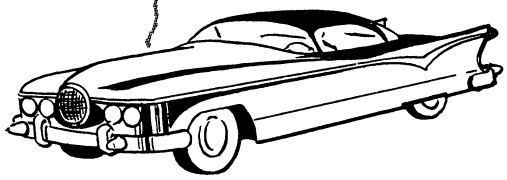
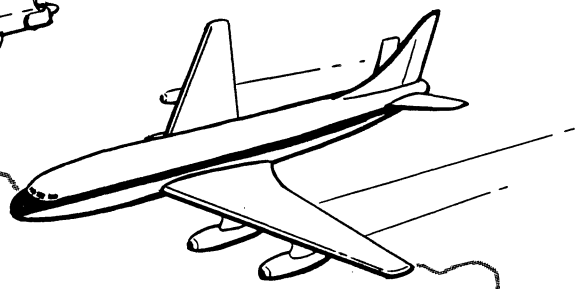
# DRIVER REQUIREMENTS IN FREEWAY ENTRANCE RAMP DESIGN





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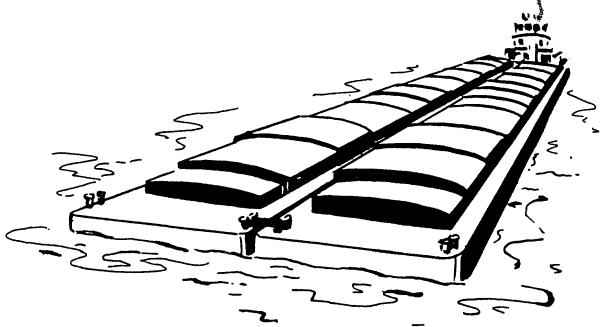

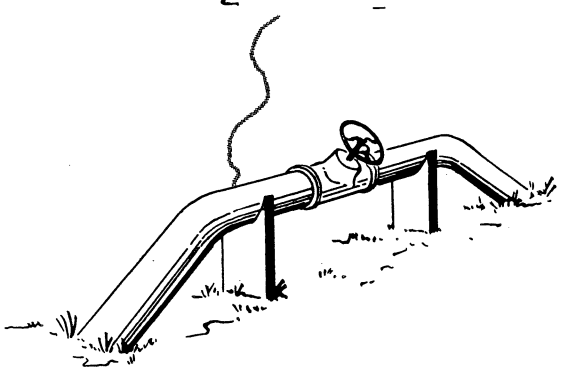

Texas Transportation Institute

***The 1960 Past Presidents' Award Paper***

# Driver Requirements in Freeway Entrance Ramp Design

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FREEWAY DESIGN and operation is still a relatively new phase of highway and traffic engineering and existing freeway systems have only recently experienced traffic volumes that permit a full evaluation of their operational efficiency. The designers of many existing freeways were faced with the difficult problem of designing a facility whose concept was entirely new with little or no operational data from which to guide the design. In the absence of operational data, the freeway designer was forced to use primarily vehicle performance data (size, speed, acceleration, etc.), topographical requirements and economy as a basis for design. In most cases this resulted in a lack of attention to the human aspect relating driver requirements and traffic behavior to design.

Safe and efficient entry maneuvers *can* be made on most of the entrance ramps in use today, but many were not designed so that the desired maneuvers are natural and easy and *will* automatically be performed by the individual drivers.

Freeway designers must become more concerned with the relationship of design and traffic behavior in order to obtain maximum operational efficiency on freeway facilities. This paper discusses operational characteristics of freeway ramp traffic and presents the essential elements in correlating ramp design with driver requirements.

## Entrance Ramp Studies

The material to be presented is based upon the results of numerous freeway ramp studies conducted on freeways in Texas. Most of the data were obtained by motion picture studies in which traffic operations at 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 that was provided by a portable tower. The movies were made at a camera speed of 10 frames per second which allowed determination of vehicle speeds, delays, headways and other traffic characteristics and also permitted the reproduction of traffic operation at near actual speed for detailed studies of operation.

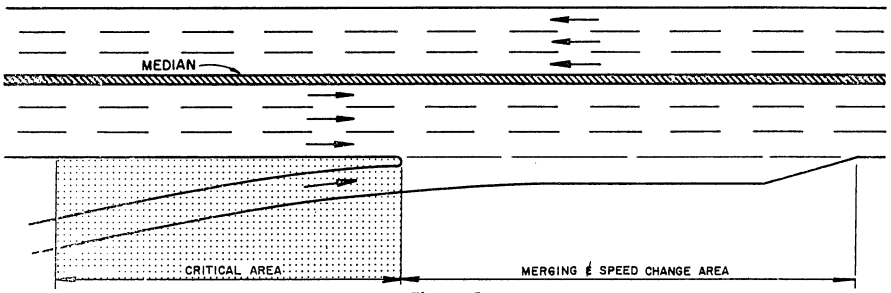



**Figure 1**
**Critical Area Ramp Design**

Eleven separate ramp studies were conducted on freeways in the cities of Dallas, Fort Worth, San Antonio and Houston, Texas. The study locations were specifically selected to provide data on various type entrance ramps operating under different volume conditions.

## Factors in Entrance Ramp Design

The studies of freeway 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 consideration for traffic behavior and driver requirements in the initial design of the ramp. These operational problems can be serious as entrance ramps are critical elements of freeway systems and the operation of the entrance ramp can have tremendous effect upon the operational efficiency of the entire freeway system. Therefore, it is essential that freeway entrance ramps be designed to obtain a maximum of operational efficiency.

Entering a high-volume and high-speed freeway is one of the most difficult maneuvers required of freeway drivers. The entering driver must approach the freeway, evaluate the traffic stream on the main freeway lanes and select a suitable gap into which he can maneuver his vehicle. He must then adjust the speed of his vehicle and make an entry maneuver while giving due consideration to other vehicles on the ramp and main freeway (both ahead and behind) that may influence his maneuver. Thus a freeway entry is a very complex maneuver requiring numerous and rapid driver decisions and the driver should be given every assistance possible in making this entry maneuver by incorporating his requirements into the design of the entrance ramp.

Most previous entrance ramp studies and discussions have considered the design of acceleration lanes. However, it was found in these studies that the most critical area in entrance ramp design is the area traversed by the entering ramp vehicle before reaching the ramp nose. In this area (Figure 1), the driver makes decisions regarding his freeway entry and the design of this area has marked influence on the entry maneuver made by an entering driver.

Reprinted from *Traffic Engineering*, December, 1960

Proper design of this critical area is essential to establishing the necessary correlation between design and operation and in providing necessary driver requirements. Results of the entrance ramp studies indicated the following factors are vital functional elements of good entrance ramp design and essential to the provision of necessary driver requirements:

1. *Angle of Entry*—formed by the intersection of entrance ramp approach and freeway lanes.

2. *Visibility Relationship*—between ramp traffic and freeway traffic.

3. *Delineation*—ramp nose and acceleration lane.

Each of these factors are related to the requirements of entering ramp drivers and when properly considered in the design of an entrance ramp they will enable ramp traffic to enter the freeway with a minimum of effort and with maximum safety and efficiency.

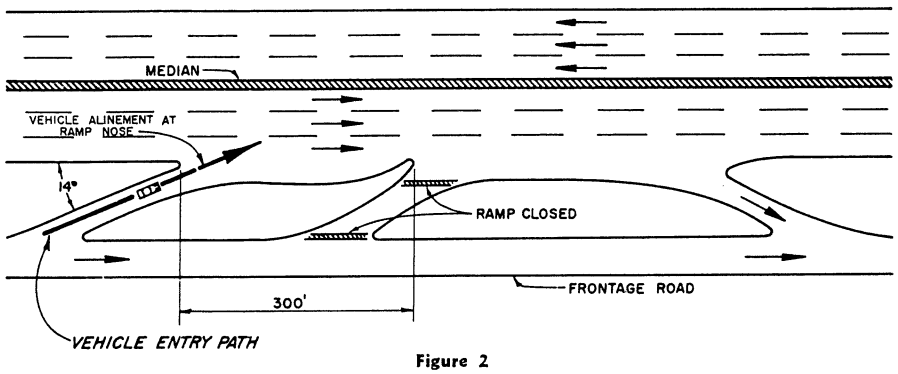
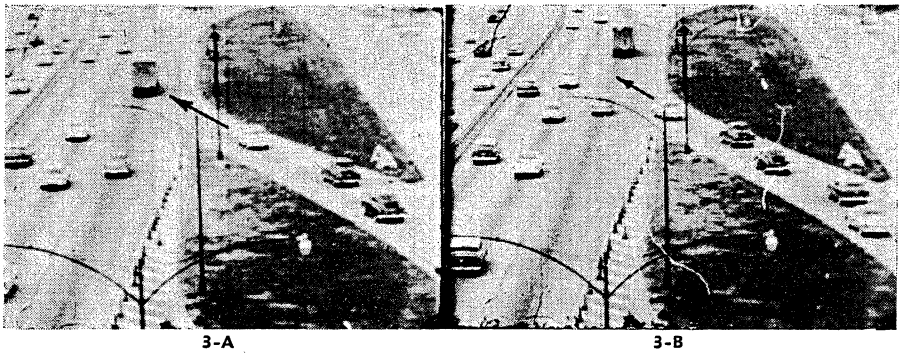
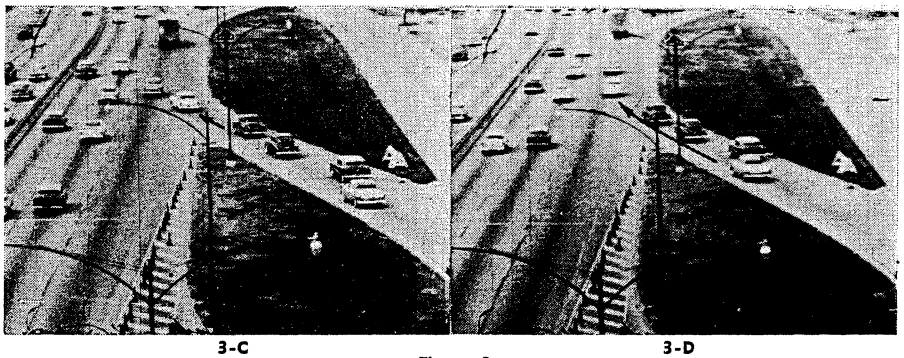



**Figure 2**
**Cullen On-Ramp, Gulf Freeway—Houston**

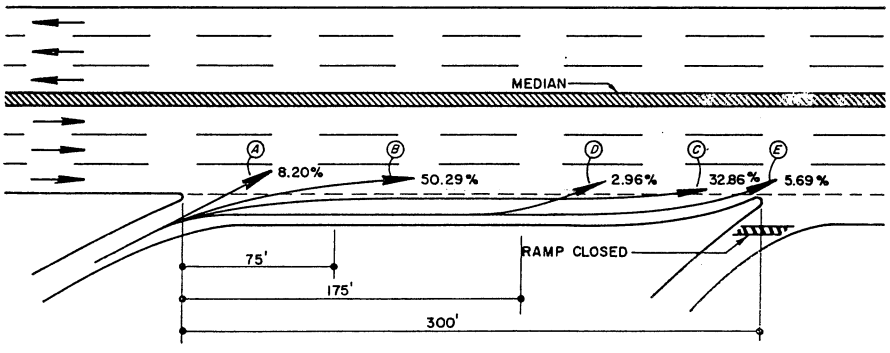


3-A 3-B



3-C 3-D

**Figure 3**
**Direct Type Vehicle Entry**




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%

**Figure 4**
**Paths of Entry, Short Acceleration Lane**

*Angle of Entry*

The initial ramp studies were conducted on the Gulf Freeway in Houston, Texas, at a location where the entrance ramps had an angle of entry (angle between main freeway lanes and entrance ramp) of approximately 14° as shown in Figure 2. This high angle of entry tended to aim the entering drivers along a direct-type entry path into the main freeway lanes as illustrated in Figure 3.

A study of vehicle entry paths at this location indicated the ramp usage pictured in Figure 4. As can be seen, a relatively small per cent (8.65) of the drivers fully utilized the acceleration lane which was 300 feet in length. The predominant direct-type entry results in the creation of a high relative speed between entering ramp traffic and main freeway traffic, which develops undesirable friction in the freeway traffic stream. During peak periods this results in inefficient and hazardous operation and sometimes complete breakdown of freeway operation.

Modifications were made in the ramp design (Figure 5) 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 acceleration lane usage and ramp operation. The entry paths on this type ramp are shown in Figure 6. The direct, high relative speed type of entry was reduced by 21.1% but was still being made by 70.18% of the entering ramp drivers.

Operational studies were also conducted on entrance ramps with a smaller angle of entry and on ramps which had been modified with paint lines to align drivers along the acceleration lane. These studies indicated an increased use of the acceleration lane and smoother merging of ramp and freeway traffic. A typical entry of this type is shown in Figure 7.

Thus it was indicated that the angle of ramp approach is the primary influence on the entry path followed by an entering driver. If desired usage of the acceleration lane is to be obtained it is necessary to align the driver along the acceleration lane by providing a flat-angle approach as indicated in Figure 8.

*Visibility Relationship*

The visibility of freeway lanes and freeway traffic provided entering ramp traffic is one of the most essential requirements of ramp drivers. Studies of traffic behavior on entrance ramp approaches where good visibility was available indicated that drivers begin their evaluation of the freeway traffic stream as far as 200 feet before reaching the ramp nose. If suitable gaps are available in the traffic stream, a decision regarding freeway entry can often be made well in advance of the entrance 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 an 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 on the acceleration lane or "speed-adjustment lane" and performs a smooth lane-change maneuver into the freeway. 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 and be delayed while selecting a freeway gap.

Figure 9 shows a sequence of telephoto shots of a driver as he enters a freeway. This driver has reduced the speed of his vehicle to a slow crawl at the ramp nose and is making his freeway gap evaluation at this location. From this point the driver must look back over his shoulder (a very uncomfortable maneuver) to judge freeway gaps and a very high relative speed (25 to 35 mph) exists between his vehicle and the main freeway traffic. This type of freeway entry is very difficult and often hazardous.

Figure 10 shows the behavior of another driver entering a freeway that has selected a gap before reaching the ramp nose. This driver moves into the freeway with a low relative speed (5

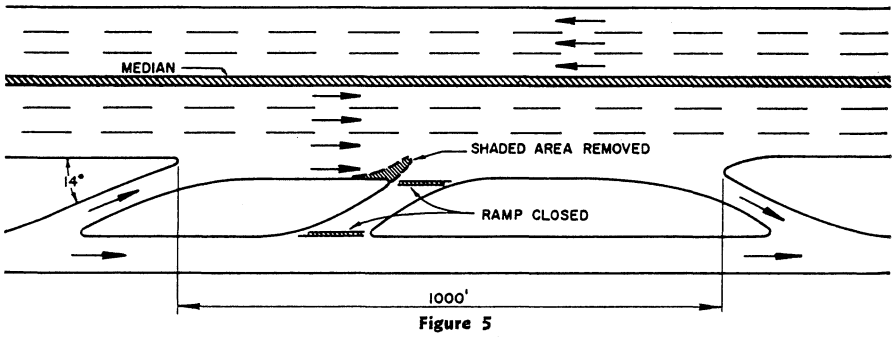



**Figure 5**
**Cullen On-Ramp Modified Nose**

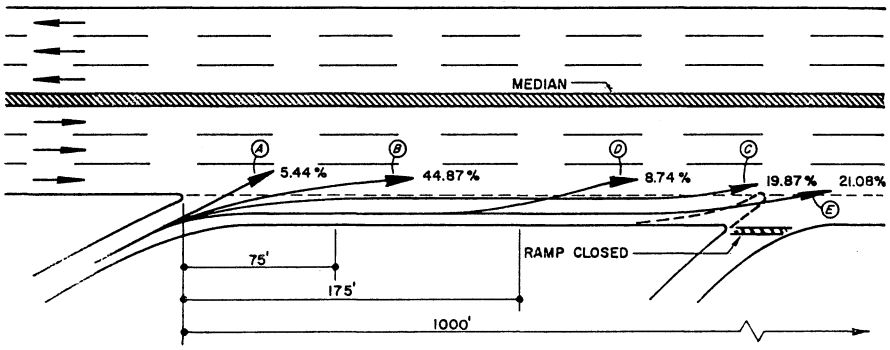
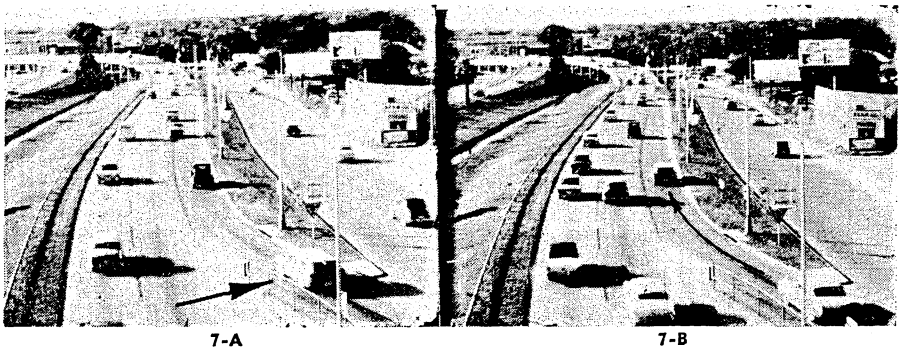
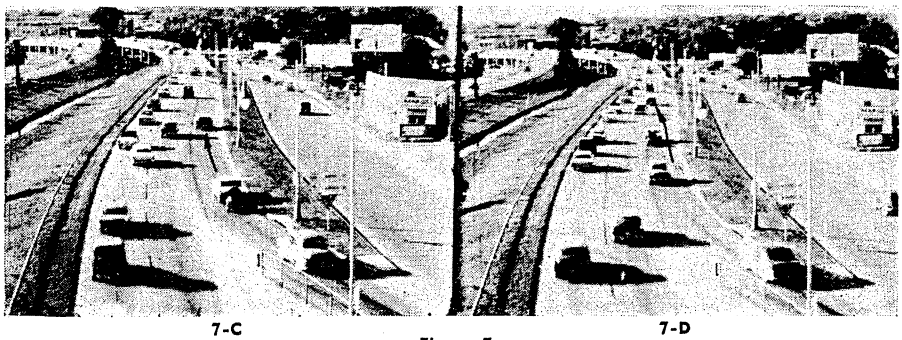



**Figure 6**
**Paths of Entry, Long Acceleration Lane**



7-A 7-B



7-C 7-D

**Figure 7**
**Desirable Vehicle Entry**

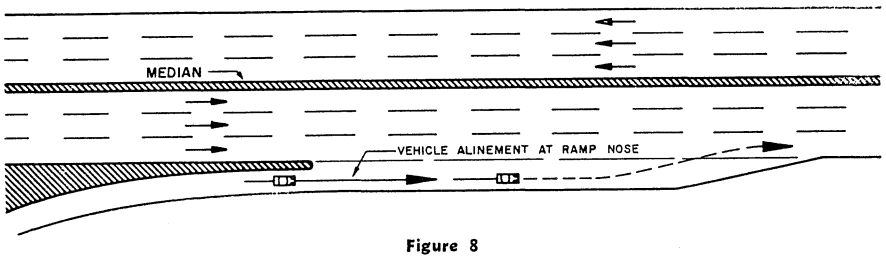
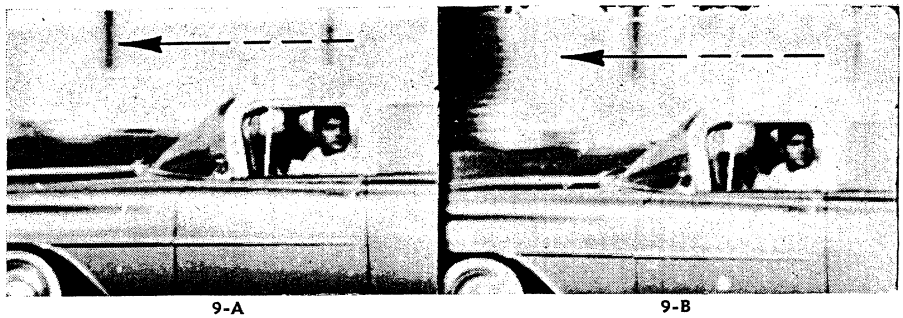



**Figure 8**
**Flat Angle Approach**



9-A 9-B

9-C 9-D

Figure 9
Behavior of Driver Entering Freeway from Ramp with High Relative Speed

10-A 10-B

10-C 10-D

Figure 10
Behavior of Driver Entering Freeway from Ramp with Low Relative Speed

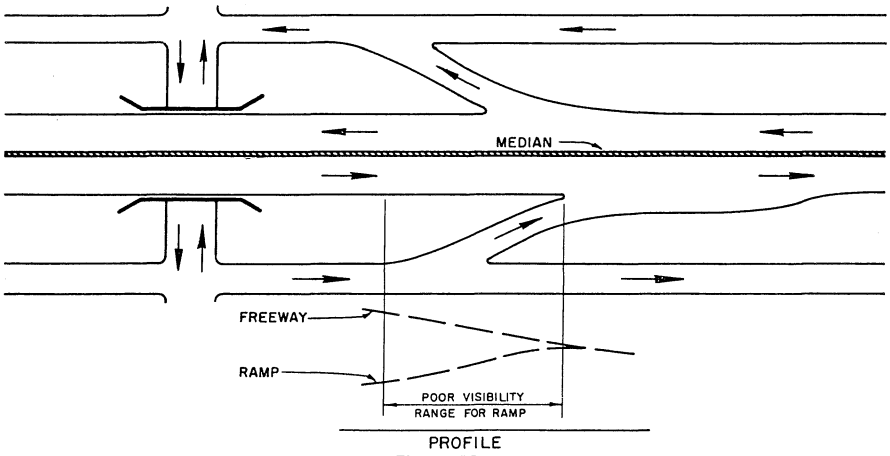



Figure 11
Diamond Interchange

to 10 mph) and with a minimum of driver effort. His entry is simply a "lane-change maneuver" and has little or no disturbing effect on the main freeway traffic.

Many existing freeway ramps do not provide this essential requirement of good visibility to the entering ramp driver. A typical problem which can develop is shown by the diamond interchange design in Figure 11. In this case the freeway is carried over the city street and an entrance ramp is introduced just past the overhead structure. As indicated by the grade profile (Figure 11) and the snapshot in Figure 12A, a very bad sight restriction exists. It is impossible for the driver on this ramp to evaluate freeway traffic before reaching the ramp nose. As a result a majority of the ramp traffic is forced to stop at the ramp nose and enter the freeway with a high relative speed.

Careful consideration in design must be given to providing adequate visibility such as is indicated in Figure 12B. Freeway entrance ramp grades (either ascending or descending) should be made to match that of the freeway a minimum of 200 feet in advance of the nose (Figure 13). This provides entering ramp traffic with adequate visibility and permits the drivers to begin evaluation and selection of freeway gaps before reaching the ramp nose.

*Delineation*

A third vital requirement of entrance ramp drivers is adequate delineation of the ramp nose and acceleration lane. Although increased use of freeways has resulted in a larger percentage of drivers educated to the use of their various elements, there are still many drivers who do not fully understand the proper method of entering a freeway. Also, there are 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 and the ramp drivers often do not know that the acceleration lane is exclusively for their use. This often results in very inefficient operation with the traffic stopping at the entrance ramp nose.

It is essential to inform the drivers of what is provided for their use in entering the freeway. Good delineation in the form of color contrast, paint striping and/or other methods should be provided to enable the drivers to

distinguish adequately between main freeway lanes and the portion of the entrance ramp specifically designed for their use. This would eliminate much driver indecision and greatly facilitate safe and efficient ramp operation.

## Entrance Ramp Accidents

Studies of accidents on freeway facilities in Texas with special emphasis on correlating accidents with design elements have indicated that entrance ramps often experience a high accident frequency. A high accident pattern on an entrance ramp is shown in Figure 14. The predominant accident type is the rear-end collision and the ramp design provides a high angle of entry, poor visibility and poor delineation.

During the various study periods five ramp accidents occurred and were recorded on film. A typical entrance ramp accident is illustrated in Figure 15. Here, as in the case of most entrance ramp accidents, the accident resulted from a false start by the leading vehicle and a collision by the trailing vehicle. The driver of a trailing vehicle on an entrance ramp is put in the unfortunate position of needing to look in two directions at the same time. He must accept a gap in the freeway traffic 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.

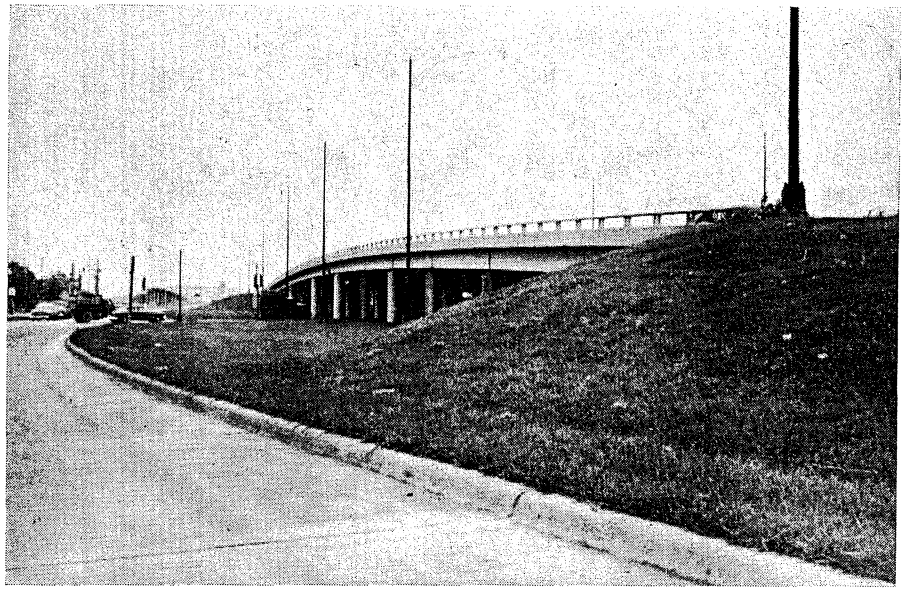
The basic cause of this accident, however, is related to the fact that many of the vehicles are required to make an abrupt stop at the ramp nose. The cause of this stop is related to a lack of design consideration for the previously discussed factors of approach angle, visibility, and delineation. If 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 and driver requirements will 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.

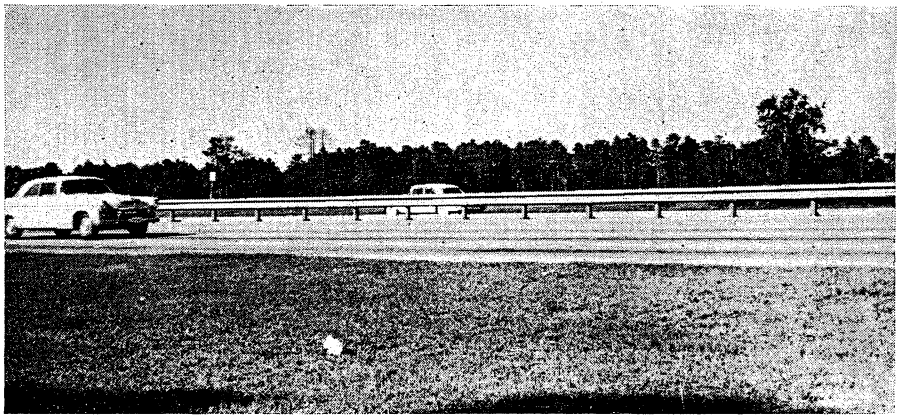
## Ramp Approach Width

Several studies were conducted on entrance ramps with wide approaches such as the one shown in Figure 16. The approach width on this ramp was designed to allow one lane for traffic movement and sufficient width to pass disabled vehicles. This design, however, illustrates a lack of consideration for traffic behavior. Rather than use the ramp for one lane operation as intended, when peak loads occur, traffic on the ramp will use the facility as a two-lane ramp. In all cases, this resulted in unsatisfactory operation.

Since only one vehicle at a time can utilize the acceleration lane, the two lanes of approaching ramp traffic must merge into single file at the ramp nose, or else, the vehicle in the left lane of



12-A
**Entering Drivers' View from Ramp Approach with Poor Visibility**



12-B
**Entering Drivers' View from Ramp Approach with Good Visibility**

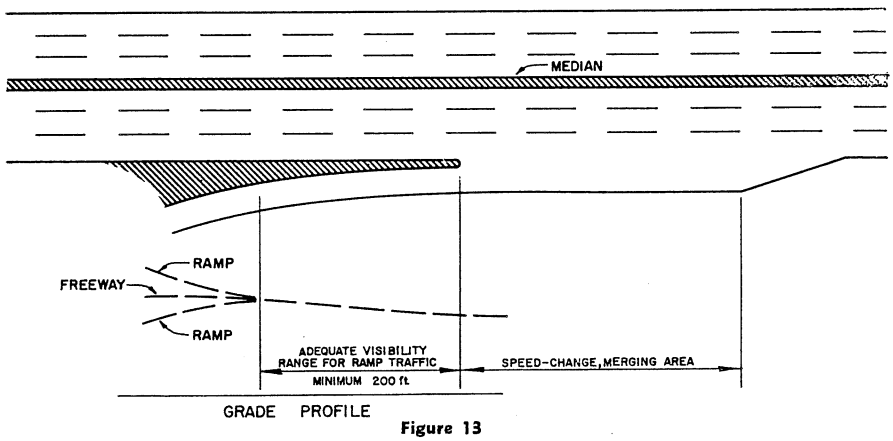
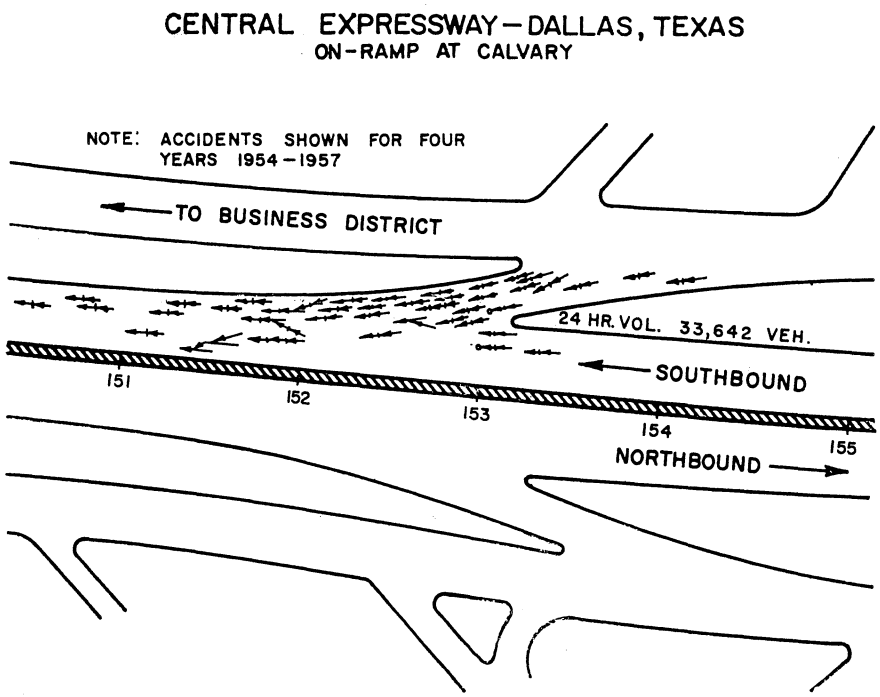



**Figure 13**
**Ramp Grade**



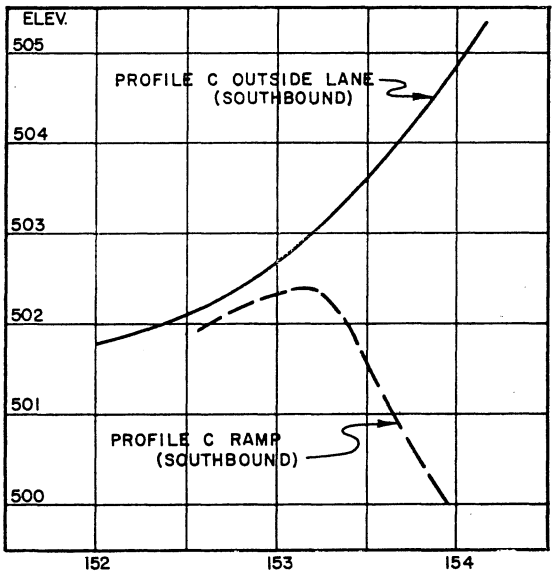
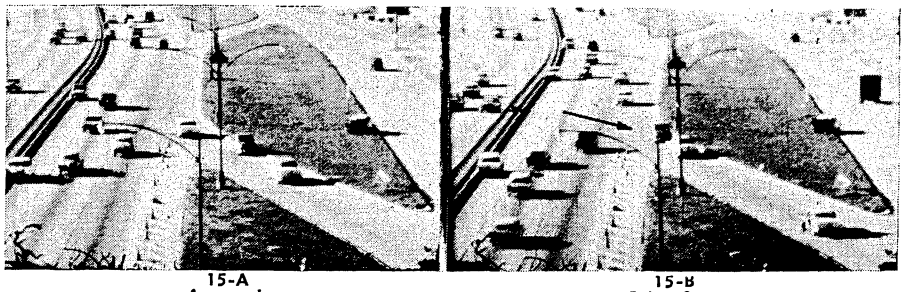
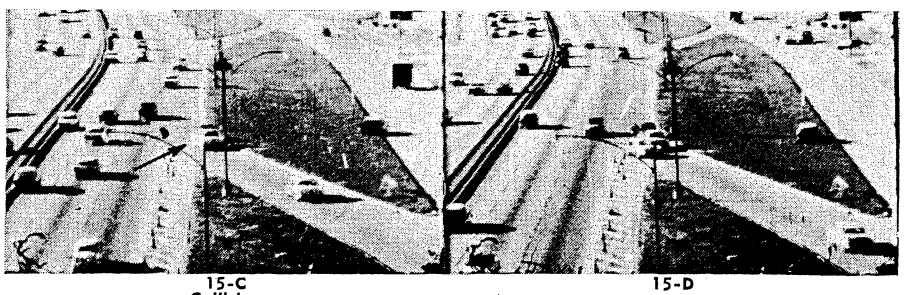




Figure 14



15-A Approach

15-B False Start



15-C Collision

15-D

Figure 15
Ramp Accident

the ramp is forced to make a direct entry into the freeway without the benefit of an acceleration lane. A typical illustration of this operation is shown in Figure 17. In this case, two-lane operation is occurring and the 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 creates a hazardous situation as traffic behind this car attempts to change lanes in order to reduce their delay.

This ramp was later modified so that only single-lane operation was permitted. "After" studies at this location indicated much smoother ramp operation and an increase in ramp capacity due to the elimination of the situation shown in Figure 17.

This led to the conclusion that the approach section of an entrance ramp should be designed to accommodate only one lane of traffic. A mountable curb and paved shoulder should be provided on the right to allow disabled vehicles to leave the traffic stream.

### Desirable Entrance Ramp Design

Figure 18 illustrates an entrance ramp design incorporating all of the features previously discussed. This design provides the necessary correlation between traffic behavior and design to provide the necessary driver requirements.

The length and design of the acceleration lane indicated is perhaps subject to question. Research is continuing in this area but data available at present indicate that the design shown in Figure 18 would operate very satisfactorily. With a low approach angle and proper visibility provided, higher entry speeds can be obtained and the acceleration lane becomes more of a "speed-adjustment lane."

Another point which should also be considered is the operation of entrance ramps during periods of peak traffic movement. It has been observed during the course of the ramp studies, that there are periods of short duration (10 to 15 minutes) during which the main freeway traffic volumes are of such magnitude that satisfactory entrance ramp operation is impossible to obtain. This is simply a case of traffic demand exceeding capacity and no improvement in ramp design will solve the problem.

There is, however, in the case of most freeway facilities approximately 23 hours a day during which the entrance ramps and adjacent freeway

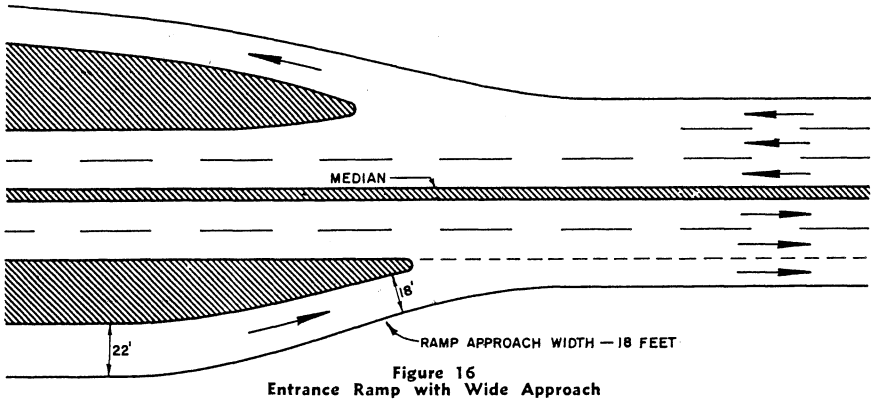
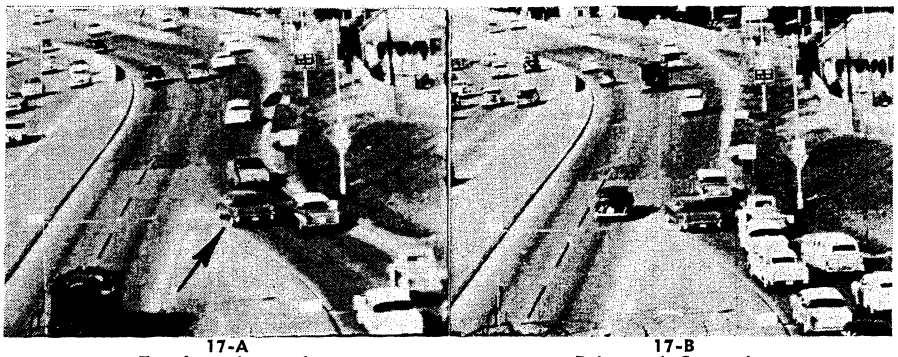
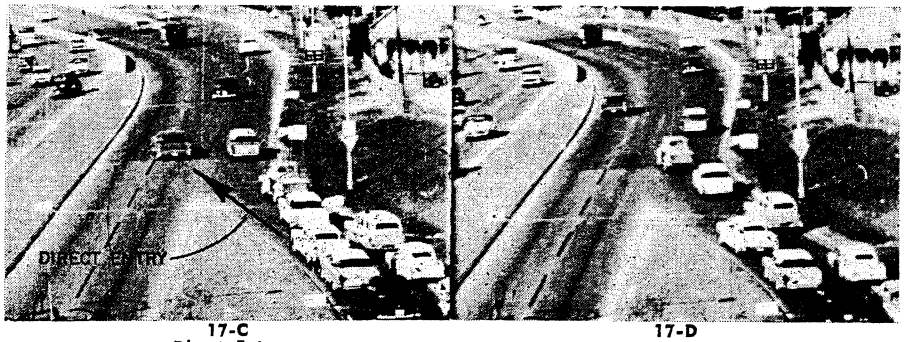



Figure 16
Entrance Ramp with Wide Approach



17-A
Two Lane Approach

17-B
Delay and Congestion




17-C
Direct Entry

17-D

Figure 17
Two Lane Ramp Operation

sections are operating below possible capacity. It is during this period that the entrance ramps should be operating with a maximum of safety and efficiency.

## Summary

Relating the design of freeway entrance ramps to traffic behavior as indicated by the requirements and desires of the driver is a necessity if maximum efficiency and safety in ramp and freeway operation is to be obtained.

Entrance ramp design should provide the following:

1. A flat angle ramp approach which aligns the driver along an easy and natural path into the freeway.
2. Adequate visibility 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 would eliminate any confusion in distinguishing between the entrance ramp elements and the main freeway lanes.

While this paper has dealt only with freeway entrance ramps, the concept of considering traffic behavior and driver requirements is applicable to all elements of freeway design. It is essential that freeway operational research be continued and that the results of such research be incorporated into the design of future freeway facilities.

## Acknowledgement

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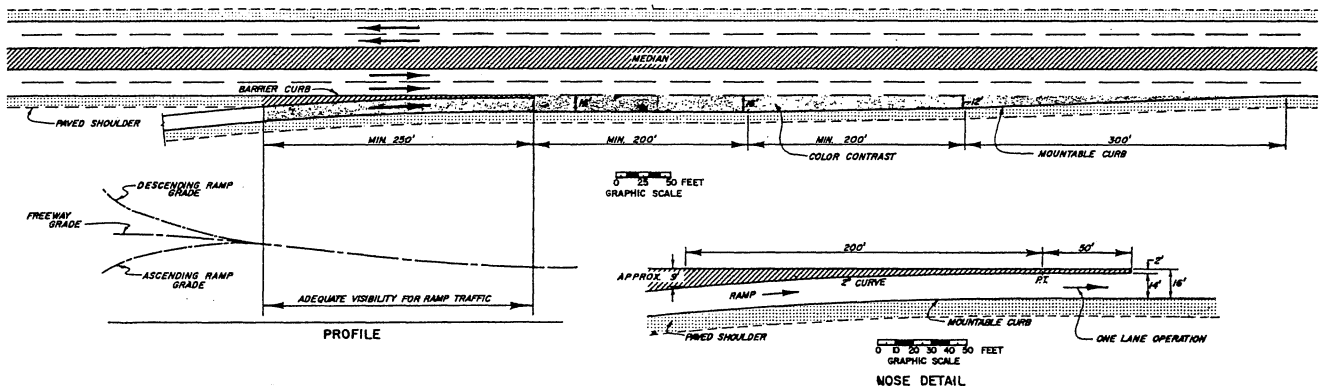


Figure 18
Desirable Entrance Ramp Design