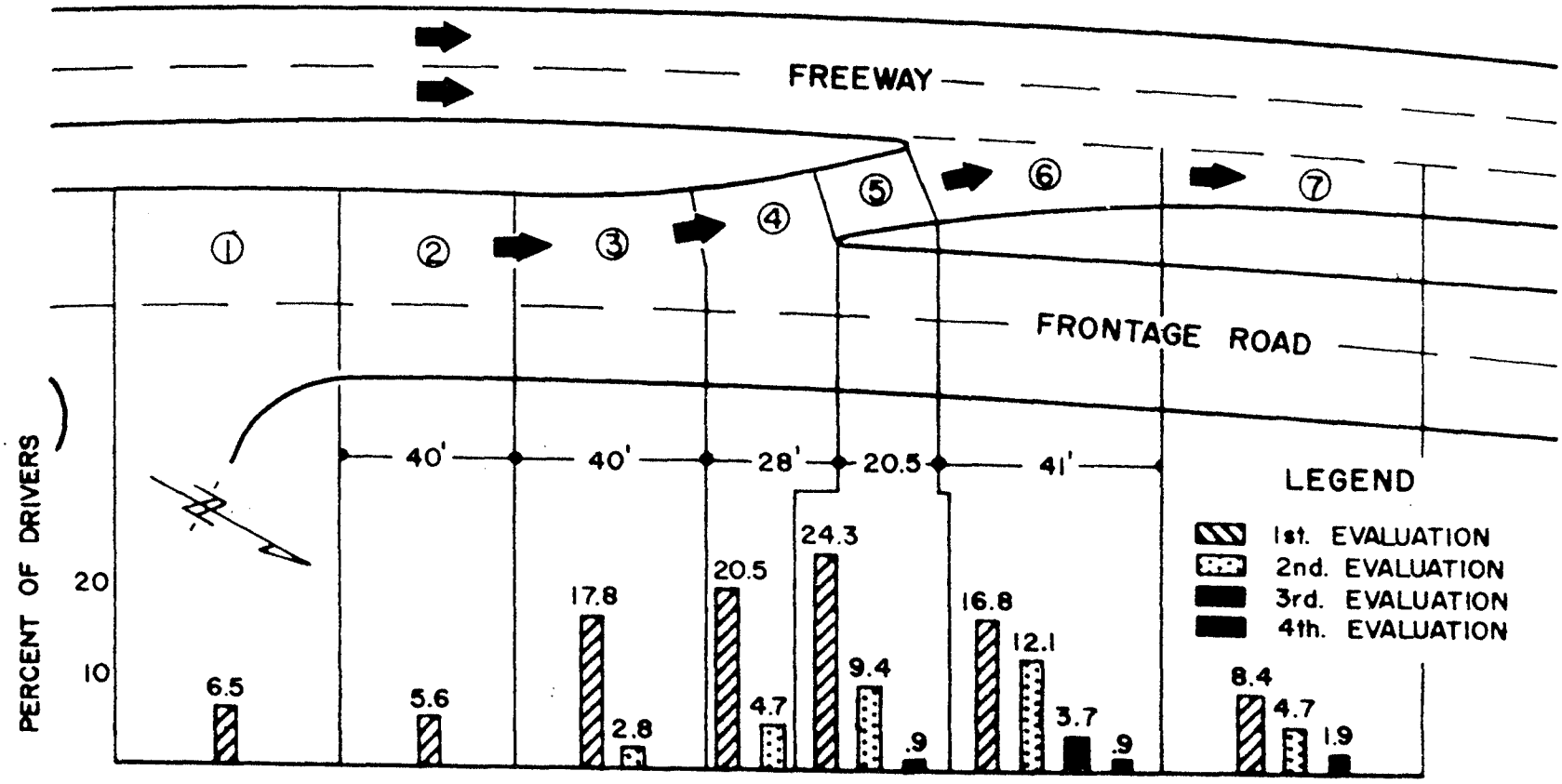
FIGURE 10

conditions on each section of the ramp and those drivers who entered or continued through the section with his or her head turned. For example, drivers were observed to move forward as much as 90 feet while looking backward. In traveling this distance the drivers moved into or through three or more of the ramp sections. Other drivers were observed to make as many as four separate evaluations of freeway conditions. The percentages shown in Figure 10 include both types of entry.

The driver evaluations shown in Figure 10 were further divided as to the first, second, third and fourth evaluations (Figure 11). It is pointed out that the difference in percentages shown in Figures 10 and 11, for corresponding sections, represent those drivers who evaluated freeway conditions in a preceding section and either continued into the section or through the ramp section without resuming a normal driving position.

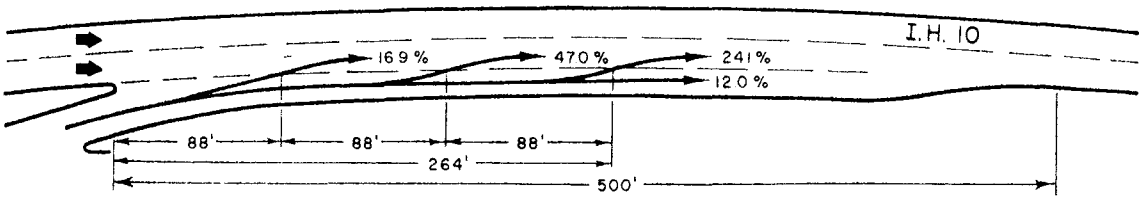
Vehicle Entry Paths

The study of freeway evaluation areas indicates the position on the ramp where the drivers actually evaluated freeway conditions. This driver evaluation area, when associated with paths of entry, entry speeds and stoppages, provides an indication of ramp usage. In this phase of the analysis, the paths of entry of the 180 drivers were grouped according to the areas in which the drivers evaluated the freeway. The paths of entry are shown in Figure 12 for the combined 180 vehicles and are grouped as follows: (a) those 73 drivers classified as "non-observers"; (b) those drivers who evaluated freeway conditions in areas one, two, three or four

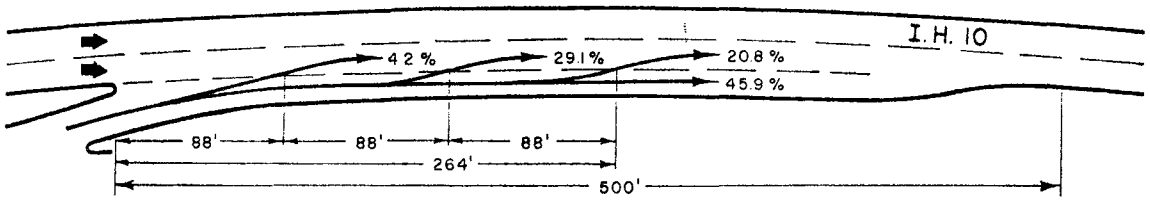


FREEWAY EVALUATION AREAS
SAN ANTONIO STUDY – 107 DRIVERS

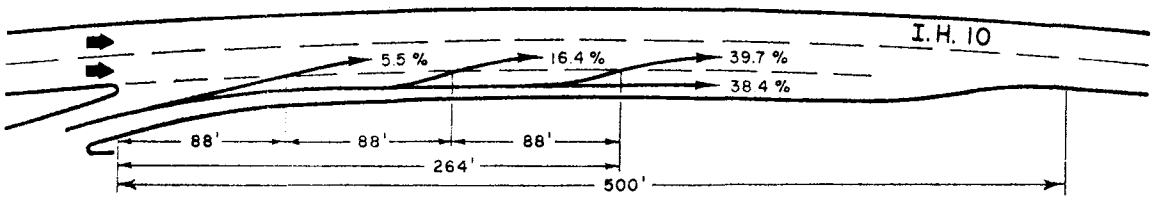
FIGURE 11



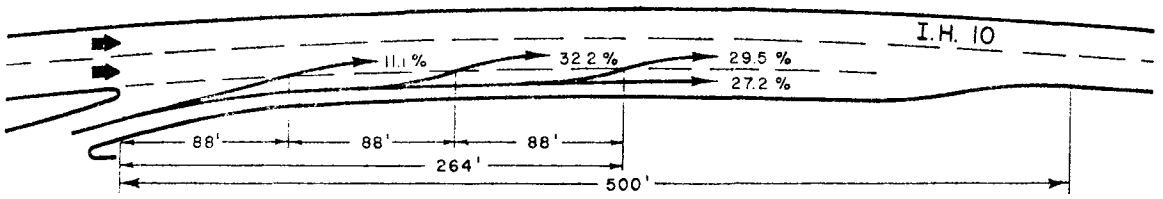
ENTRY PATH OF DRIVERS WHO EVALUATED FREEWAY
IN SECTIONS 5,6, OR 7
83 VEHICLES



ENTRY PATH OF DRIVERS WHO EVALUATED FREEWAY
IN SECTIONS 1,2,3, OR 4
24 VEHICLES



ENTRY PATH OF NON-OBSERVERS
73 VEHICLES



COMBINED ENTRY PATHS
180 VEHICLES

PATH OF ENTRY
SAN ANTONIO STUDY
SAMPLE SIZE 180 VEHICLES

FIGURE 12

[illegible] areas five, six or seven. It can be seen from Figure 12 that 11.1 per cent of the combined sample made a direct entry onto the freeway and 32.2 per cent entered the freeway within the first 176 feet of the acceleration lane. By separating the paths of entry as to the areas in which the drivers evaluated freeway conditions, the results show that drivers who were classified as "non-observers" and those drivers who made early freeway evaluation used a greater length of the acceleration lane than did those drivers who evaluated freeway conditions in the vicinity of the ramp nose.

Entry Speeds

An additional analysis was made to determine the effect of freeway evaluation area on entry speeds. It was found that drivers classified as "non-observers" entered the freeway with an average speed of 41.7 miles per hour whereas those drivers evaluating freeway conditions in areas one, two, three or four had an average entry speed of 39.6 miles per hour. Drivers evaluating freeway conditions in areas five, six or seven had an average entry speed of 32.2 miles per hour. Only those drivers previously classified as alone or leading were considered.

Ramp Stoppages

Seven drivers or 16 per cent of those previously classified as alone or leading, stopped at the ramp nose prior to entering the freeway. These drivers stopped to make freeway evaluations rather than turn onto the

acceleration lane as intended by the designer. After stopping, five of the seven drivers waited for a large enough gap in the freeway traffic stream to permit a direct entry onto the freeway.

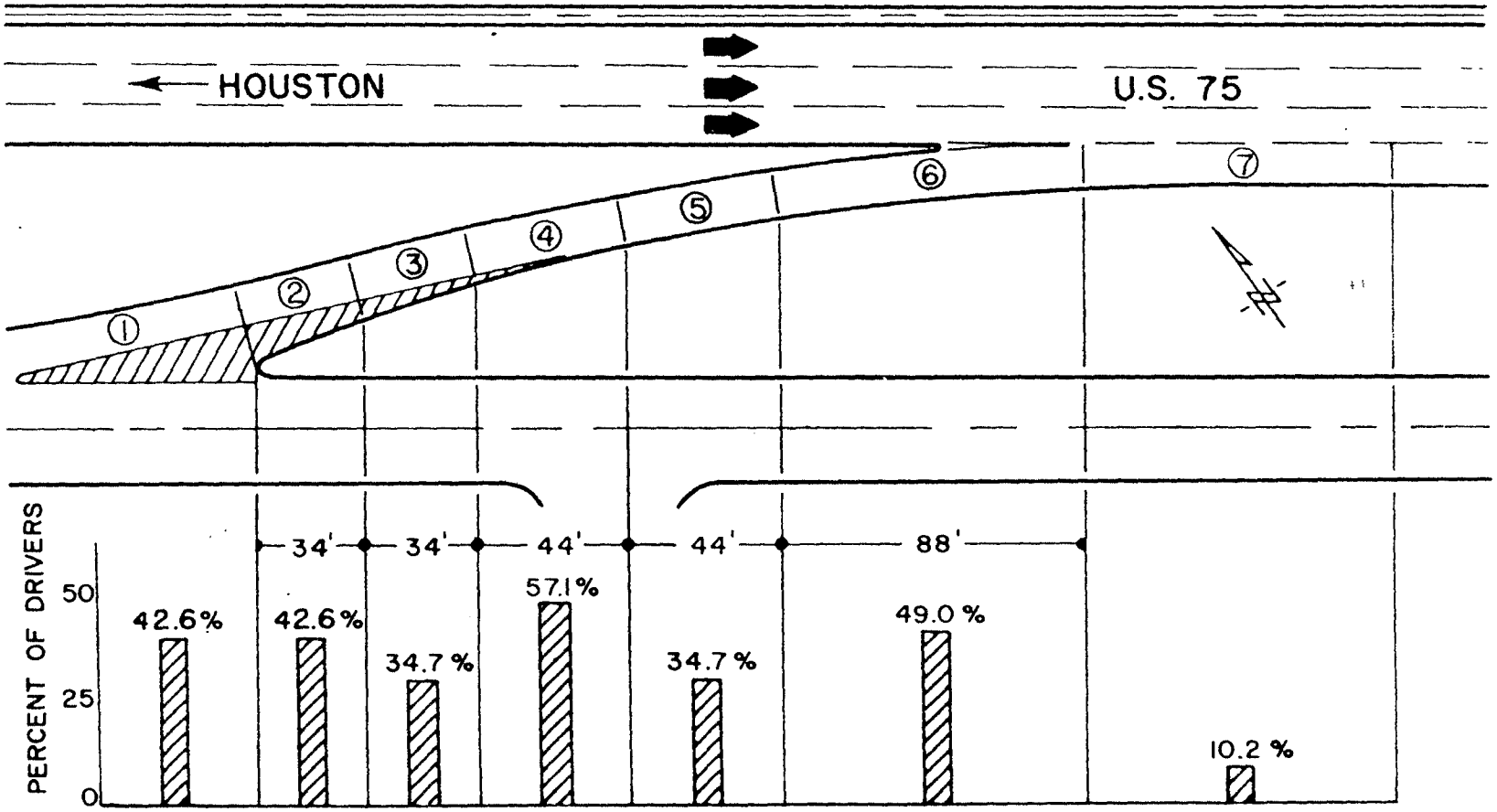
Houston Study

Driver Classification

Due to a camera malfunction, a sample size of 51 vehicles was obtained during the Houston study. Of these 51 drivers, 47, or 92 per cent, turned his or her head in excess of 90 degrees one or more times prior to entering the freeway. These 47 drivers were classified as "observers."

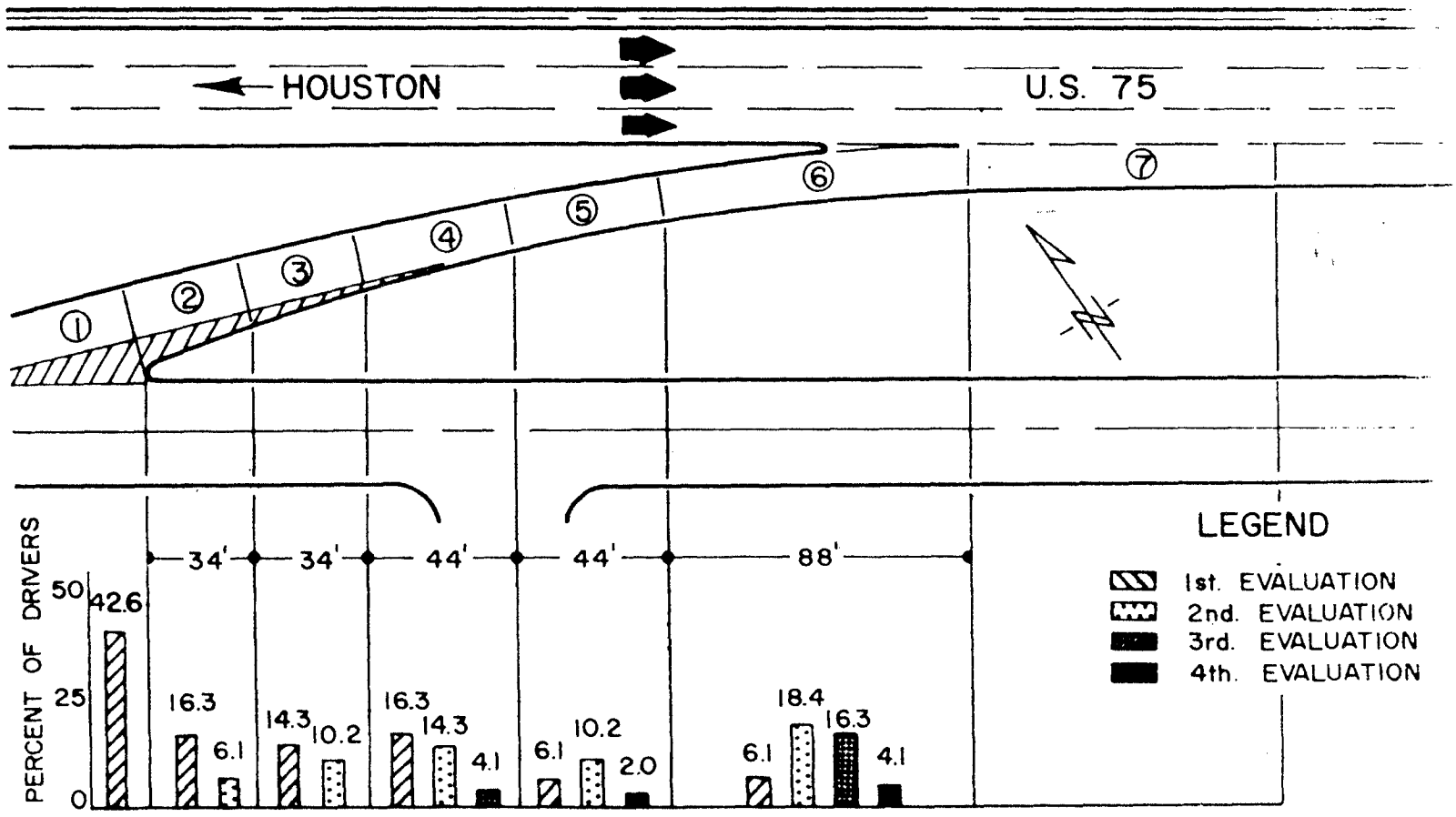
Freeway Evaluation Area

The location on the ramp at which the entering drivers evaluated freeway traffic conditions is shown in Figure 13. It can be seen that approximately one-half, 49 per cent, of the drivers evaluated freeway conditions at the ramp nose. It is again pointed out that these percentages represent the per cent of the drivers classified as "observers" who either turned 90 degrees or more in that specific area or continued through the area looking backward. For a more detailed analysis, the evaluations were divided according to the first, second, third and fourth evaluations (Figure 14). This shows that 42.6 per cent of the drivers studied made their first evaluation of freeway conditions as far back as 244 feet prior to entering the freeway. This however, seems to lose some of its significance when it is noted that of those 20 drivers, all but two re-evaluated



COMBINED OBSERVATIONS
HOUSTON STUDY- 47 DRIVERS

FIGURE 13



FREEWAY EVALUATION AREAS
HOUSTON STUDY - 47 DRIVERS

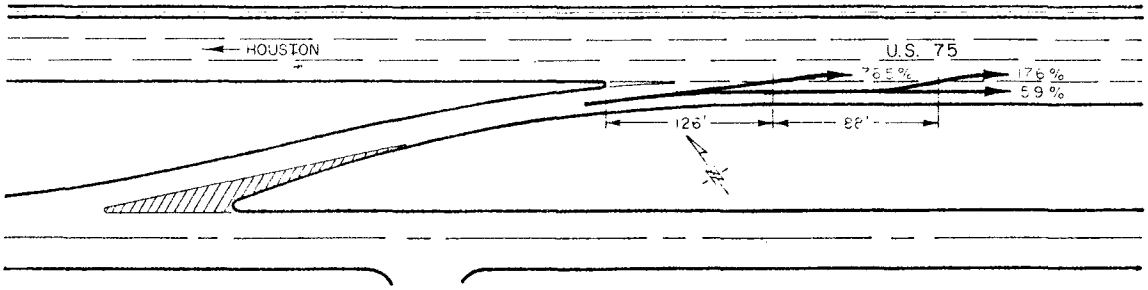
FIGURE 14

the freeway one or more times prior to entering. It is further pointed out that 13 of these 20 drivers made one of those re-evaluations just prior to entering the freeway.

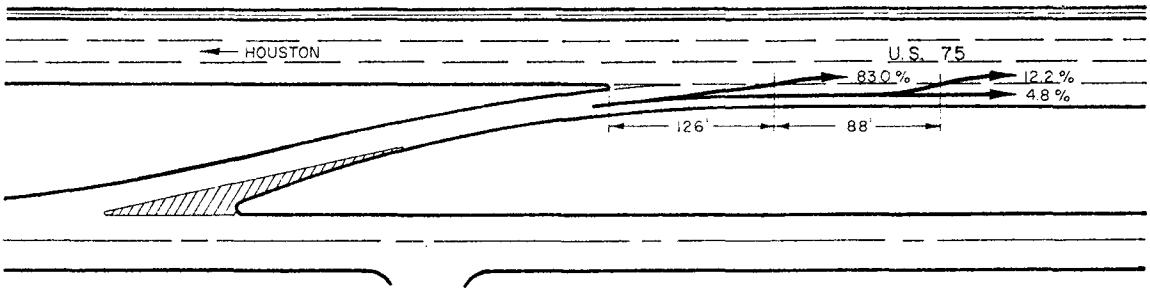
Vehicle Entry Paths

The small sample obtained in the Houston study presented no major problem in the driver behavior portion of the study as the only objective was to determine where the drivers were evaluating freeway conditions. This small sample did, however, present a problem when attempting to correlate driver behavior with vehicle maneuvers. This problem was brought about by the fact that it was impossible to group the drivers for such specific studies as paths of entry and average entry speeds as was done in the analysis of the San Antonio study. The drivers were therefore divided into two groups. The first of these groups was composed of those drivers who were classified as "non-observers" and those drivers who evaluated freeway traffic conditions in areas one, two or three. This resulted in a sample of ten vehicles. The second group comprised those drivers who evaluated freeway conditions in areas four, five, six or seven.

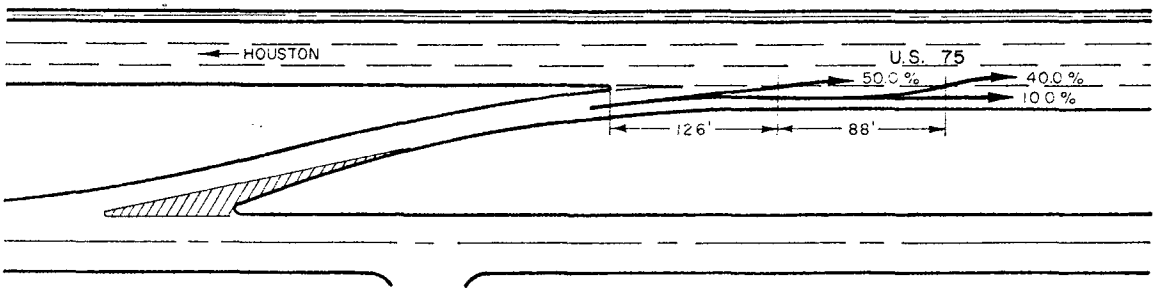
Of the drivers studied, as seen in Figure 15, 76.5 per cent of the combined sample entered the freeway within the first 126 feet of the acceleration lane while only 23.5 per cent utilized 214 feet or more of the acceleration lane. It can also be seen that of the drivers evaluating freeway conditions in areas four, five, six or seven, 83 per cent made a direct entry, whereas, of those drivers classified as "non-observers"



COMBINED ENTRY PATHS
51 VEHICLES



DRIVERS THAT EVALUATED FREEWAY IN AREAS 4,5,6, AND 7
41 VEHICLES



NON-OBSERVER AND DRIVERS THAT EVALUATED FREEWAY IN AREAS 1, 2, OR 3
10 VEHICLES

PATHS OF ENTRY
HOUSTON STUDY
SAMPLE SIZE 51 VEHICLES

FIGURE 15

and those who evaluated freeway conditions in areas one, two or three, 50 per cent made a direct entry.

Entry Speeds

An analysis was made as to the evaluation area and the resulting entry speeds. The results showed that those drivers who evaluated freeway conditions in areas four, five, six or seven entered the freeway with an average speed of 24.3 miles per hour, whereas those drivers classified as "non-observers" and those drivers evaluating freeway conditions in areas one, two or three had an average entry speed of 32.1 miles per hour. As in the San Antonio analysis this included only those vehicles which had previously been classified as alone or leading.

Entry speeds thus reflected the advantage of increased acceleration lane usuage.

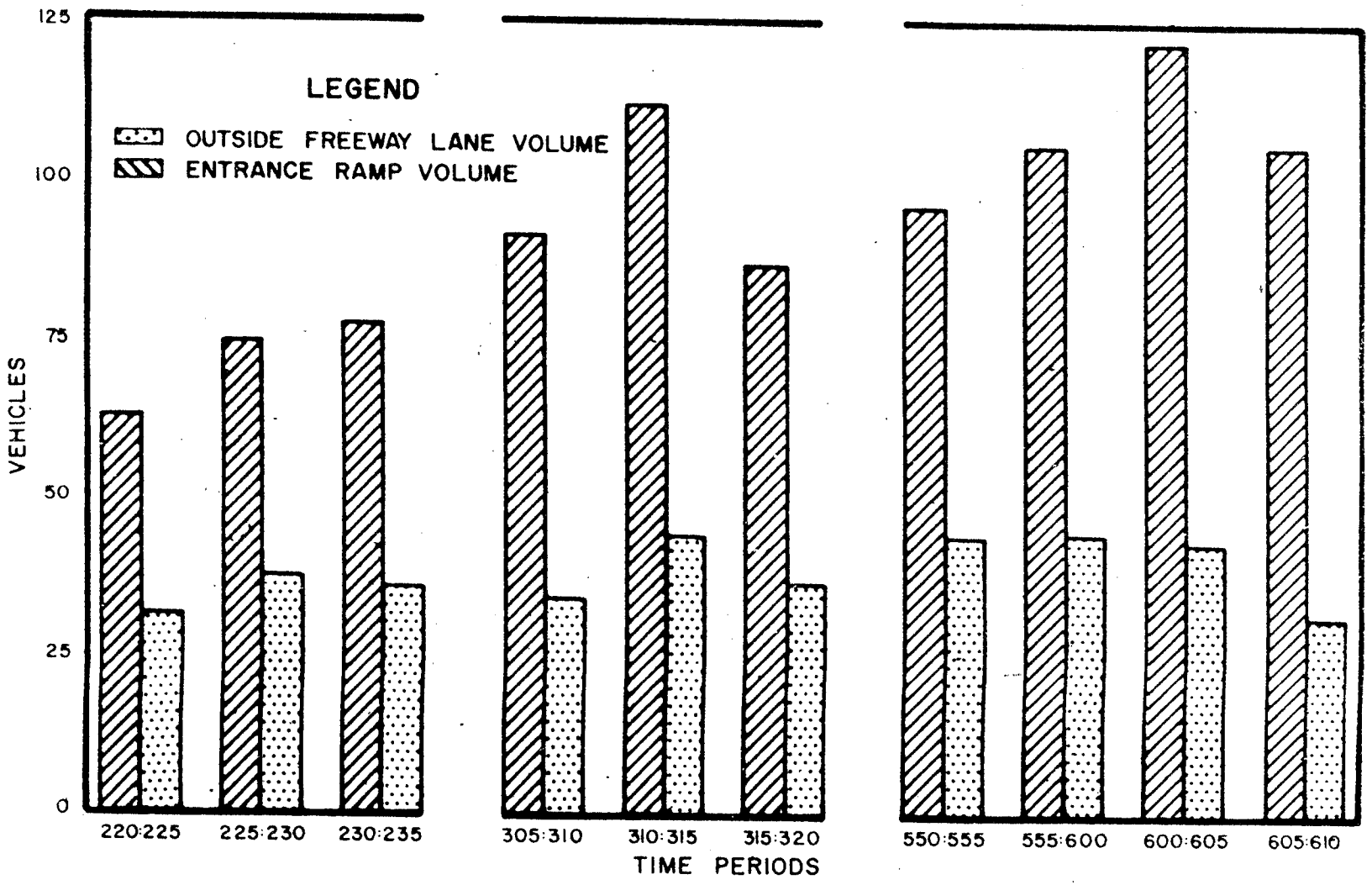
Ramp Stoppages

Of the 51 drivers included in the Houston study, eight, or approximately 16 per cent of the total sample, stopped prior to entering the freeway. Those drivers had previously been classified as alone or leading so there was no apparent need for their stopping. All eight of those drivers made freeway evaluations at the ramp nose and seven of those drivers waited for a large enough gap in the freeway traffic stream to permit a direct entry onto the freeway.

DISCUSSION OF RESULTS

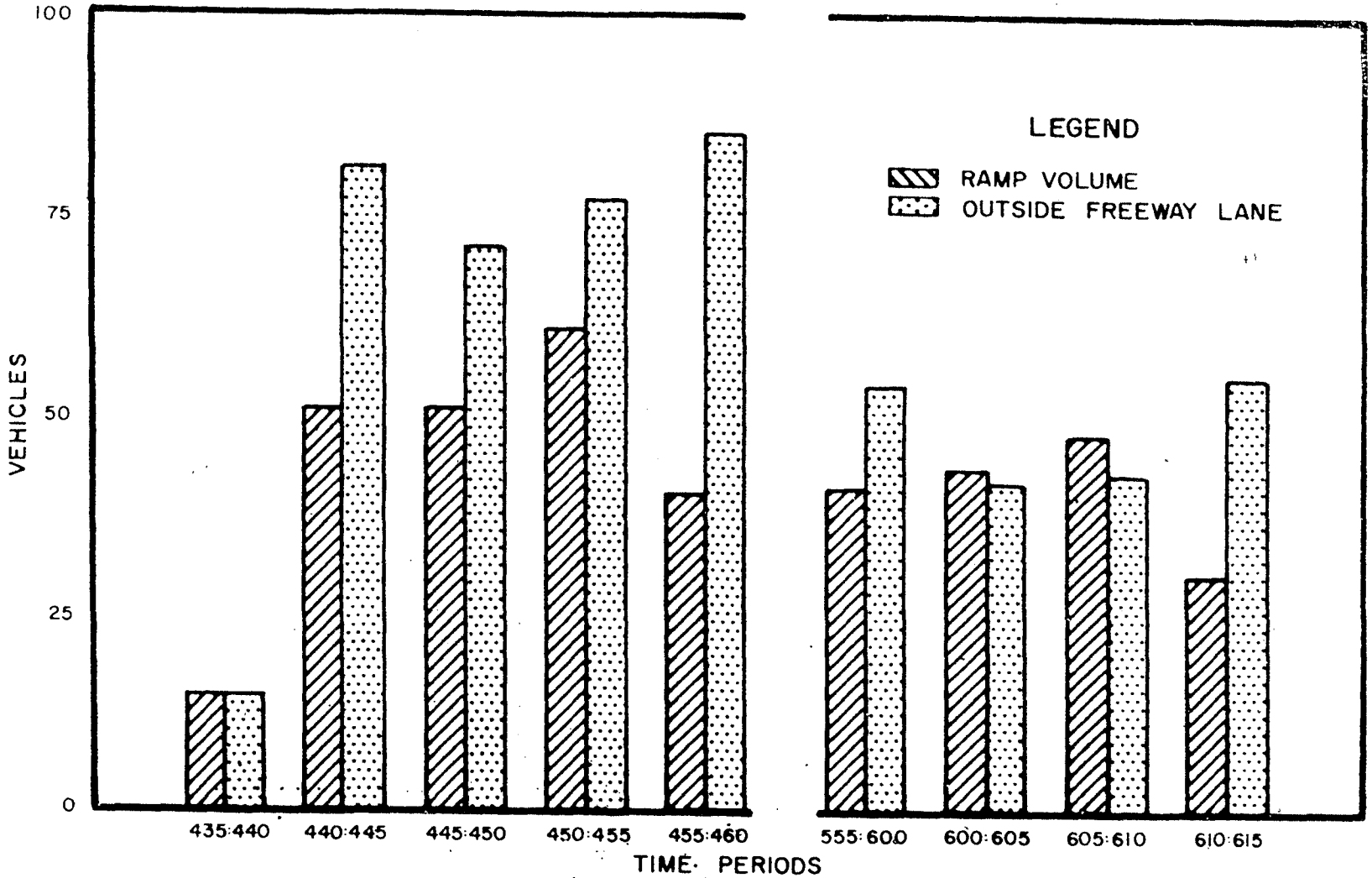
The results of the driver behavior study indicated that the manner in which a driver evaluated freeway traffic conditions and the location on the ramp approach at which the evaluation was made affected not only the operation of the ramp but the operation of the freeway as well. This operation was reflected by the path followed by the ramp vehicle onto the freeway, the speed at which the vehicle entered the freeway and the smoothness of entry.

This study revealed that the major portion of the entering drivers at both study locations made freeway evaluations by turning their heads in excess of 90 degrees one or more times and in some cases as many as four times. Considering both study locations, 67 per cent of the drivers studied made freeway evaluations in this manner. This percentage varied with the two study locations from approximately 60 per cent at the Marshall Street entrance ramp to 92 per cent at the Griggs entrance ramp. Since the sight distance afforded the entering drivers was unrestricted at both study locations, these differences in percentages are believed to be the result of a combination of factors, such as differences in the freeway volumes (Figures 16 and 17) and the difference in the two freeway entrance designs. As seen on the detailed layouts of the study sites, Figure 2, page 9 and Figure 4, page 12, the entering driver on the Marshall Street entrance ramp paralleled the freeway traffic, separated by only 15 feet, for some distance prior to entering the freeway. This



OUTSIDE FREEWAY LANE AND RAMP VOLUME DURING STUDY PERIOD
SAN ANTONIO STUDY

FIGURE 16



OUTSIDE FREEWAY LANE AND RAMP VOLUMES DURING STUDY PERIOD
HOUSTON STUDY

FIGURE 17

afforded the entering drivers an opportunity to evaluate freeway conditions by the use of rear view mirrors or side glances and a number of drivers were observed to move onto the freeway after making such an evaluation. However, on the Griggs entrance ramp, the ramp driver, prior to entering the freeway, was separated from the freeway traffic by a distance of approximately 50 feet and was not afforded a good opportunity to evaluate freeway conditions until he was in the ramp proper and approached the ramp nose. Since the study also revealed that many of the drivers made one or more evaluations of the freeway prior to arriving at the ramp nose, the design of the Griggs entrance ramp limited the driver as to the manner in which he could make early evaluations.

By separating the drivers as to the area in which they evaluated freeway conditions, the results of this study revealed that there was a direct correlation between freeway evaluation area and the acceleration lane usage. Drivers who evaluated freeway conditions in the vicinity of the ramp nose tended to make a more direct entry onto the freeway whereas the drivers who were classified as "non-observers" and drivers who made early freeway evaluations utilized a greater length of the acceleration lane. In both studies, drivers who made a direct entry onto the freeway entered the freeway with higher speed differentials, whereas with increased usage of the acceleration lane this speed differential was decreased.

Efficient freeway ramp operations depend upon a smooth uniform flow of traffic onto the freeway. Any deviation from this type of operation, even for short periods, results in undesirable operation. Certainly one of the major difficulties encountered in freeway entrance ramp operation results from the timid driver who stops at the ramp nose prior to entering the freeway. Ramp stoppages appeared to be directly associated with the area in which the driver evaluated the freeway. In both studies the drivers who stopped at the ramp nose stopped, and turned their heads to make freeway evaluations rather than turn onto the acceleration lane as intended by the designer. All of those vehicles had previously been classified as alone or leading, so there was no apparent need for stopping. Of those drivers that stopped, 80 per cent waited for a large enough gap in the freeway traffic stream to permit a direct entry, thus causing considerable delay to other ramp vehicles. Ramp stoppages are also one of the contributing factors in the typical rear-end accident pattern at freeway entrances. Many of the drivers studied were observed to make evaluations by turning his or her head in excess of 90 degrees one or more times. In making this type of evaluation the driver moved forward for some distance with his head turned in excess of 90 degrees. This type of entry placed the entering driver in the undesirable position of moving forward while he was looking backward. Previous research has shown that this situation, coupled with a sudden stop by a vehicle in front, can and often does result in a rear-end accident.

SUMMARY OF FINDINGS

1. The motion picture method developed for studying driver behavior can be utilized in the evaluation of freeway entrance ramp design.

2. The major portion of the drivers studied made freeway evaluations by turning his or her head in excess of 90 degrees one or more times.

3. This study revealed that drivers, when afforded the opportunity, will make freeway evaluations in excess of 200 feet prior to entering the freeway. The fact that some drivers made as many as four evaluations of freeway traffic conditions prior to entering, points out the need for the provision of unrestricted visibility so that early freeway evaluations can be made.

4. The area in which a driver evaluates freeway traffic conditions and the manner in which this is accomplished affect the operation on the ramp as well as the operation on the freeway. This is reflected in entry speeds, paths of entry and ramp stoppages. Of the drivers studied, those who were classified as "non-observers" entered the freeway with higher speeds and utilized a greater length of the acceleration lane. Drivers who made freeway evaluations at the ramp nose made a more direct entry onto the freeway and entered the freeway with higher speed differentials.

5. Many drivers tend to follow the path onto the freeway along which they are aimed rather than turn onto the acceleration lane as is desired. The results of the study indicated that if a freeway entrance

design permits a direct entry onto the freeway, some drivers stop at the ramp nose and wait for a large enough gap in the freeway traffic stream to permit such an entry rather than utilize the acceleration lane as intended by the designer.

6. The study of driver behavior on freeway entrance ramps has pointed to two characteristics in an entrance design which, from an operational standpoint, appear desirable.

A. It should align the entering driver along a direct path onto the acceleration lane and

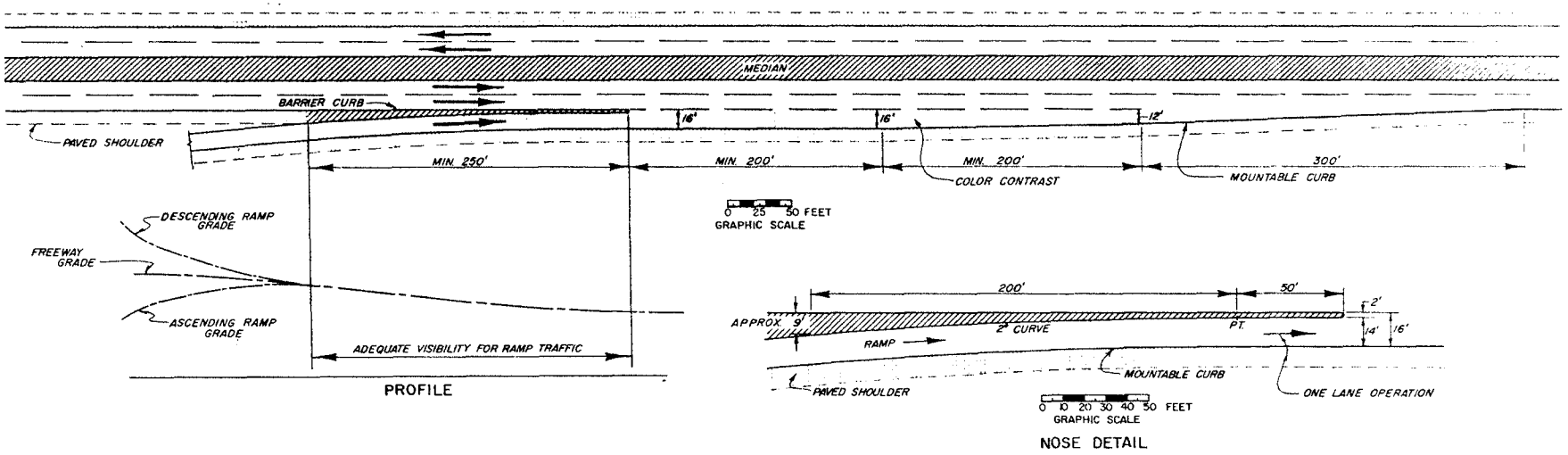
B. It should position the entering driver in such a manner that he parallels the freeway, close enough to make freeway evaluations either by the use of a rear view mirror or side glances for some distance prior to entering the freeway.

RECOMMENDATIONS

The operational difficulties now being experienced at many of the freeway entrances stand as proof that drivers are not utilizing the design as intended by the designer. Since driver behavior appears to be the source of operational difficulty, one possible solution to the problem would be to provide a design which would encourage proper usage of the freeway ramp.

At a 1960 meeting of The American Society of Civil Engineers, Mr. Charles Pinnell presented a paper in which he proposed the freeway entrance design shown in Figure 18 (9). It is believed that a design of this nature would eliminate many of the problems now being encountered at freeway entrances by aligning the driver along a natural path onto the acceleration lane and preventing a direct entry onto the freeway. This design should reduce ramp stoppages, encourage acceleration lane usage and resolve a freeway entrance into a simple lane-change maneuver. With this type of usage the driver should enter the freeway with a higher speed and be in a position to utilize the smaller freeway gaps.

The subject of driver behavior is not new. The attempt to evaluate design and operation based on the study of driver behavior is new. This study has proven the feasibility of the approach; however, there are many unanswered questions. Further study of driver behavior will provide some of these answers.



DESIRABLE ENTRANCE
RAMP DESIGN

FIGURE 18

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