

FREEWAY RAMPS

A Report to the Texas Highway Department

On Research Project RP-16

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We are sorry but some of the older reports are AS IS.

The pictures are of poor quality.

## SUMMARY

On the basis of research studies, it is felt that highway designers must become more concerned with the relationship of design and traffic behavior. Relating the design of freeway ramps to traffic behavior as indicated by the requirements and desires of drivers is a necessity if maximum efficiency and safety in ramp and freeway operation are to be obtained.

Entrance ramp design should provide the following:

1. A ramp approach which aligns the driver along an easy and natural entry path into the freeway.
2. Adequate sight distance to allow the entrance ramp driver to judge and accept a freeway gap with a minimum of effort.
3. A clearly marked and delineated entrance ramp which will eliminate any confusion in distinguishing between entrance ramp elements and main freeway lanes.

Exit ramp design should provide the following:

1. A natural and easy exit path which will require a minimum of driver maneuvering.
2. Adequate deceleration and sight distance past the ramp nose to allow the driver to safely maneuver through the ramp terminal area.
3. Good delineation at the exit ramp area to eliminate any confusion in distinguishing between main freeway lanes and exit ramp area.

## INTRODUCTION

The results of freeway ramp research indicate a need for more consideration of traffic behavior and driver requirements in the design of entrance ramp facilities. The correlation of traffic behavior and design is not a new concept. The late Mr. Thomas H. McDonald, former commissioner of the Bureau of Public Roads, discussed this subject in a paper delivered to the Washington, D. C., Section of the Society of

Automotive Engineers in 1948. In this presentation Mr. McDonald made the following statement, "We have reached the point in our knowledge of the manner in which highways are used by the mass of traffic to coordinate 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."

Freeway design and operation is still a relatively new phase of highway engineering and only a few of the existing freeway systems in Texas have experienced traffic volumes that permit a full evaluation of their operating efficiency. The impact of postwar growth in vehicle registration has placed a heavy burden upon those responsible for providing adequate highway facilities and has left little time for critical review of freeway operational efficiency.

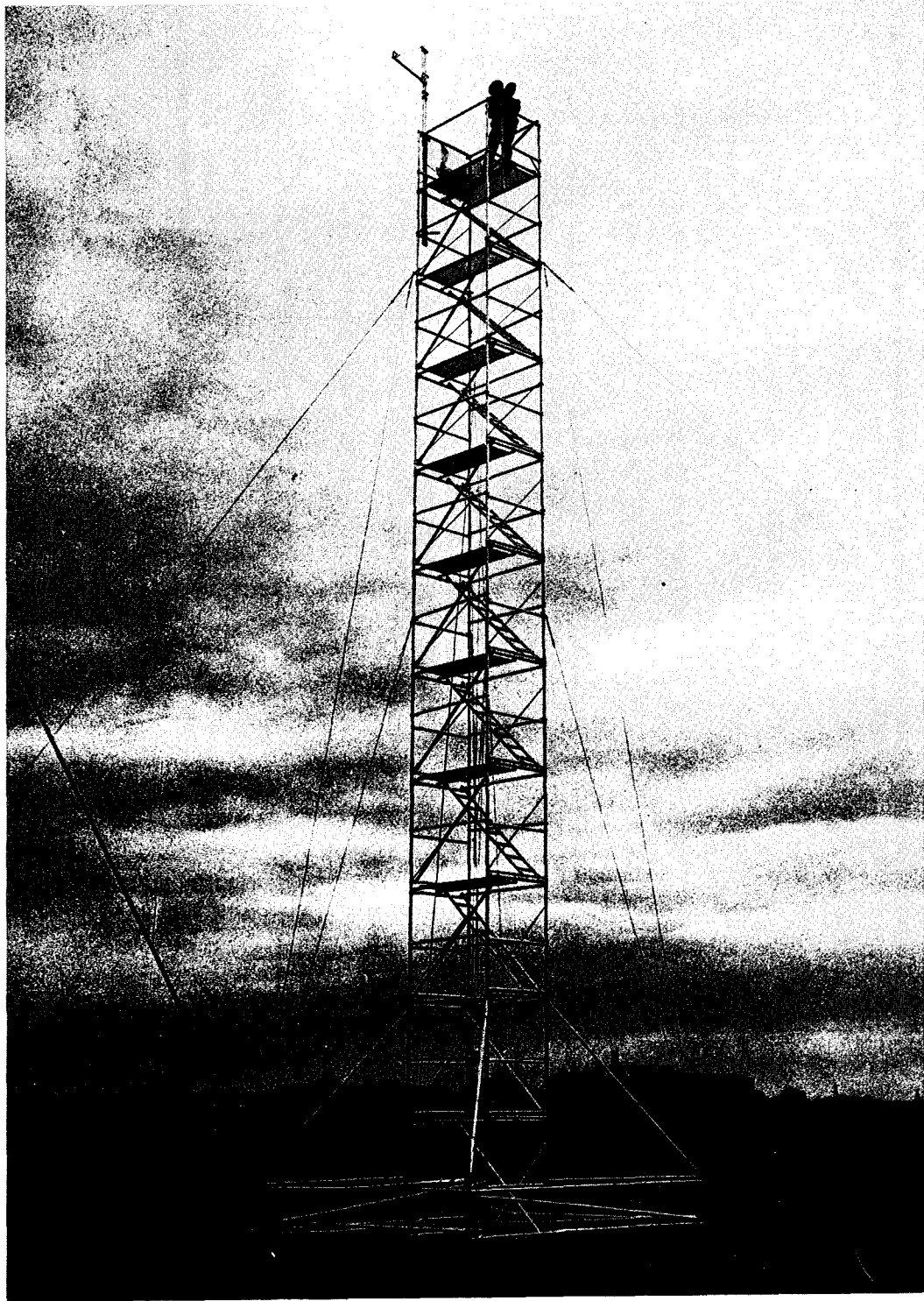
The purpose of this research project has been to develop data on the operational and traffic behavior aspects of freeway ramp operation in order to provide the designer with data that will enable a correlation of ramp design with the human aspect relating traffic behavior and driver requirements.

#### RAMP STUDIES

Eleven separate ramp studies were conducted on freeways in the cities of Dallas, Fort Worth, San Antonio, and Houston by the Texas Transportation Institute in cooperation with the Texas Highway Department. The study locations were specifically selected to provide data on various types of ramps operating under different volume conditions.

Data were obtained mostly by motion picture studies in which traffic operations at the ramp study locations were recorded on film by use of a 16mm motion picture camera. The filming was done from a vantage point approximately 60 feet above the traffic stream. This vantage point was provided by a portable tower (Figure 1) or tower truck. The movies were made at a fixed camera speed of 10 frames per second which allowed the determination of vehicle speeds, delays, headways, placement, and other traffic characteristics and also permitted the reproduction of traffic operation at near actual speed for detailed operation studies.

The data were analyzed by use of the projector shown in Figure 2, which allowed "still" or single-frame viewing with accurate framing and no heating or warping of the film. A frame counter and fingertip control (reverse or forward) allowed manipulation of individual frames and the determination of specific data on speeds or headways.



PORTABLE TOWER USED IN FILMING TRAFFIC

FIGURE 1



TIME-MOTION STUDY PROJECTOR USED IN ANALYSIS OF MOTION PICTURES

FIGURE 2

Data on speed, volume, paths of entry and over-all operation were tabulated for each study, and specific features were given special study as indicated in Table 1.

TABLE 1 — RAMP STUDY SITES

Study No.	Study Location	Major Study Feature
1	Cullen On-Ramp Gulf Freeway Houston, Texas	Paths of entry with short acceleration lane
2	Cullen On-Ramp Gulf Freeway Houston, Texas	Paths of entry with long acceleration lane
3	Fitzhugh On-Ramp Dallas, Texas	No acceleration lane
4	University On-Ramp Fort Worth, Texas	Two-lane operation
5	Cullen On-Ramp Gulf Freeway Houston, Texas	Visibility afforded ramp traffic
6	Stadium On-Ramp Gulf Freeway Houston, Texas	Visibility afforded ramp traffic
7	Griggs On-Ramp Gulf Freeway Houston, Texas	Visibility and angle of entry "before" study
8	Griggs On-Ramp Gulf Freeway Houston, Texas	Visibility and angle of entry "after" study
9	Alamo On-Ramp San Antonio, Texas	Paths of entry and visibility
10	Mar shall On-Ramp San Antonio, Texas	Paths of entry and visibility
11	Culebra On-Ramp San Antonio, Texas	Delineation

## ENTRANCE RAMP DESIGN

The studies of entrance ramp operation produced much valuable information and resulted in the development of some new concepts of entrance ramp problems and operation. The operational problems observed on most of the entrance ramps, were the result of a lack of proper consideration for traffic requirements and driver behavior in the initial design of the ramp.

Most previous ramp studies and discussions have dealt with the design of acceleration lanes. It was found in these studies, however, that the most critical area in entrance ramp design is the area traversed by the entering ramp vehicle before reaching the ramp nose. This critical area is illustrated in Figure 3. Proper design of this area is essential in establishing the necessary correlation between design and operation.

The results of the entrance ramp studies indicated that the following factors are vital, functional elements of good entrance ramp design:

1. Angle of Entry — Formed by the intersection of the entrance ramp approach and freeway lanes.
2. Visibility Relationship — Between ramp traffic and freeway traffic.
3. Delineation — Ramp nose and acceleration lane.

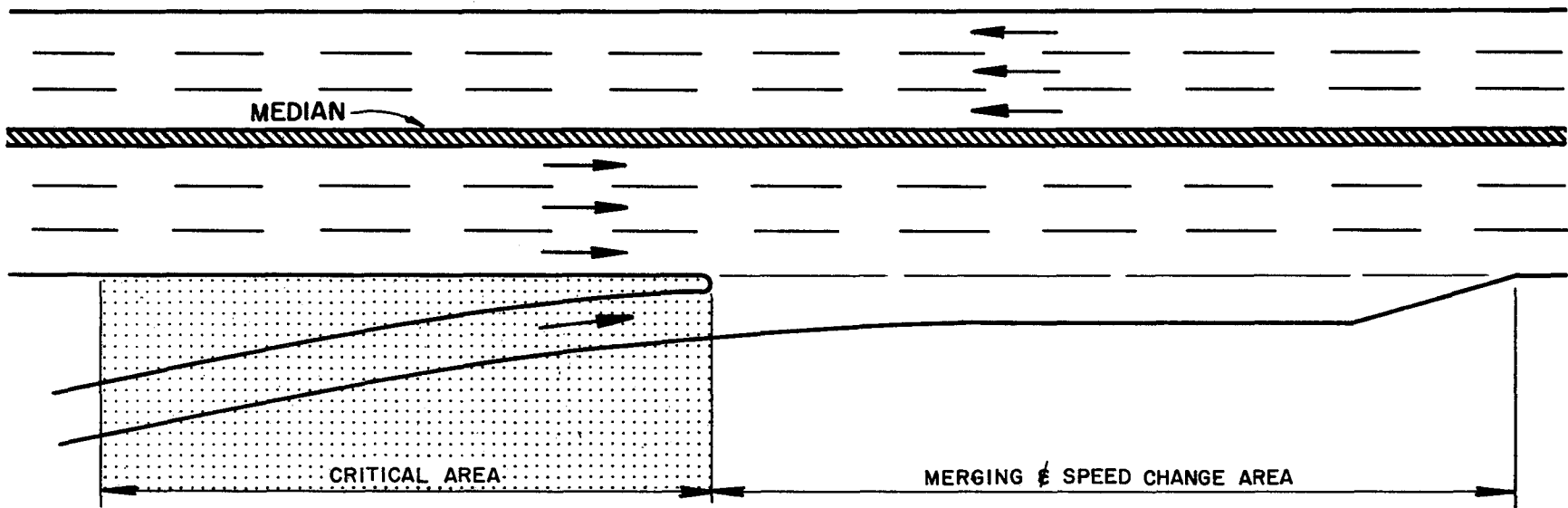
The correlation of each of these factors with traffic behavior will be discussed in the following material.

### Angle of Entry

The initial ramp studies were conducted on the Gulf Freeway in Houston, Texas, at a location where the ramps had an angle of entry of approximately  $14^{\circ}$  as shown in Figure 4. It was found that this high angle of entry aimed the entering drivers into a direct-type entry path into the main freeway lanes. A typical maneuver of this type is shown in Figure 5. A majority of drivers prefer to follow the easy, direct path along which they are aimed rather than make the proper but more difficult maneuver of turning along the acceleration lane.

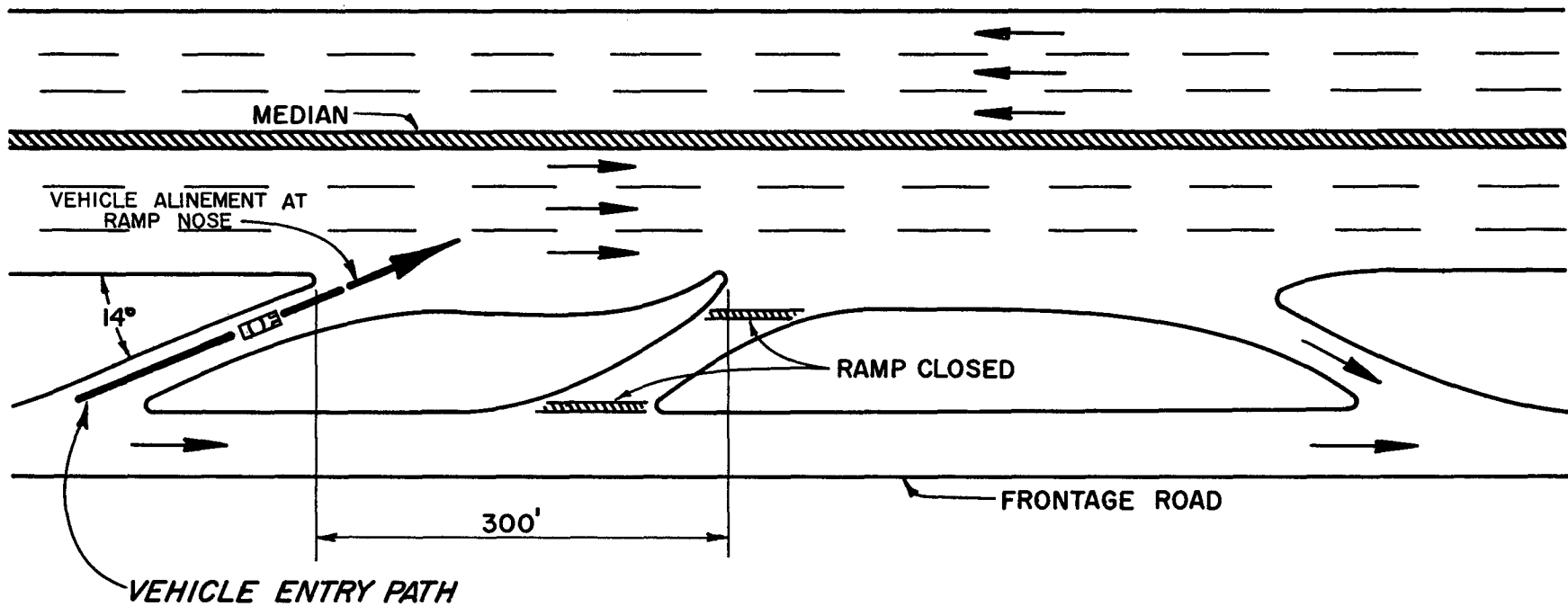
Studies of vehicle entry paths indicated the ramp usage pictured in Figure 6. As can be seen, a relatively small per cent (8.65) of the drivers utilized the acceleration lane. The predominant direct-type of entry





### CRITICAL AREA RAMP DESIGN

FIGURE 3



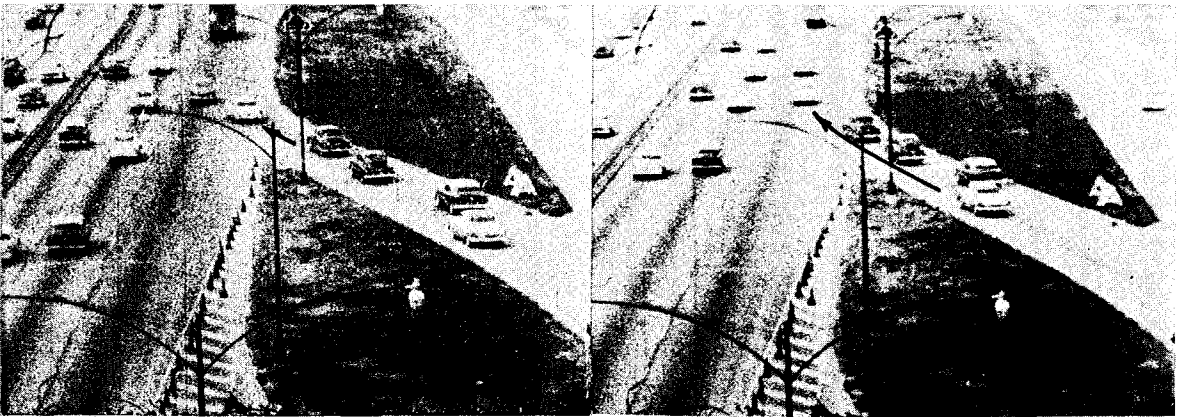
CULLEN ON RAMP  
 GULF FREEWAY-HOUSTON

FIGURE 4



5-A

5-B

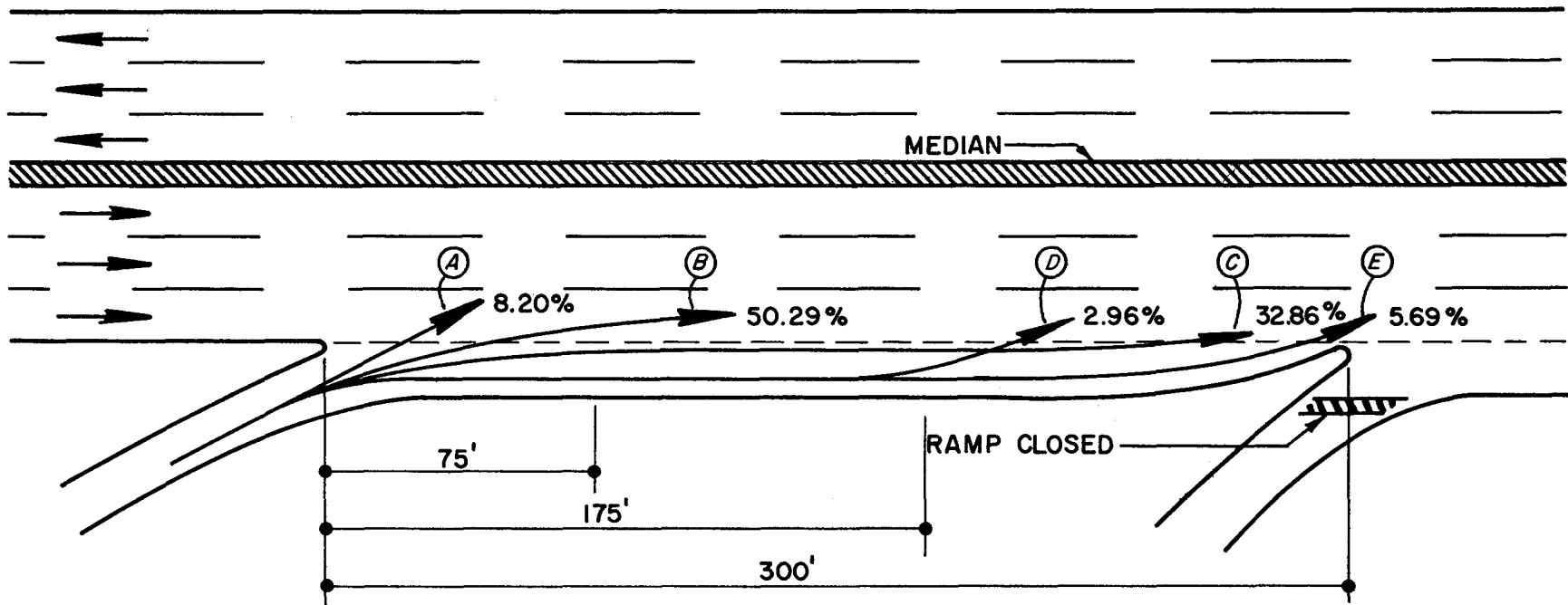


5-C

5-D

**DIRECT TYPE VEHICLE ENTRY**

**FIGURE 5**



A - DIRECT ENTRY PATH.  
 B - DIRECT ENTRY PATH.  
 C - DIRECT ENTRY INTO FREEWAY WITH ENCROACHMENT ON FREEWAY AND RAMP LANES.

D - ENTRY PATH ALONG ACCELERATION LANE.  
 E - ENTRY PATH ALONG ACCELERATION LANE.  
 SUM OF A, B, & C = 91.35%  
 SUM OF D & E = 8.65%

**PATHS OF ENTRY  
 SHORT ACCELERATION LANE**

**FIGURE 6**

results in the creation of a high relative speed between entering ramp traffic and freeway traffic. This high speed differential creates undesirable friction in the freeway traffic stream and produces a large number of weaves in the ramp area resulting in inefficient, hazardous operation.

Modifications were made in the ramp design (Figure 7) to allow the extension of the acceleration lane to approximately 1,000 feet in length. This was done in order to determine if an increase in the length of the acceleration lane would improve ramp operation. The usage of this ramp is shown in Figure 8. The direct, high relative speed type of entry was reduced by 21.17 per cent but was still being made by 70.18 per cent of the entering drivers.

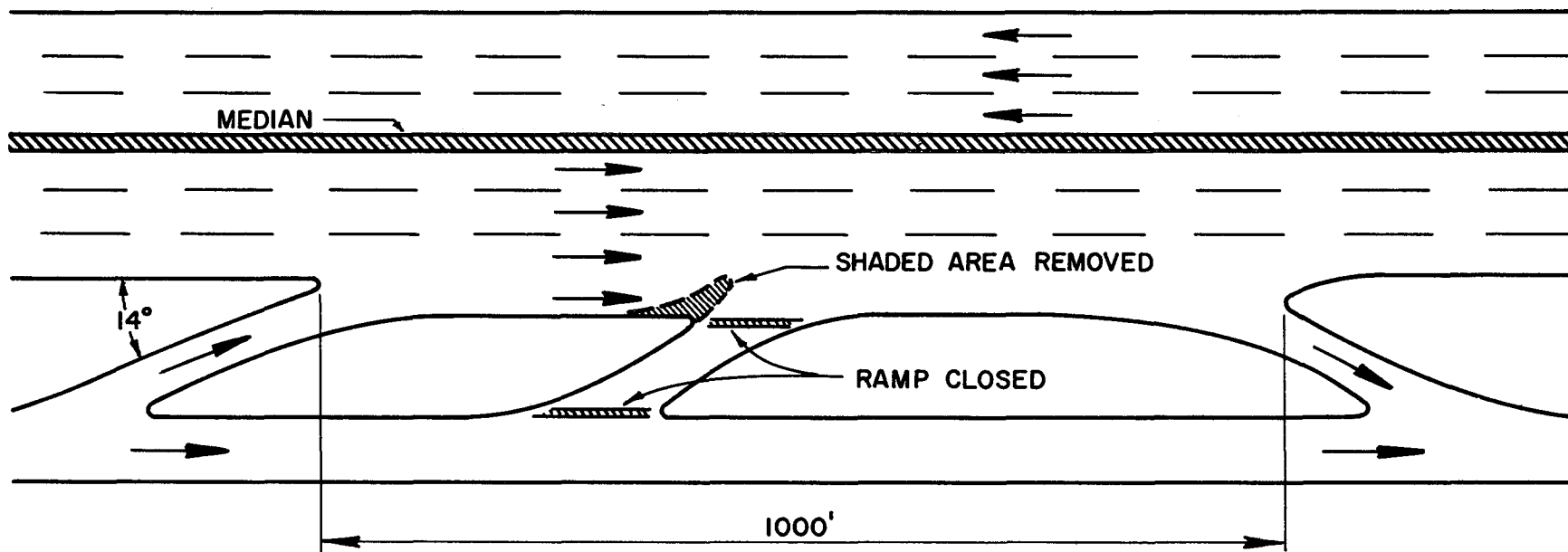
Thus the studies indicated that the primary influence on the path followed by an entering driver is directly related to the angle of ramp approach. If desired usage of the acceleration lane is to be obtained, it is necessary to align the driver along the acceleration lane. The driver can then follow a natural and easy path into the freeway utilizing the acceleration lane as a speed adjustment area and performing a simple lane-change maneuver into the freeway. This can be accomplished by providing a flat-angle ramp approach as indicated in Figure 9.

Studies were also made on entrance ramps having a more desirable design and on one ramp which had been modified with paint striping to align drivers along the acceleration lane. These studies indicated an increased use of the acceleration lane and smoother merging of the ramp and freeway traffic. A typical entry of this type is shown in Figure 10.

### Visibility Relationship

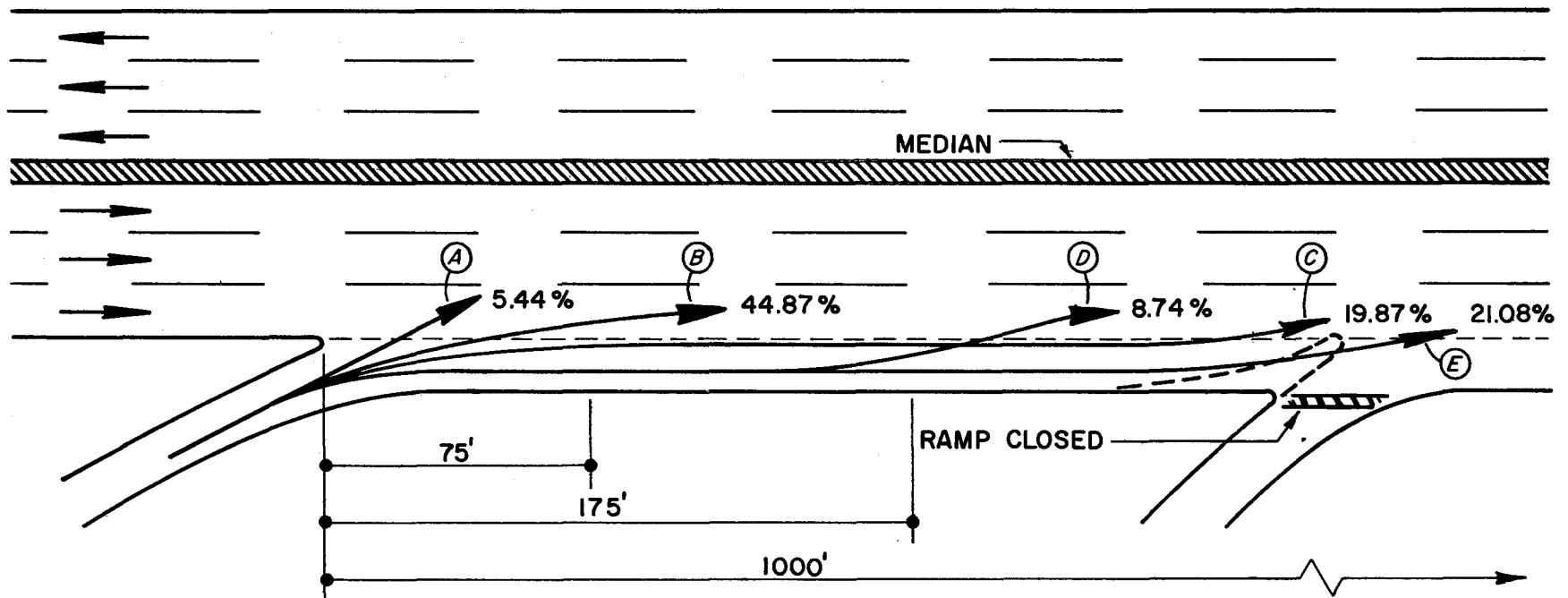
The visibility of main freeway lanes and freeway traffic that is provided to the entering ramp traffic is another integral part of good freeway ramp design. Studies of traffic behavior on entrance ramp approaches where good visibility was available, indicated that the driver begins his evaluation of the freeway traffic stream and makes his decision regarding freeway entry as far as 200 feet before reaching the ramp nose.

This changes somewhat the concept of how ramp traffic enters a freeway. Instead of arriving at the nose at a slow speed and then accelerating along the acceleration lane, the most desirable entry maneuver is made by the driver who approaches the ramp nose at a fairly high rate of speed. This driver selects a gap in the freeway traffic stream before reaching the ramp nose, adjusts his speed, if necessary, on the acceleration lane and performs a smooth "lane change" maneuver into the freeway.



CULLEN ON-RAMP  
MODIFIED NOSE

FIGURE 7

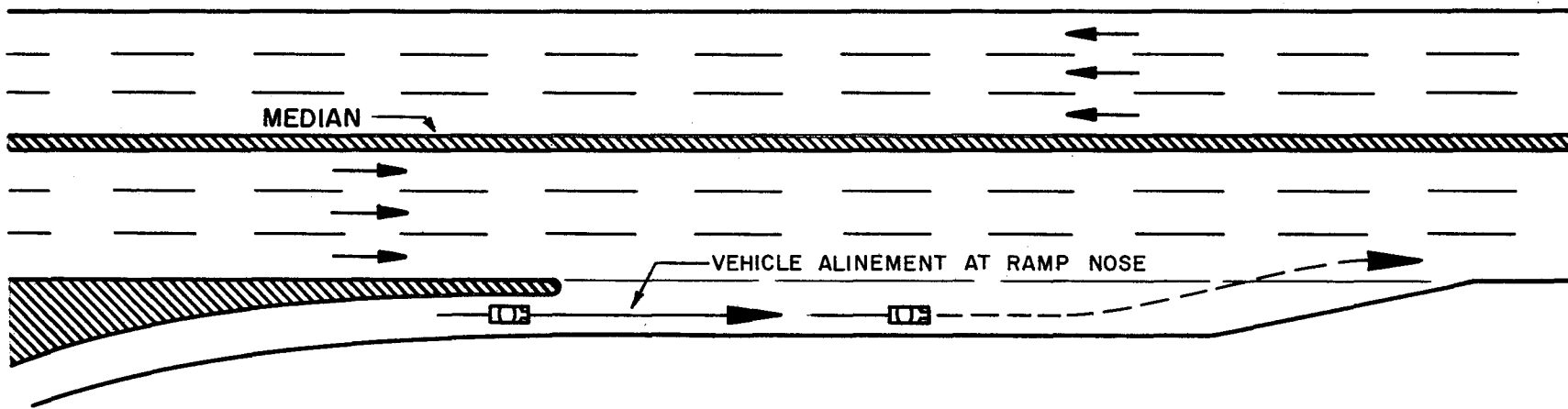


A - DIRECT ENTRY PATH.  
 B - DIRECT ENTRY PATH.  
 C - DIRECT ENTRY INTO FREEWAY WITH ENCROACHMENT ON FREEWAY AND RAMP LANES.

D - ENTRY PATH ALONG ACCELERATION LANE.  
 E - ENTRY PATH ALONG ACCELERATION LANE.  
 SUM OF A, B, & C = 70.18 %  
 SUM OF D & E = 29.82 %

### PATHS OF ENTRY LONG ACCELERATION LANE

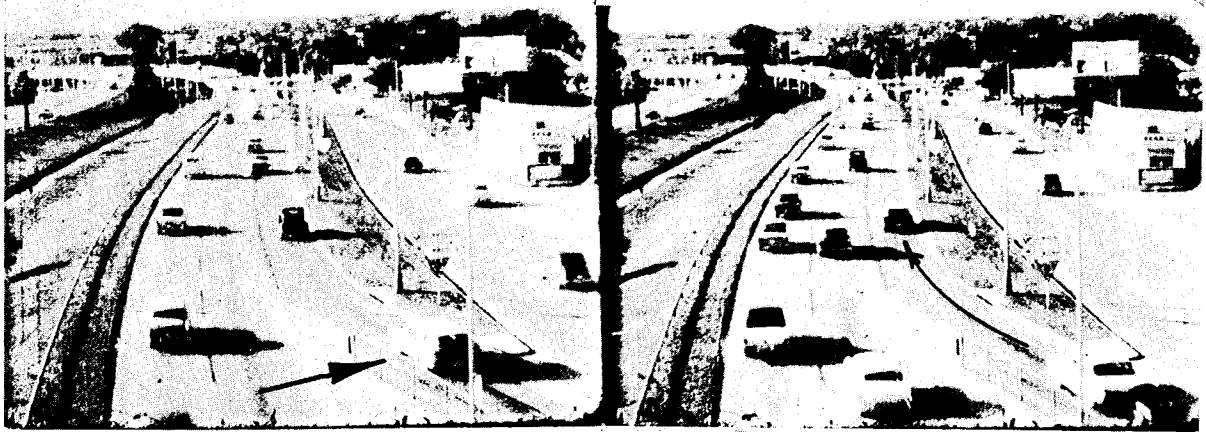
FIGURE 8



FLAT ANGLE APPROACH

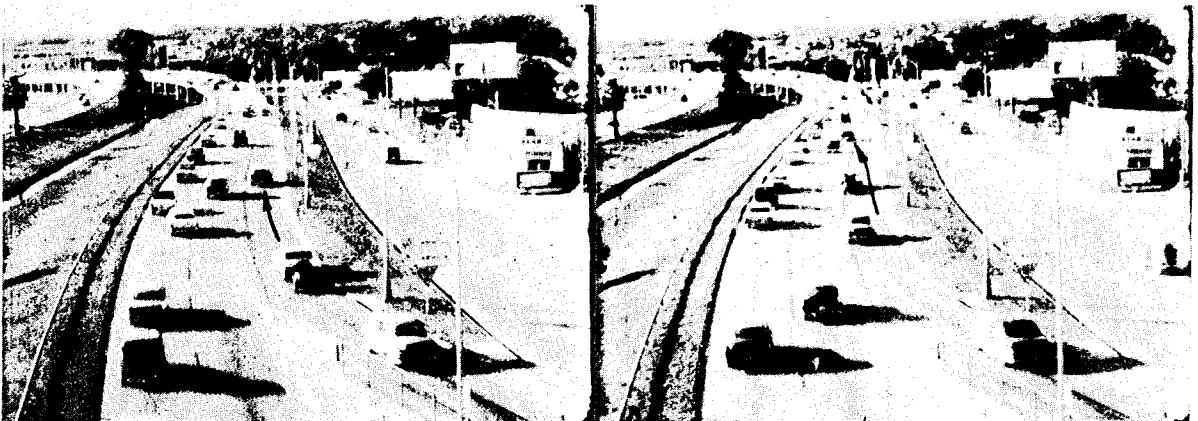
FIGURE 9





10-A

10-B



10-C

10-D

**DESIRABLE VEHICLE ENTRY**

**FIGURE 10**

If the driver is unable to observe the freeway in the proper perspective before reaching the ramp nose, then it is usually necessary for him to stop at the ramp nose and be delayed while selecting a freeway gap. Figure 11 shows the behavior of an entering driver that has stopped at the ramp nose and is looking back over his shoulder to judge a freeway gap. A high relative speed exists between his vehicle and the main freeway traffic and his maneuver into the freeway traffic stream is difficult and hazardous. Figure 12 shows the behavior of another driver, entering the freeway at the same location, who has selected a gap before reaching the ramp nose and moves into the freeway with a minimum of effort and with little or no effect on freeway traffic.

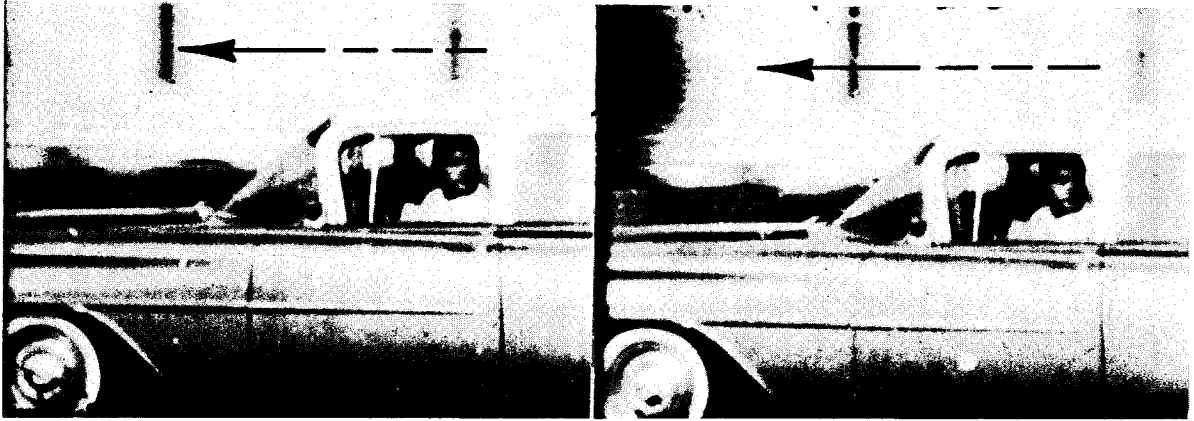
Care must be exercised in the location of ramps to prevent any obstructions to view. A typical problem which can develop is illustrated by the interchange design in Figure 13. In this case the freeway is carried over the major street and the freeway entrance ramp is introduced just past the overhead structure. As indicated by the grade profiles (Figure 13) and the snapshot in Figure 14A, a very bad sight restriction exists. It is impossible for the drivers on this ramp to evaluate freeway traffic before reaching the ramp nose. As a result, a majority of the drivers must stop at the ramp nose before entering the freeway.

Freeway entrance ramp grades should be treated as shown in Figure 15. The entrance ramp grade (either ascending or descending) should be made to match that of the freeway a minimum of 250 feet in advance of the nose. This provides the ramp traffic with adequate visibility as illustrated in Figure 14B, and permits the entering ramp traffic to begin evaluation and selection of freeway gaps before reaching the ramp nose.

### Delineation

A third factor of importance in entrance ramp operation is delineation of the ramp nose and acceleration lane. While the increased use of freeways has resulted in a larger number of drivers educated to the use of various freeway elements, there are still many drivers who do not fully understand the proper method of using freeway entrance ramps. Also, there are so many different types of entrance ramps (without acceleration lanes, with short acceleration lanes, long acceleration lanes, and with additional freeway lane at ramp) being utilized, that the driver often does not know what to expect.

Some of the ramps studied were not well delineated and in many cases the actions of the drivers indicated they did not know the acceleration lane was exclusively for their use. This often resulted in very inefficient operation with the traffic stopping at the nose and creating delay and congestion on the



II-A

II-B



II-C

II-D

BEHAVIOR OF DRIVER ENTERING  
FREEWAY FROM RAMP WITH  
HIGH RELATIVE SPEED

FIGURE II



12-A

12-B

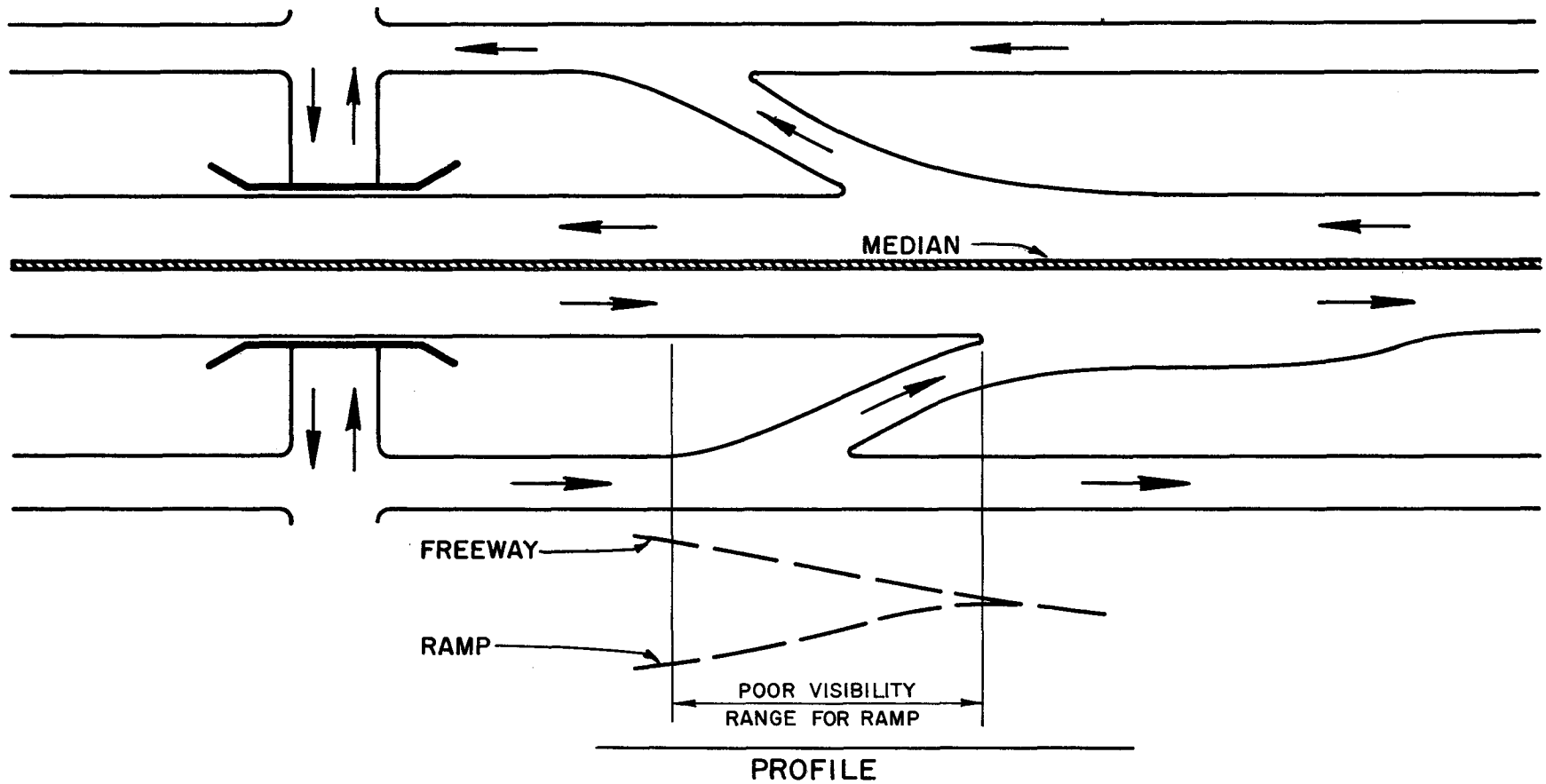


12-C

12-D

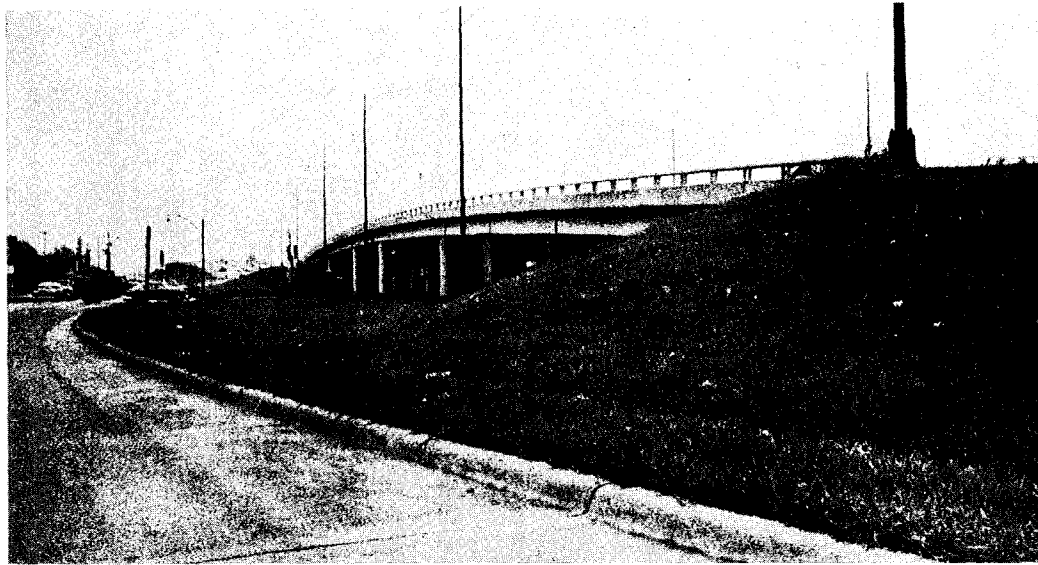
**BEHAVIOR OF DRIVER ENTERING  
FREEWAY FROM RAMP WITH  
LOW RELATIVE SPEED**

FIGURE 12



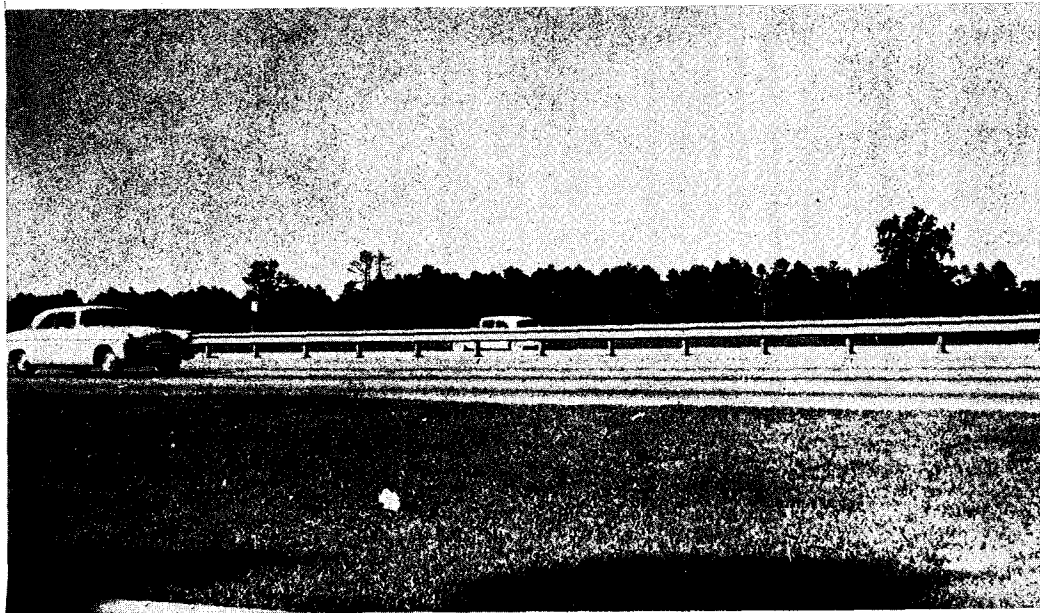
### DIAMOND INTERCHANGE

FIGURE 13



14-A

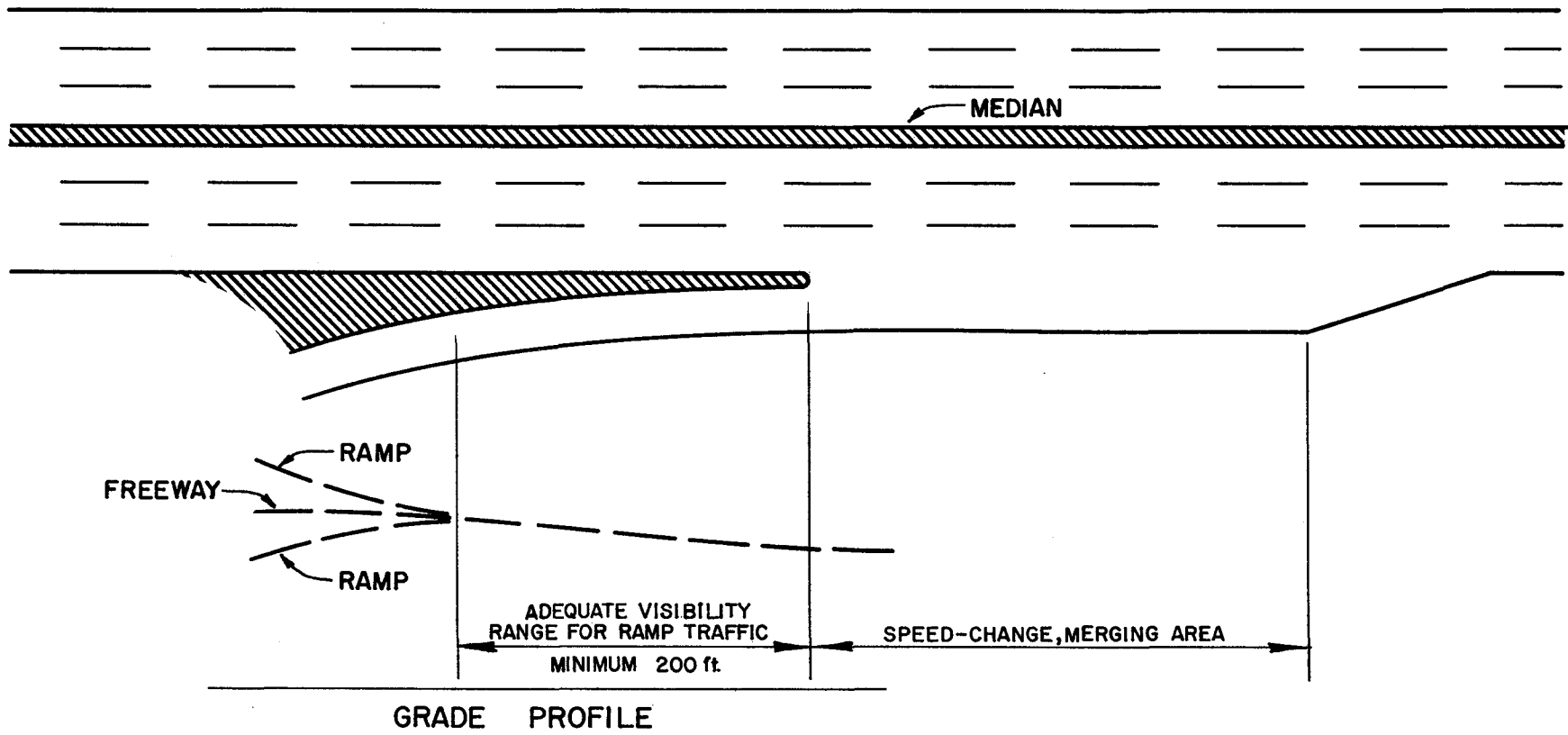
ENTERING DRIVERS' VIEW FROM  
RAMP APPROACH WITH POOR VISIBILITY



14-B

ENTERING DRIVERS' VIEW FROM  
RAMP APPROACH WITH GOOD VISIBILITY

FIGURE 14



### RAMP GRADE

FIGURE 15

ramp. Some of the study locations were later modified by the use of paint lines to better delineate the area to be used by the entering ramp traffic. "After" studies of these locations indicated much improved operation and a decrease in the number of vehicles stopping at the ramp nose.

Good delineation—in the form of color contrast, paint striping and/or other methods—should be provided to enable the drivers to adequately distinguish between the main freeway lanes and the portions of the entrance ramps specifically designed for their use.

### ENTRANCE RAMP ACCIDENTS

Studies of accidents on freeway facilities in Texas<sup>8\*</sup> with special emphasis on correlating accidents with design elements have indicated that entrance ramps often experience a high accident frequency. A typical accident pattern on an entrance ramp is shown in Figure 16. The predominant accident type is the rear-end collision.

During the various study periods, five ramp accidents occurred and were recorded on film. A typical entrance ramp accident is illustrated in Figure 17. Here, as in most entrance ramp accidents, the accident resulted from a "false-start" by the leading vehicle and a collision by a trailing vehicle. In this case, the driver of the trailing vehicle is put in the unfortunate position of needing to look two directions at the same time. He must evaluate and accept a gap in the freeway stream and also keep an eye on the vehicle ahead. The trailing driver often assumes that the lead vehicle is going into the freeway and looks back while his vehicle is moving forward. If the lead vehicle stops, a rear-end collision often results.

The basic cause of this accident, however, is related to the fact that many of the vehicles stop at the ramp nose. The cause of this stop is related to the lack of design consideration for the previously discussed factors of approach angle, visibility, and delineation. If the drivers were properly aligned along the acceleration lane, provided adequate visibility, and were sure of the purpose of the acceleration lane, a majority would move into the freeway in a continuous movement. Even if a gap were not available in the freeway stream there would be no need for an abrupt stop.

Thus the inclusion of the proper design elements should serve not only to produce a smoother merge of the ramp and freeway traffic but should also aid in reducing the accident problem that exists on many entrance ramps.

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\*Refers to the Bibliography.



# CENTRAL EXPRESSWAY – DALLAS, TEXAS ON-RAMP AT CALVARY

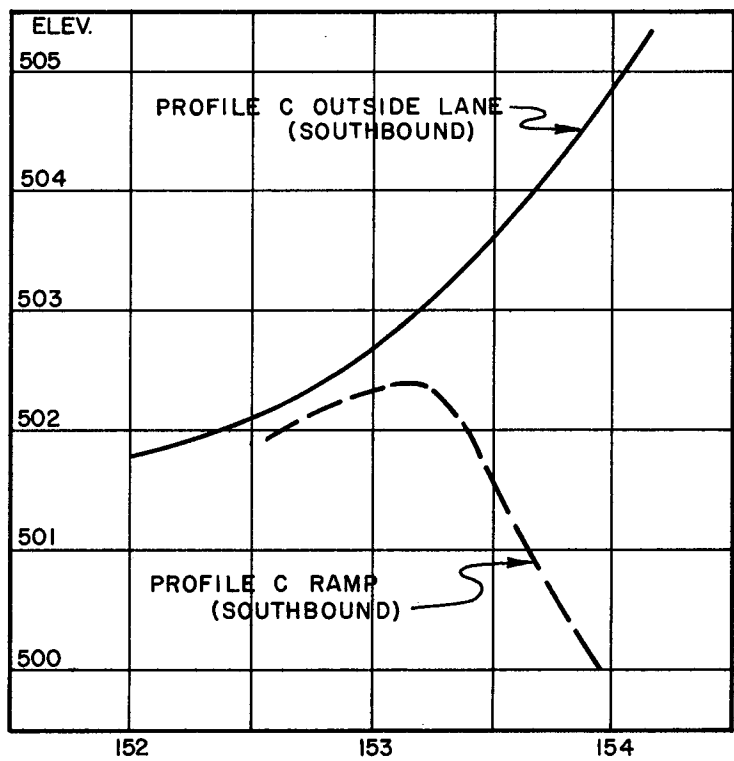
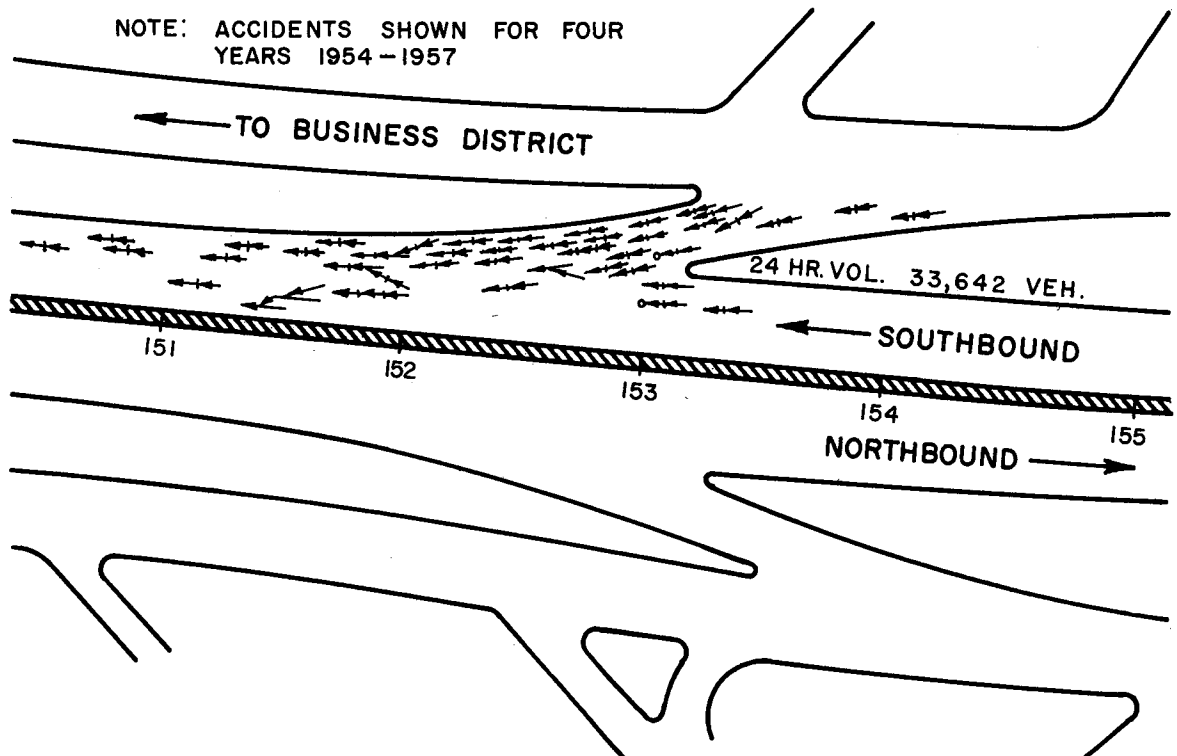
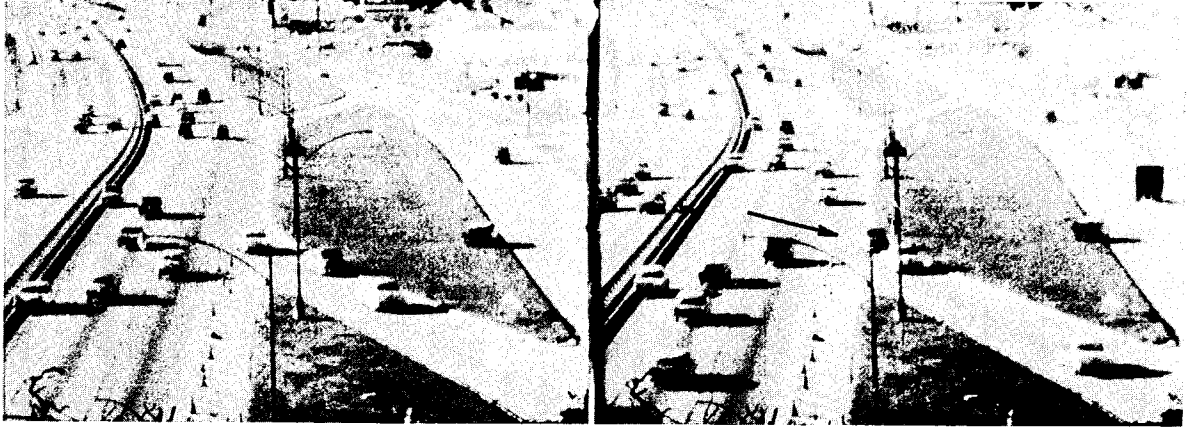
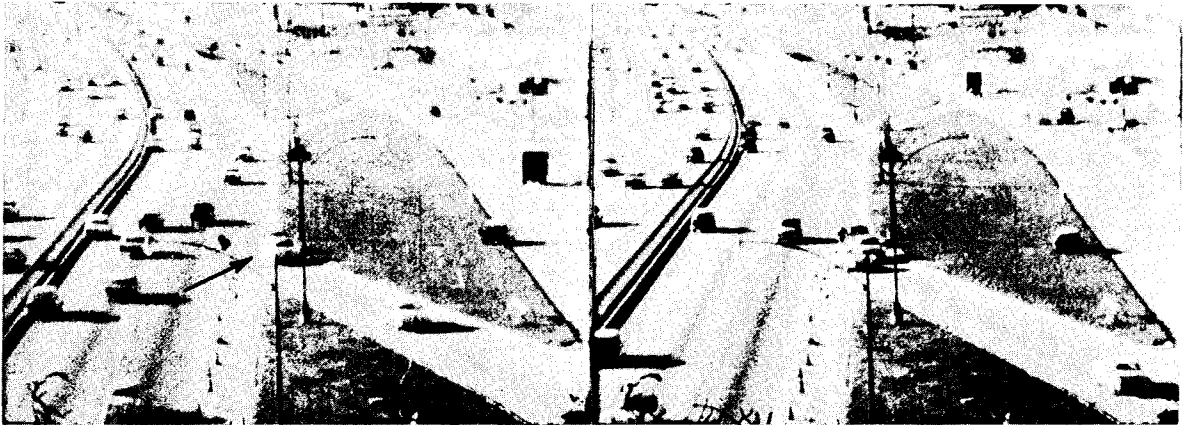


FIGURE 16



17-A  
APPROACH

17-B  
FALSE START



17-C  
COLLISION

17-C

RAMP ACCIDENT

FIGURE 17

## RAMP APPROACH WIDTH

Studies were conducted on entrance ramps with wide approaches such as the one shown in Figure 18. The approach width on this ramp was wide enough to allow two lanes of traffic to approach the ramp nose. Though the ramp is not marked for two-lane operation, traffic during peak periods of flow approaches the ramp nose in two lanes.

Several ramps with similar wide approaches were studied, and in all cases unsatisfactory operation was indicated. Since only one vehicle at a time can utilize the acceleration lane, the two lanes of ramp traffic must merge into single file before reaching the ramp nose or else the vehicles in the left lane of the ramp are forced to make a direct entry into the freeway without benefit of an acceleration lane. A typical illustration of this operation is shown in Figure 19. In this case two-lane operation is occurring and a car in the inside lane is waiting to make a direct freeway entry. This car is blocking the visibility of the other ramp traffic and is creating a hazardous situation as the trailing cars attempt to change lanes in order to reduce their delay.

The ramp shown in Figure 19 was later modified by paint lines to allow only one lane of traffic to approach the ramp nose. "After" studies at this location indicated much smoother operation and an increase in capacity.

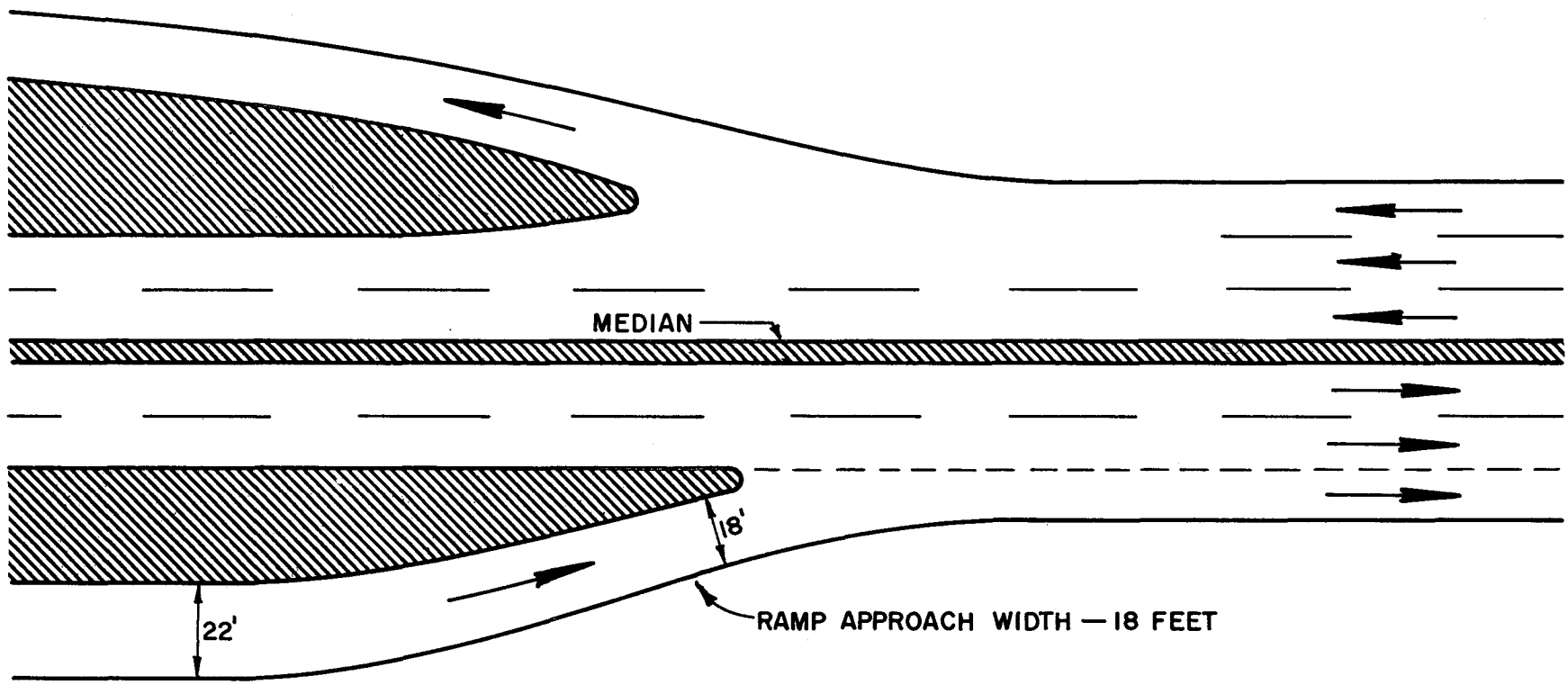
Much better ramp operation is obtained on ramps designed to allow only one lane of traffic. The approach section should be designed for one traffic lane with a mountable curb and shoulder on the right to allow disabled vehicles to leave the traffic stream and thus eliminate the need for providing ramp width (which will be utilized as a second lane) for emergency storage.

## DESIRABLE ENTRANCE RAMP DESIGN

Figure 20 shows an entrance ramp design incorporating all of the features previously discussed. This design should provide the necessary correlation between traffic behavior and design to obtain the maximum efficiency in entrance ramp operation.

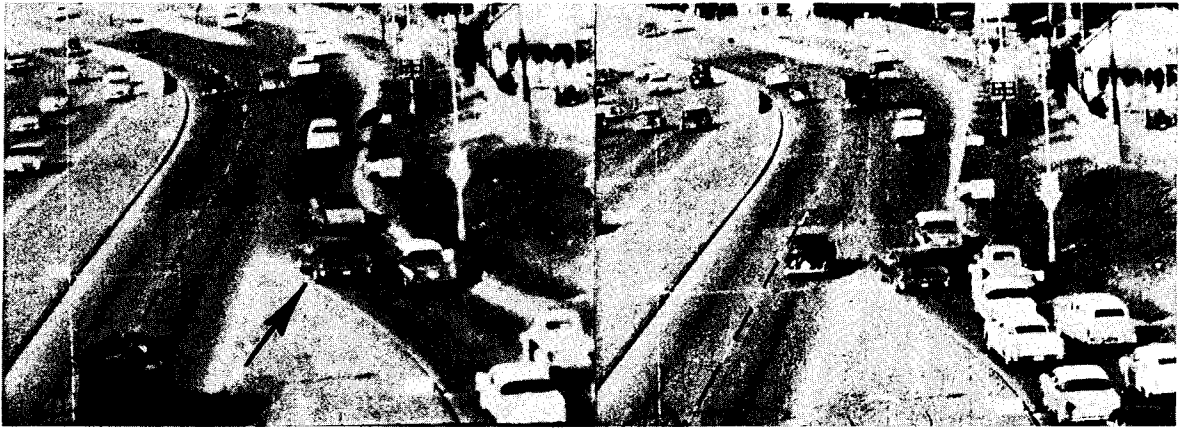
The desirable length of acceleration or "speed adjustment" lanes is a point of question and additional research is continuing in this area. The data available at present indicate that the length can be reduced and the design indicated in Figure 20 is a trend in this direction.

Another point which should also be considered is the operation of entrance ramps during periods of peak flow. It has been observed during



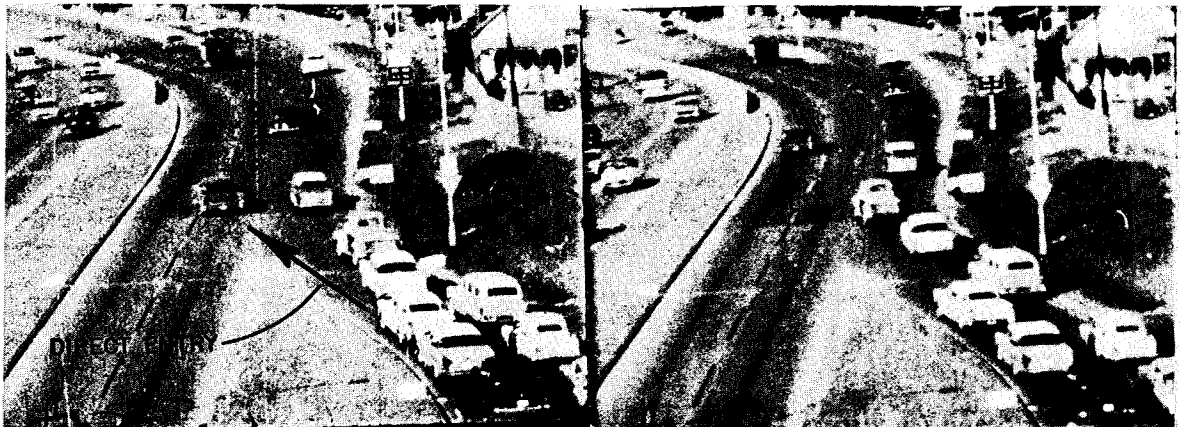
ENTRANCE RAMP  
WITH WIDE APPROACH

FIGURE 18



19-A  
TWO LANE APPROACH

19-B  
DELAY AND CONGESTION

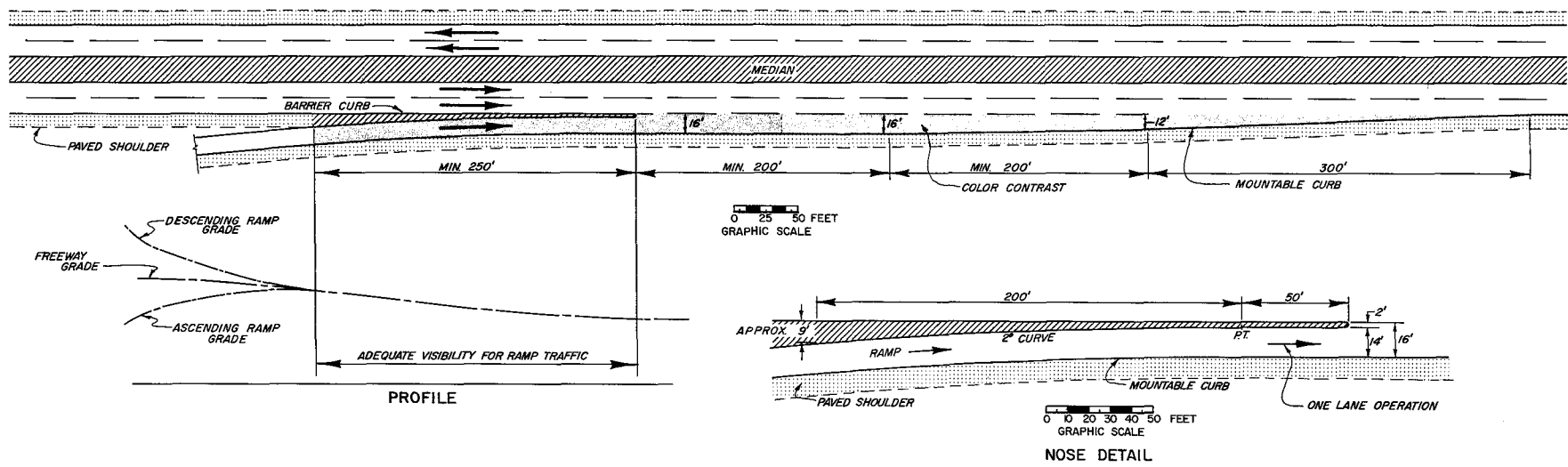


19-C  
DIRECT ENTRY

19-D

**TWO LANE RAMP OPERATION**

FIGURE 19



### DESIRABLE ENTRANCE RAMP DESIGN

FIGURE 20

the course of the ramp studies, that there are periods of short duration (10-15 minutes) during which the main freeway traffic volume is of such a magnitude that satisfactory entrance ramp operation is impossible to obtain. This is simply a case of demand exceeding capacity and no improvement in ramp design will solve the problem.

However, during approximately 23 hours a day most freeway ramps and adjacent freeway sections are operating below possible capacity. It is during this period that entrance ramps should operate with a maximum of safety and efficiency.

### EXIT RAMPS

The research studies have been specifically aimed at entrance ramps as it was felt that these represent one of the most critical elements of freeway facilities. There has been some opportunity, however, to observe exit ramp operation and it is felt that some of the knowledge gained during the entrance ramp studies is applicable to exit ramp design. For this reason a discussion of exit ramp design is being included although specific research has not been completed in this area.

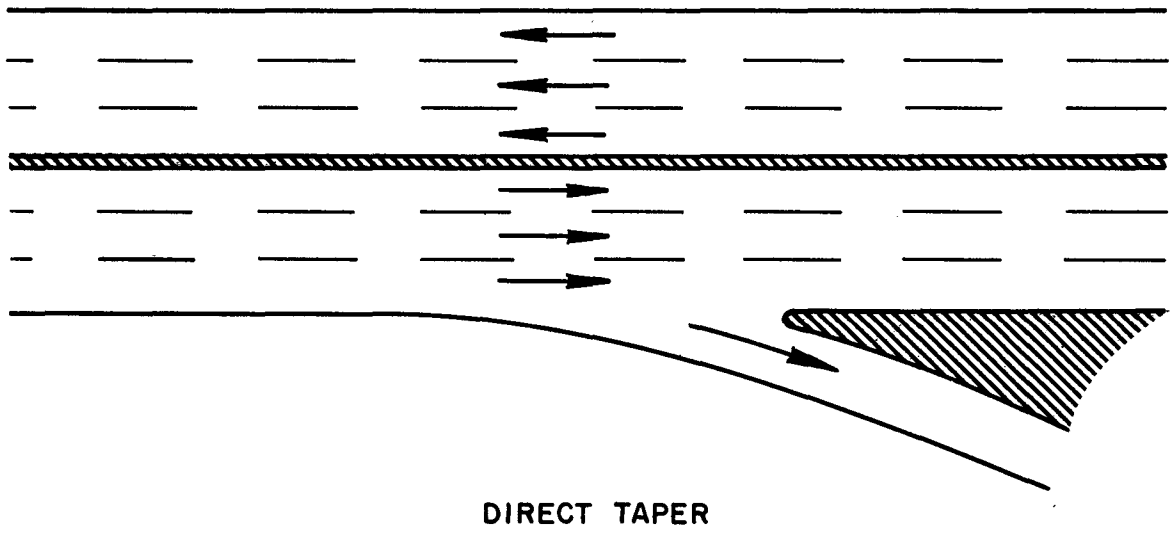
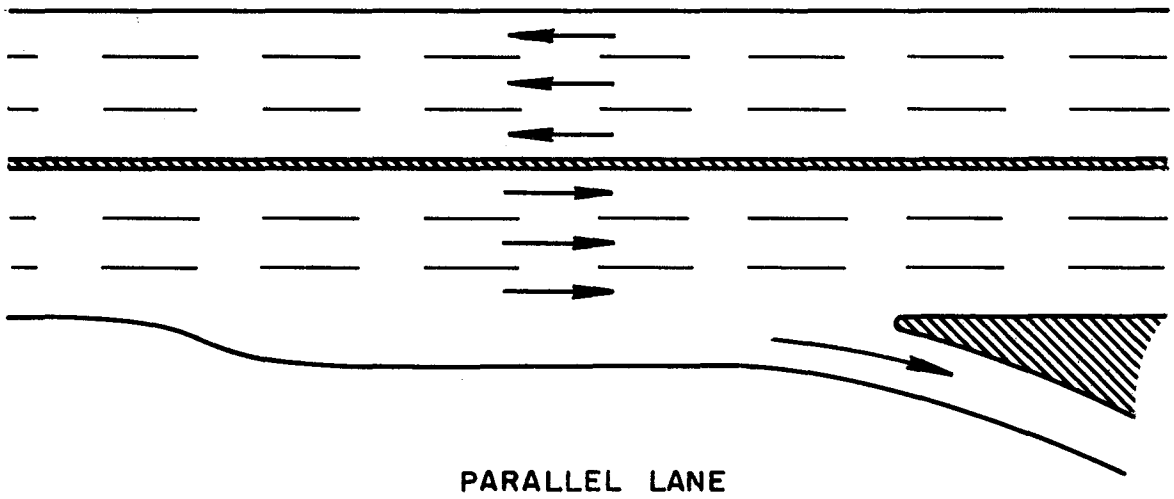
Studies and consideration of exit ramp operation also indicate a need for the correlation of traffic behavior and exit ramp design. Exit ramp design should accommodate the following:

- a. A natural exit path with adequate deceleration distance provided past the ramp nose.
- b. Adequate sight distance on the exit ramp to allow evaluation of conditions at the exit ramp terminal.
- c. Delineation of the exit ramp nose and deceleration area.

#### Natural Exit Path

The two most prevalent types of exit ramps are shown in Figure 21. The basic difference in the two ramps is in the provision for vehicle deceleration. One allows for deceleration on a parallel lane adjacent to the main freeway lanes and the other type provides for deceleration off of the main freeway lanes.

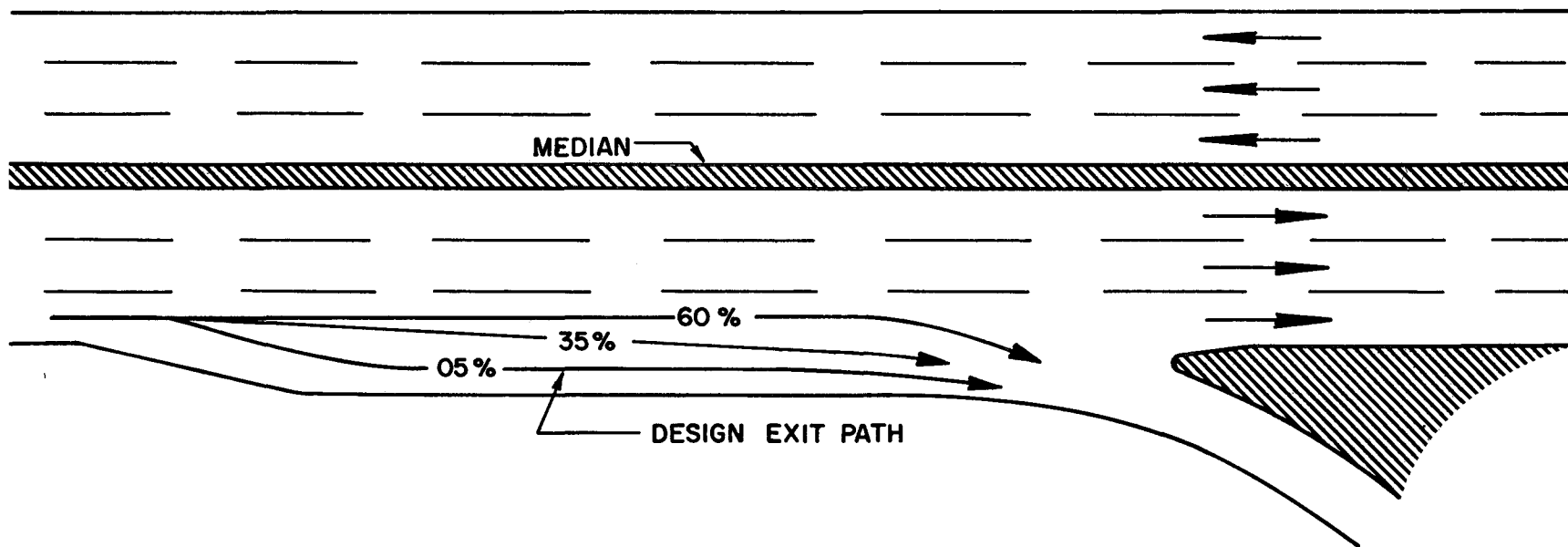
Figure 22 shows the exit paths of vehicles using an exit ramp on the Gulf Freeway. At this location a parallel lane is provided for deceleration but receives little use as indicated by the vehicle paths. This lack of



## EXIT RAMP TYPES

FIGURE 21





EXIT PATHS

FIGURE 22

usage is related to the exit ramp driver's desire to follow a natural and easy exit path requiring a minimum of maneuvering. Use of the parallel deceleration lane requires a reverse curve movement which represents additional driver maneuvering.

Thus, if design of exit ramps is to be fitted to actual traffic behavior, a natural, direct-type off-ramp appears to be necessary. Other studies<sup>4</sup> have also indicated the desirability of the direct-type exit due to the minimum effect on the freeway traffic stream. If the ramp is designed to accommodate traffic exiting at freeway design speed, then the exit maneuver is accomplished with a very low relative speed and little or no effect on the main freeway traffic.

#### Adequate Sight and Deceleration Distance

If the design of the exit ramp allows off-ramp traffic to exit from the freeway at design speed as discussed in the previous section, careful consideration must be given to the design of that portion of the exit ramp which lies past the ramp nose. A sufficient deceleration distance must be provided and adequate sight distance should be available to allow the driver to judge conditions and adjust his vehicle to a proper speed for traversing the terminal area.

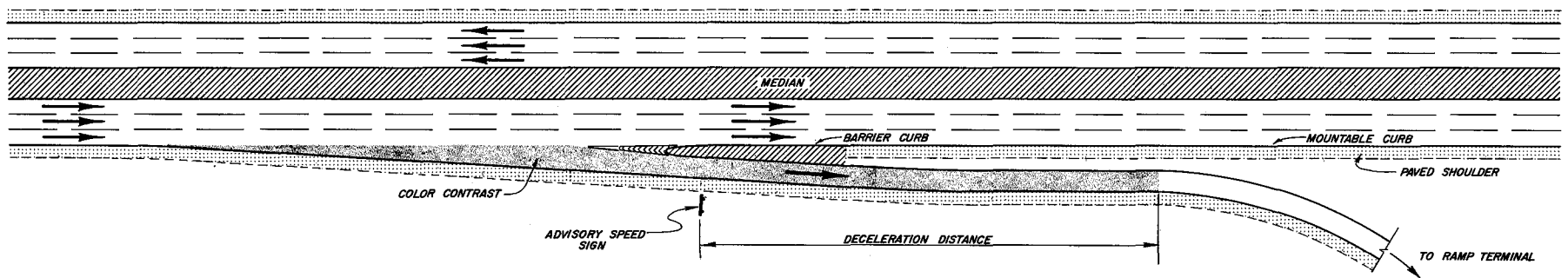
Due to variation in interchange designs and ramp connections there are many different types of ramp terminals confronting exit drivers. Each type of terminal may require different operation of the vehicle. The exit ramp should be designed so the driver will be able to safely maneuver through the terminal area regardless of its design.

#### Delineation of Ramp Nose and Exit Area

Care must also be exercised to assure that the driver can adequately distinguish the exit ramp and be able to make the proper maneuver. The driver can be materially aided in this respect by providing good contrast and delineation of the exit ramp. This can be accomplished by paint, paint striping, and color differences between main freeway lanes and exit ramp area.

#### Desirable Exit Ramp Design

Figure 23 shows an exit ramp design which incorporates the features previously discussed. This design correlates the needs and desires of traffic with design features to obtain maximum safety and efficiency of operation. Since the design will vary slightly with such features as design speed, terminal conditions, etc., no specific figure or dimensions have



DESIRABLE EXIT  
RAMP DESIGN

FIGURE 23

been indicated. The suggested design shown, however, could be adapted to specific conditions as required.

#### ACKNOWLEDGEMENT

Grateful acknowledgement is made to representatives of the Texas Highway Department and the cities of Houston, Dallas, Fort Worth, and San Antonio for their cooperation, valuable advice, and assistance.

Gratitude is also expressed to Fred H. Edwards, graduate student in civil engineering at A. & M. College of Texas, who made significant contributions to the study.

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