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16. Abstract

This report documents the findings of a detailed study of freeway frontage road operation and safety. Vehicles were video taped during the exit and entry maneuver to and from frontage roads for all types of ramps. Erratic maneuvers were identified and recorded. The master file of the Department of Public Safety accident file was searched and accidents occurring in the ramp areas identified.

The report documents the types of erratic maneuvers observed and the recommended treatments to reduce the number of erratic traffic movements in ramp areas. There was no apparent pattern to erratic maneuvers except that slip ramps to one-way frontage roads had the largest percentage of these maneuvers. The accident analysis revealed that ramp type was not a significant contributor to accident experience at the ramp-frontage road intersection. Frontage road ADT and degree of roadside development were found to be significant.

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OPERATIONAL AND SAFETY ANALYSIS

OF TWO-WAY AND ONE-WAY FRONTAGE ROADS

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Research Report 288-2

Freeway Ramp and Frontage Road Operation
Research Study Number 2-18-80-288

Sponsored by

State Department of Highways and Public Transportation
In Cooperation with the
U.S. Department of Transportation
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Texas Transportation Institute
The Texas A&M University System
College Station, Texas

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ABSTRACT

This report documents the findings of a detailed study of freeway frontage road operation and safety. Vehicles were videotaped during the exit and entry maneuver to and from frontage roads for all types of ramps. Erratic maneuvers were identified and recorded. In addition, the master file of the Department of Public Safety accident files was searched for accidents occurring in the ramp area.

The report findings document the types of erratic maneuvers observed and recommend treatments to reduce the problem. In this study, there was no apparent pattern to erratic maneuvers except that slip ramps to one-way frontage roads had the largest percentage of these manuevers. The accident analysis revealed that ramp type was not a significant contributor to accident experience at the ramp-frontage road intersection. However, frontage road average daily traffic (ADT) and degree of roadside development were found to be significant.

ACKNOWLEDGEMENT

The authors wish to thank the State Department of Highways and Public Transportation for providing the support necessary to conduct this study.

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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1. INTRODUCTION

1.1 Need for the Study

Frontage roads have been an intregal part of freeways in Texas. When frontage road volumes are relatively low, two-way frontage road operation is relatively safe and efficient. Increases in roadside development and the associated increase in frontage road traffic make two-way operation less safe. At some point, conversion to one-way operation is desirable. The purpose of this study was to define the operational and safety problems of frontage roads. Further, warrants for conversion from two-way to one-way operation were to be developed. This report documents the safety and operational studies conducted at ramp terminals and points of transition from one-way to two-way operation.

1.2 The Basic Problem of Two-Way Operation at Intersecting Roadways

Roadways intersecting with the freeway are typically grade separated, resulting in two rather closely spaced frontage road intersections. With two-way operation, these two closely spaced intersections are difficult to signalize and are sometimes unsafe. Figure 1 illustrates the complexity of this intersection.

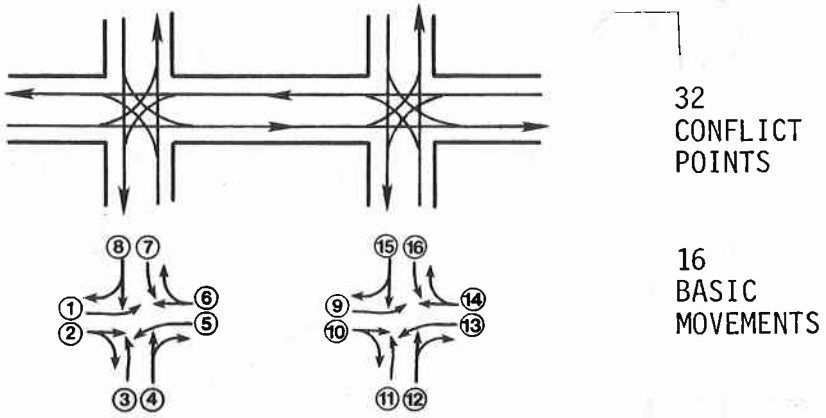


Figure 1
Conflict Points with Two-Way Operation

Figure 2
Conflict Points with One-Way Operation

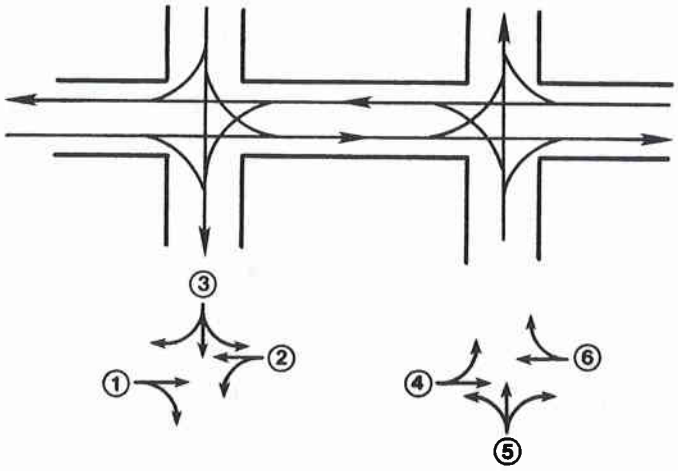


Figure 2 illustrates the less complicated operation of the two closely spaced intersections with one-way operation.

Thus, one-way operation should be much safer (only ten conflict points rather than 32 for two-way operation) and far easier to signalize (only six basic movements rather than 16 in two-way operation). As the traffic volumes increase to the point where capacity is a concern, conversion to one-way operation becomes increasingly attractive.

The two closely spaced intersections also create a basic storage problem when they are signalized. This storage problem increases delay, reduces capacity, and forces the two intersections to be signalized as a unit. The obvious solution is to convert to one-way operation on the frontage road. However, this action is politically sensitive. Businesses located on the basis of two-way operation fear a loss of business potential as a result of the conversion. Customer trip length is frequently increased, resulting in greater fuel consumption and trip time. For these reasons, conversion from two-way operation to one-way operation is unpopular. This point is described in greater detail in the subsequent section.

1.3 Public Reaction to Frontage Road Conversion

Based on the feedback from Districts 2 and 14 and a few cities (Austin, Amarillo, Fort Worth and Abilene) regarding freeway frontage road conversion from two-way to one-way operation, two basic public complaints surfaced:

1) Business loss due to reduced volume of traffic in front of the establishment; and,

2) Greater travel distance required to access a business or other roadside development.

In both instances, there is a degree of credibility. Businesses which have been built around two-way access can be adversely affected by conversion to one-way operation. This effect may well be one of accelerating the rate of decline as opposed to creating a decline in business, similar to the effect of highway bypasses on smaller commmunities. Businesses which are marginal may be forced out of business due to the shock of the change before the traffic patterns adapt to the revised operating condition.

The second concern, that of added travel distance, also needs to be addressed. Figure 3 illustrates the added travel times for interchange or overpass spacings of one-half, one, and one-and-one-half miles, assuming direct access to the interchange. The situation illustrated in Figure 3 (on a percentage basis) is the worse case situation. Figure 3 indicates that the added distance of travel for a half-mile spacing is about 50 percent.

Providing access to a residential development is also a difficult problem when converting from two-way to a one-way frontage road operation. Every potential conversion must be carefully reviewed and potential access problems solved prior to the conversion date. Access from other points must

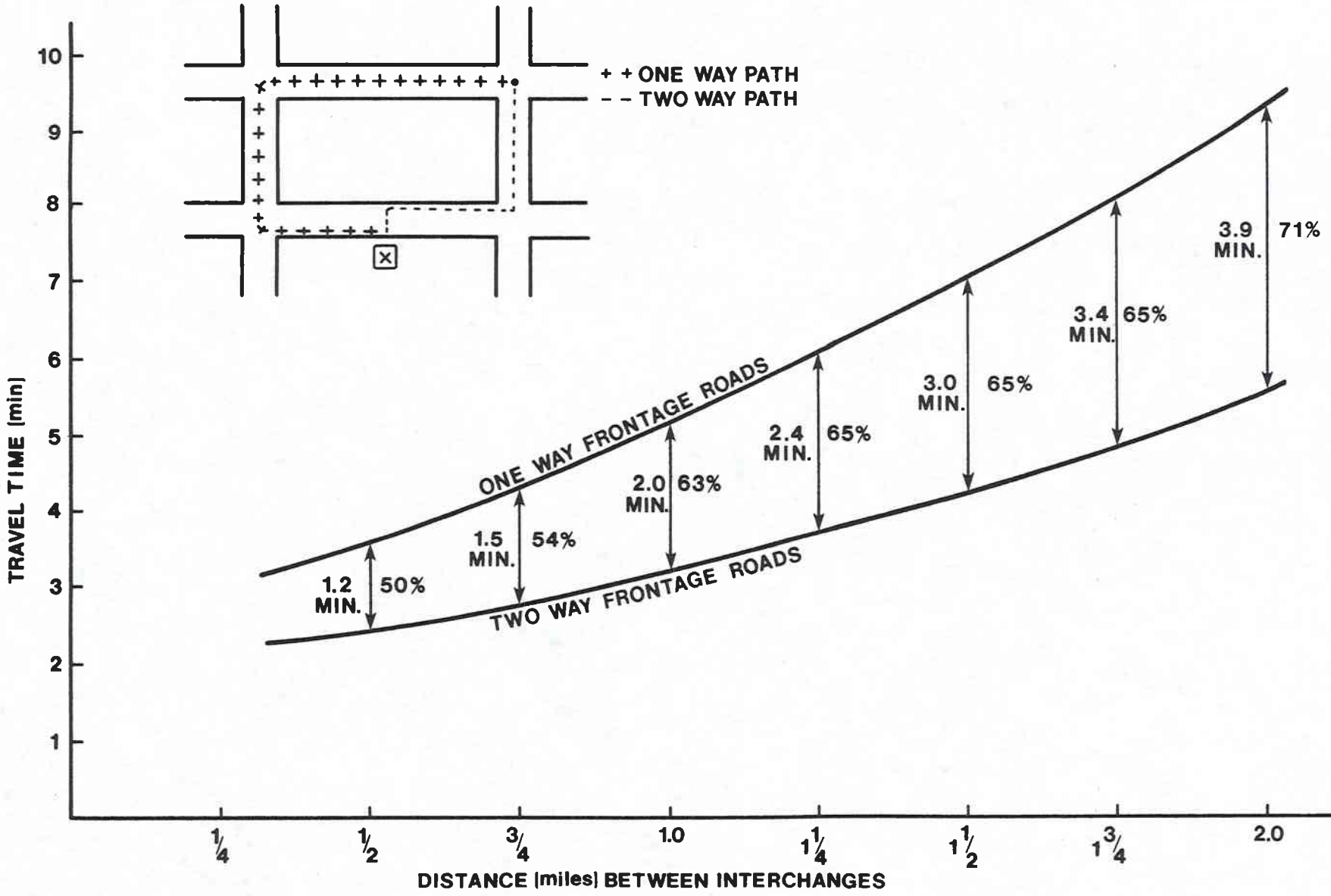


Figure 3

Travel Disadvantage: One-Way vs. Two-Way

be provided to make conversion to one-way operation even reasonably acceptable. Until one or more alternate access roads have been completed, conversion should be delayed. One typical case is illustrated in Figure 4.

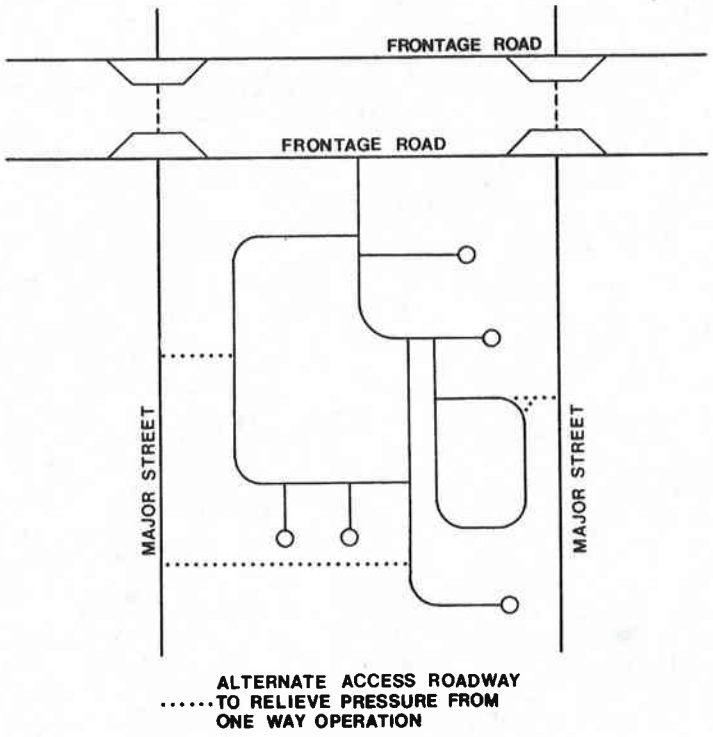


Figure 4
Schematic of Alternate Access Routes

However, problems due to conversion to one-way frontage roads can be minimized by providing for such conversion in the original residential development plan. To do this, SDHPT would permit initial access to a two-way frontage road only if at least one and preferably two access points to major streets are provided. Alternative access routes are the responsibility of local government and must be referred to the proper jurisdiction for handling.

The public complaints on frontage road conversion are basic public relations problems. A well organized public information compaign should be mounted to coincide with the announcement that conversion is being considered. The program should stress:

1. The need for one-way operation.
2. The safety problems of two-way operation documented by photographs and slides.
3. The measures taken by SHDPT to reduce the impacts of the conversion to one-way operation.
4. Both the positive and negative aspects of conversion:
   a) May temporarily impact business during the traffic readjustment period.
   b) Will require additional enforcement for about a two-week period after conversion.
   c) Will increase travel distance and time to and from some points. An added travel time contour map for each major area along the frontage road can effectively convey the added travel requirements to property owners.

A model program might be organized as follows:

Step 1. Identify the potential problem areas in frontage road conversion. Watch especially for businesses which will be isolated or disadvantaged by the conversion.

Step 2. Work out detailed solutions for each problem so identified.

Step 3. Review conversion plans with appropriate SDHPT officials and obtain necessary approvals.

Step 4. Prepare high quality P-R program on conversion plans. A slide presentation and a printed document (pamphlet, reports, etc.) summarizing the effects of the conversion should be prepared as a minimum.

Step 5. Present conversion plan to local elected officials and obtain feedback.

Step 6. Make necessary adjustments in the conversion plan and obtain support of local elected officials, if at all possible.

Step 7. Arrange a briefing for the Chamber of Commerce Transportation Committee.**

Step 8. Call news conference to announce to local media plans for conversion. The news conference should be very specific about the date of conversion and the associated benefits and disadvantages to the public.

Step 9. Mail announcement of conversion date and detailed description of benefits and disadvantages to all affected property owners. Be certain to include the name and address of person to whom comments or reactions are to be directed.

Step 10. Arrange for enforcement support immediately after conversion.*

Step 11. Prepare series of news releases to be used for the last week prior to conversion, the day of conversion, and for a few days after conversion.**

Step 12. Coordinate signalization, signing and marking changes required by conversion.

** Cooperation of SDHPT and Local Government

* Local Government Responsibility

Step 13. At least two weeks in advance of conversion date, review every detail of conversion plan to be certain that nothing has been overlooked. Make necessary adjustments.

Step 14. Implement conversion program.

Step 15. Follow-up analyses, adjustments.

1.4 Technical Approach in this Research

Ramp terminals and points of transition from one-way to two-way operation were observed in order to identify the nature and frequency of vehicular conflicts. Accident data were also obtained for each ramp and transition point studied. Extended sections of freeway frontage roads converted from two-way to one-way operation were compared on a "before" and "after" accident basis to determine the safety effects of conversion.

The ramp study included all ramp types for both one-way and two-way frontage road operation (slip ramps, with and without a separate lane; braided ramps; and buttonhook ramps). Two traffic levels were included in the study: (1) light to moderate and (2) moderate to heavy. These subjective frontage road volume groups were necessary in the initial phases of the study, as frontage road and freeway mainlane traffic volumes were merged in the basic ADT files of the Department. The basic experimental design for the study was based on the following hypothesis:

"There is a statistically significant difference in the frequency and/or rate of reported accidents and observed erratic maneuvers with increasing levels of intersection complexity and traffic volume levels."

Figure 5 illustrates the statistical nature of this concept.

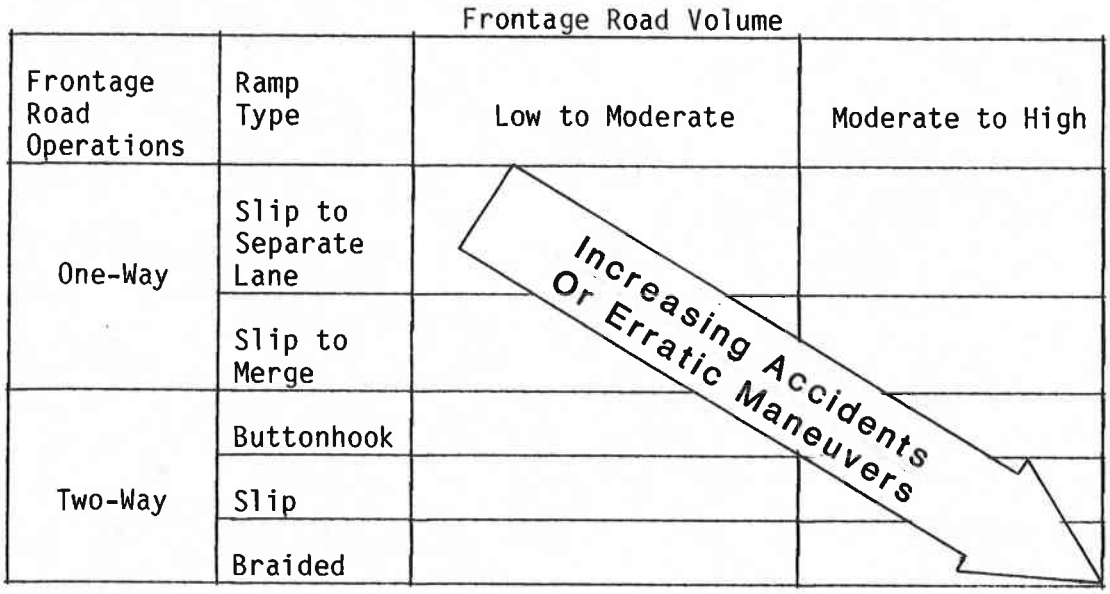


Figure 5

Conceptual Sketch of Expected Effects

Since the ramp types within each type of frontage road operation category were not identically the same, the basic analysis was conducted in two stages:

1. Test to determine if a significant difference could be found within each operational category (one-way or two-way).

If no significant difference within an operational category was found to exist, the experimental matrix could be collapsed into a 2 x 2 factorial matrix involving one-way and two-way operation with low to moderate and moderate to high frontage road traffic levels. Figure 6 illustrates this concept. The second stage of the analysis was, then:

2. Test to determine if a significant difference could be found between frontage road operation types (one-way vs. two-way).

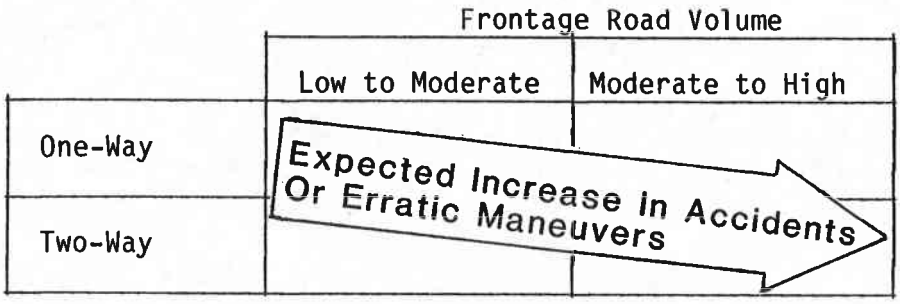


Figure 6

Collapsed Matrix of Expected Effects

It must be recognized at the outset that frontage road volume is greatly influenced by the degree of roadside development. Indeed, this interaction (traffic volume level x degree of roadside development) dominated every relationship which was tested. Each depends upon the other. While both were included in the statistical testing, it should be recognized that they are both measures of essentially the same thing and, therefore, should be treated as one measure in the final analysis.

2. BASIC OPERATIONAL DATA COLLECTION

2.1 Introduction

Operational data were collected on videotape for each ramp type and frontage road operation type shown in Figure 5. Table 1 contains the number of ramp vehicles included in the data analysis for each cell of the experimental matrix along with the number of sites observed.

Table 1. Number of Observations in Each Cell of the Experimental Matrix

Type of Frontage Road Operations	Ramp Type (See Figures 7 to 16 for drawings of types)	On/ Off the Frwy.	Sample Size	
			Sites	Observations
One-Way	Slip Ramp to and from A Separate Lane	ON	6	300
		OFF	6	300
	Slip Ramp to A Merge Situation	ON	5	250
		OFF	4	200
Two-Way	Buttonhook Ramp	ON	4	200
		OFF	4	200
	Slip Ramp	ON	3	150
		OFF	2	100
	Braided Ramp	ON	3	150
		OFF	4	200

2.2 Selection of Data Collection Sites

Prior to collecting data, criteria for the study sites were established. Frontage road sites had specific requirements regarding length, roadside development, traffic volumes, direction of travel (one-way and two-way), number of lanes on the frontage road, and type of ramps. From the frontage road site data, the ramp study sites were chosen with regard to ramp type, frontage road volume, roadside development, and direction of travel on the frontage road. Frontage road transition sites were selected with regard to the type of traffic control in place. Specifically, three types of control were sought: (1) signs only, (2) signs with special markings, and (3) signals with complementary signs and markings. Additionally, sites were selected in several areas of the State in order to eliminate any bias that might exist by having exactly the same treatment at every site.

2.3 Frontage Road Sites

Initially, the various SDHPT Districts were contacted requesting maps locating and describing one-way and two-way frontage roads within their District. From these maps, areas were determined which had the most potential for fulfilling the needs of the study. Next, a two-person team field evaluated the frontage road sections to see if they met the various requirements for selection as a frontage road study site.

To qualify as a frontage road site, the frontage road section between crossroad intersections had to meet a number of requirements: 1) It must have a frontage road one or two miles long on each side of the main lanes of the freeway. 2) Roadside development had to be approximately the same on both frontage roads in each site. Roadside development was classified into one of three categories: urban, intermediate, or rural. Urban development was defined as continuous development from one end of the site to the other. Intermediate development was less than fully urban, but had some development within the site. Rural described a site with little or no development. The volume on the frontage road site was defined as either low-medium or medium-high. This was strictly a subjective judgment made by the data collection team when it was at the site. A number of factors affected the observed traffic on the frontage road; therefore, the volume classification was a best estimate. However, after these data had been collected, the SDHPT provided traffic volumes for the frontage road sites. These were then used to convert accident frequency to accident rates.

Frontage road study sites were classified by the types of frontage road traffic lanes and the type of ramp within the site. The basic site descriptions were:

1. One-way frontage road slip entrance ramp from a combined use lane.
2. One-way frontage road slip entrance ramp from a separate lane.
3. One-way frontage road slip exit ramp to a combined use lane.
4. One-way frontage road slip exit ramp to a separate lane.
5. Two-way frontage road buttonhook entrance ramp.
6. Two-way frontage road buttonhook exit ramp.
7. Two-way frontage road slip entrance ramp.
8. Two-way frontage road slip exit ramp.

9. Two-way frontage road braided entrance ramp.
10. Two-way frontage road braided exit ramp.

Once a frontage road section was chosen as a study site, it was inventoried on color videotape. The lengths of the site were measured using a distance measuring instrument (DMI). Reference points within the site, such as driveways and ramp gore areas, were read from the DMI on to the videotape.

Following the site inventory, the RI-1 sheets and volume data were obtained from the Transportation Planning Division (File D-10) of the SDHPT. Using the mile point data from the RI-1 sheets, the Department of Public Safety (DPS) files were then searched to determine the number of recorded accidents at each site.

2.4 Ramp Study Site

In determining which ramps were to be included in the erratic maneuver study, ramps located in the previously filmed frontage road sites were reviewed. From these data, potential ramp study sites were selected.

Once a potential site was chosen, a data collection team visited it. The team reviewed the site's characteristics, and made a decision as to it's suitability for the study of ramp erratic maneuvers. Once a site was chosen the videotape unit was used to record traffic at the site. A total of 50 ramp vehicles were recorded, and a scale diagram of the ramp was prepared.

The videotape of ramp site operation was reviewed using a Panasonic VHS Omnivision II Tabletop Recorder and 19-inch Panasonic Color Television. Erratic maneuvers observed were diagrammed and categorized into nine erratic maneuver types. These were then tabulated by ramp type and expressed as a percentage of all vehicles observed.

2.5 Transition Study Sites

To locate the one-way to two-way frontage road points of transition within the state, the frontage road maps provided by the Districts were reviewed. These transitions inherently occur at an intersection. The Districts were consulted as to the exact location and type of traffic control at the transition site. From these sources, it was determined that transitions were handled in one of three ways: (1) signs alone, (2) signs with channelization islands, or (3) traffic signals and signs together. Since there were only three different traffic control schemes, it was decided to study six different transition sites, two of each type. In order to get a different type traffic control system within each category, each transition study site within a category was chosen from a different SDHPT District.

The sites chosen were videotaped and diagrammed. At least 50 vehicles were filmed at each site in order to observe any erratic maneuvers that might take place due to the traffic control system.

2.6 Data Analysis

Nine unique types of ramp erratic maneuvers were identified. These types are described in Table 2, while illustrations of these maneuvers are shown in Figures 7 thru 16. The number in the circle (X) on each illustration corresponds to the erratic maneuver descriptions presented in Table 2. The percentages given on each figure are calculated from the observed erratic manuever data.

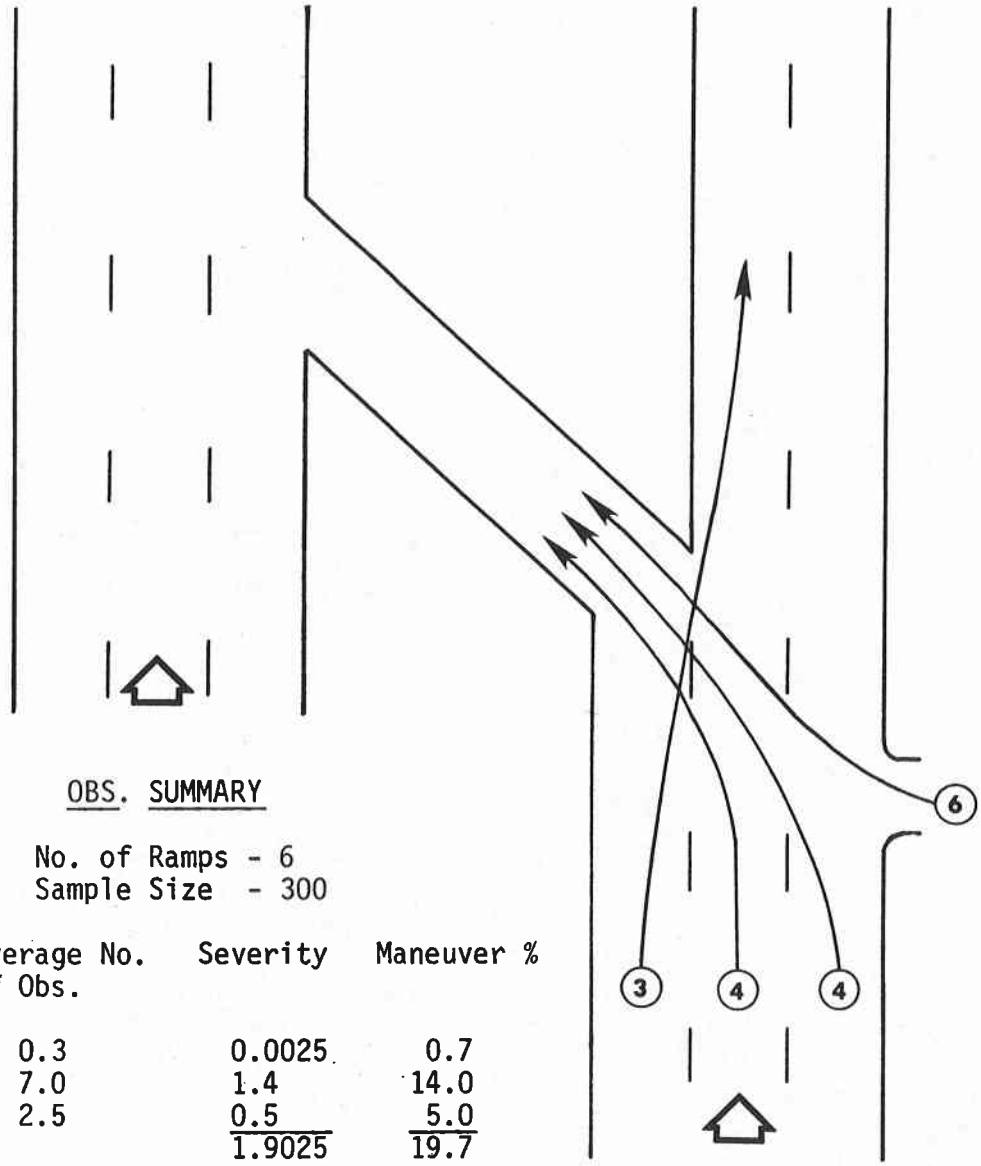
All erratic maneuvers occurring during on and off ramp operations were grouped under four major headings (Angle, Headon, Rear-end, Other). Then each of these groups were divided into three major parts (Fatality, Injury, Property Damage). Each injury type was assigned a value in dollars. For each accident type, the probability of occurrence was obtained from McFarland's Work (1). An index of potential accident severity for each type of erratic maneuver was determined by multiplying the probability of occurrence by its dollar value. The resulting values were added. The erratic maneuver type with the largest dollar value was assigned a value of 10. To determine the ranking of the other types, their monetary value was divided by the value of the most severe maneuver, and that value was then multiplied by 10 in order to obtain their relative severity. Table 3 contains a summary of the observed erratic maneuver percentage by Ramp Type. Two plots of relative severity versus observed accident experience revealed that the erratic maneuvers were very weakly associated with accident experience, if any relationship existed at all. The use of the severity data is <u>not</u> recommended.

Table 2. Definitions of Erratic Maneuvers on Freeway Frontage Roads

Maneuver Number		Description
1	RAMP YIELD	Vehicles on the ramp yield somewhere on the ramp. This can be due to the failure of frontage road traffic to yield the right-of-way, or due to driver hesitation.
2	FRONTAGE ROAD YIELD FAILURE	Frontage road traffic fails to yield the right-of-way to ramp traffic. This manuever takes place on both one- and two-way frontage roads.
3	LAST MINUTE SWERVE	A vehicle on the frontage road that either approaches the gore area of the entrance ramp and then steers out at the last moment or exits the forced entrance lane at the last possible moment by crossing the gore area. This maneuver can occur on one-way or two-way frontage roads.
4	LANE CROSS TO RAMP	A vehicle on the frontage road crosses one or more travel lanes on the frontage road to enter a slip ramp. The maneuver can occur in two- or three-lane, one-way frontage roads.
5	LANE CROSS FROM RAMP	A vehicle exiting from a ramp into a frontage road (1) crosses one or more travel lanes of a one-way frontage road, or (2) stays in the lane of opposing traffic for some time before moving into the proper lanes for a two-way frontage road, or (3) directly crosses all lanes in order to exit into a side street or driveway for both one- and two-way frontage roads.
6	OPPOSING OR CROSSING TRAFFIC	A vehicle entering a ramp from a frontage road (1) moves into the opposing traffic lanes before entering the ramp or (2) directly crosses all lanes of traffic (both one- and two-way) from a side street or driveway to the ramp.
7	CURB CLIP	A vehicle on an entrance or exit ramp strikes or clips the curb or shoulder of the ramp with either its left or right hand side. This maneuver takes place on both one- and two-way frontage roads.
8	BRAIDED RAMP OPPOSITION TO TRAFFIC	A vehicle entering a frontage road from a side street adjacent to a braided ramp forces its way into the travel lane of opposing traffic until it is past the ramp channelization. This maneuver can take place only on braided ramp entrances or exits on two-way frontage road sections.
9	CIRCLING THE CHANNELIZATION	A vehicle making U-turn around the channelization until it ends up going the direction it was originally headed. This maneuver occurs only on braided ramp entrances or exits, on two-way frontage road sections.

Figure 7

Erratic Maneuvers - One-Way Operation
Slip On-Ramp With a Lane Drop



OBS. SUMMARY

No. of Ramps - 6
Sample Size - 300

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
3	0.3	0.0025	0.7
4	7.0	1.4	14.0
6	2.5	0.5	5.0
		1.9025	19.7

Figure 8

Erratic Maneuvers - One-Way Operation

Slip Off-Ramp Into a Separate Lane

OBS. SUMMARY

No. of Ramps - 6
Sample Size - 300

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
3	2.2	0.44	4.3
5	18.7	3.74	37.3
		4.18	41.6

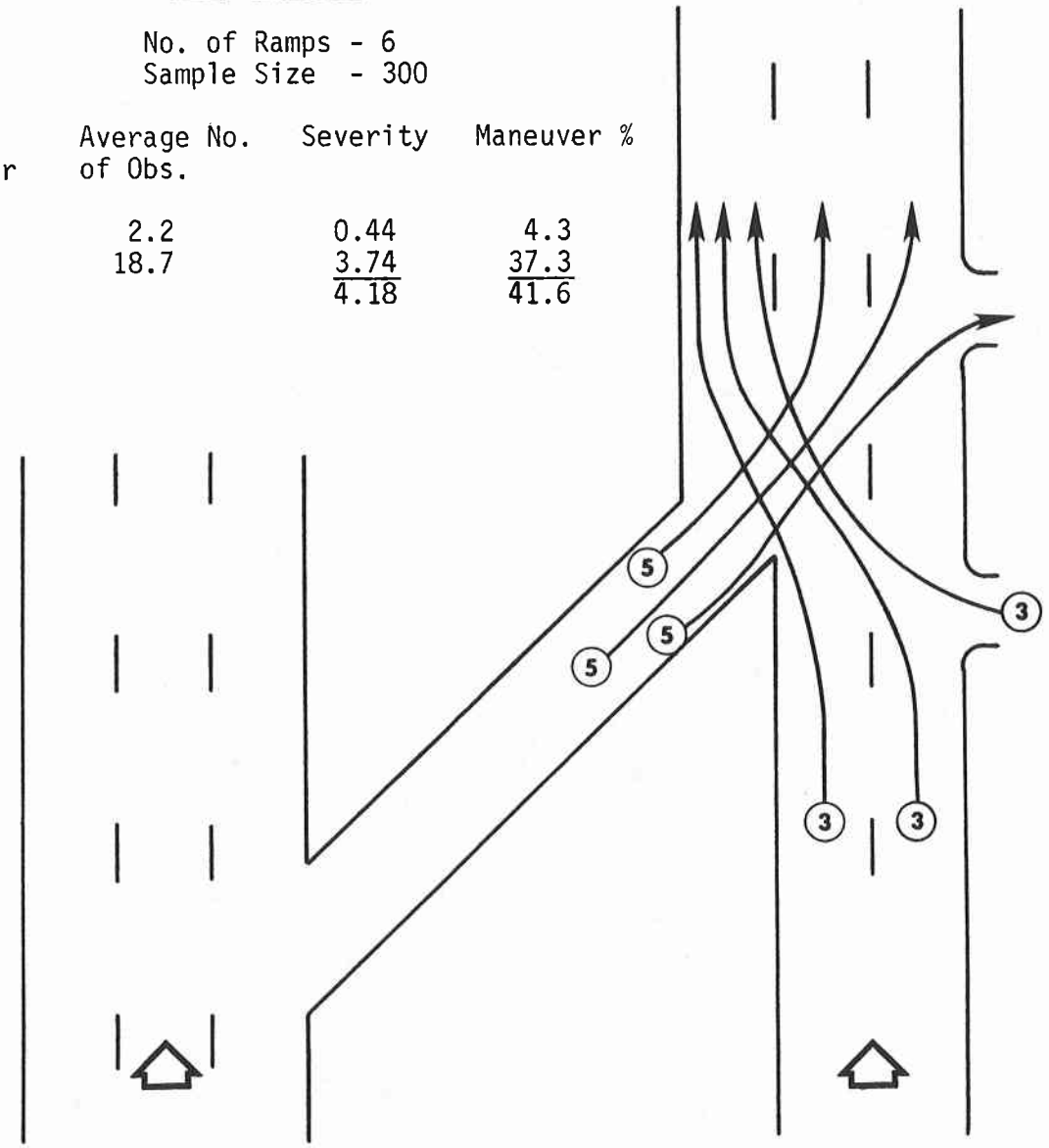
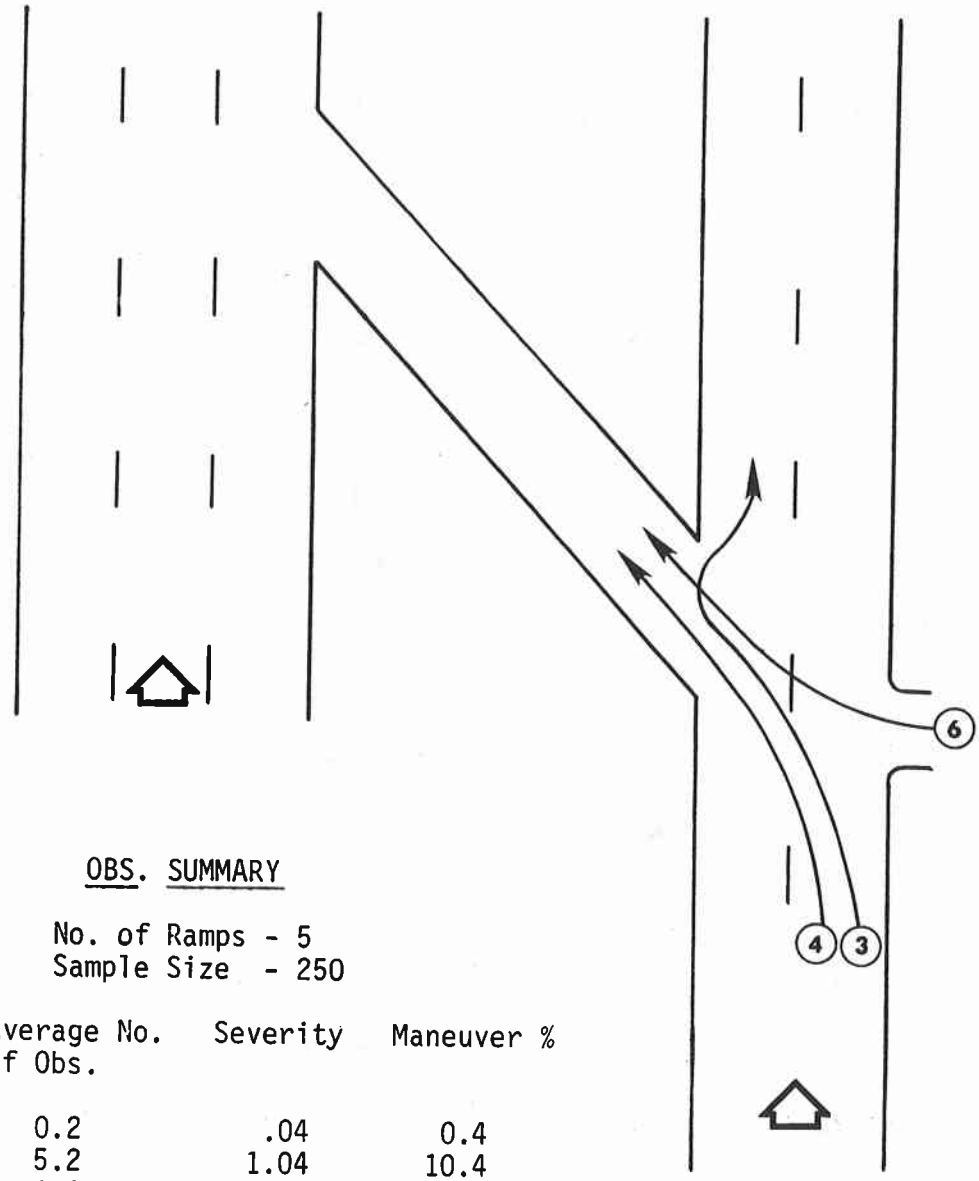


Figure 9

Erratic Maneuvers - One-Way Operation
Slip On-Ramp to a Freeway



OBS. SUMMARY

No. of Ramps - 5
Sample Size - 250

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
3	0.2	.04	0.4
4	5.2	1.04	10.4
6	1.4	.28	2.8
		1.36	13.6

Figure 10

Erratic Maneuvers - One-Way Operation
Slip Off-Ramp to a Two-Lane Frontage Road

OBS. SUMMARY

No. of Ramps - 4
Sample Size - 200

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
1	0.2	0.02	0.5
2	2.0	0.16	4.0
5	14.5	2.9	29.0
		3.08	33.5

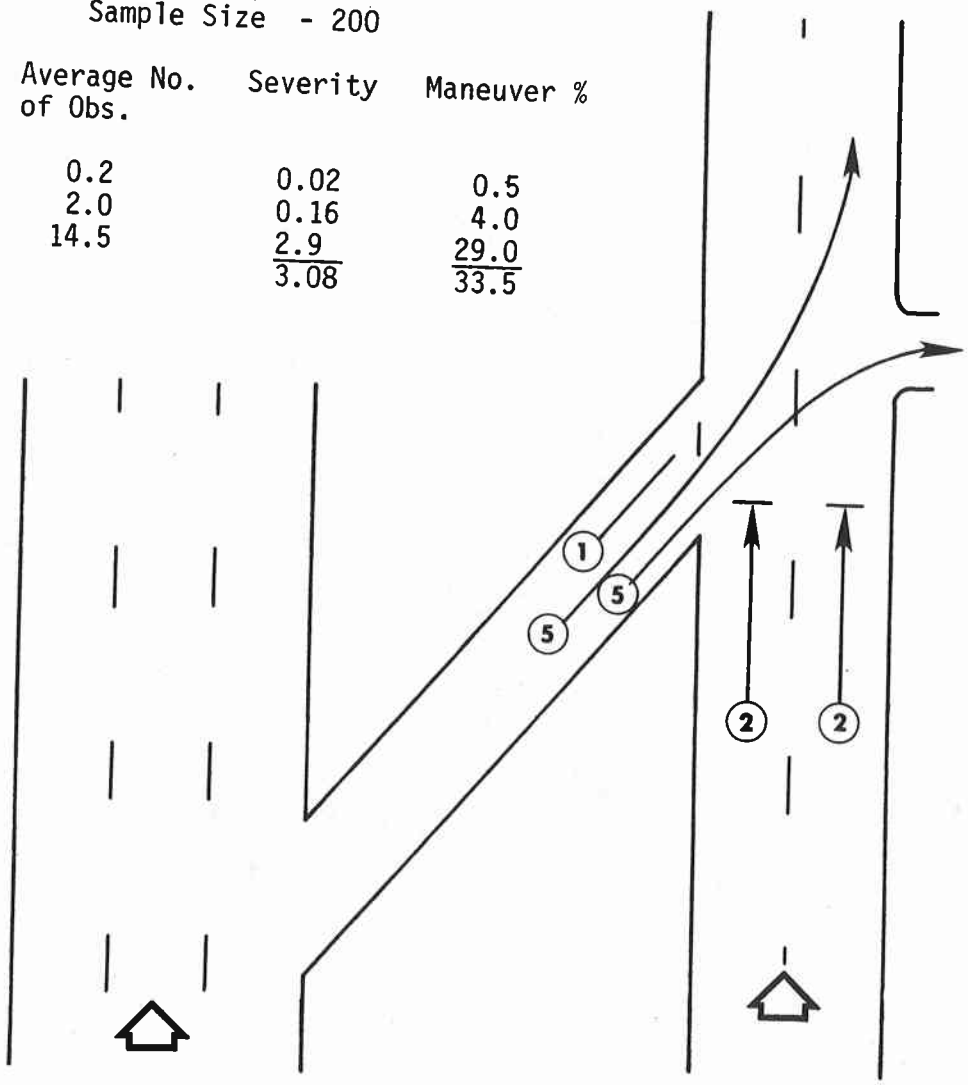
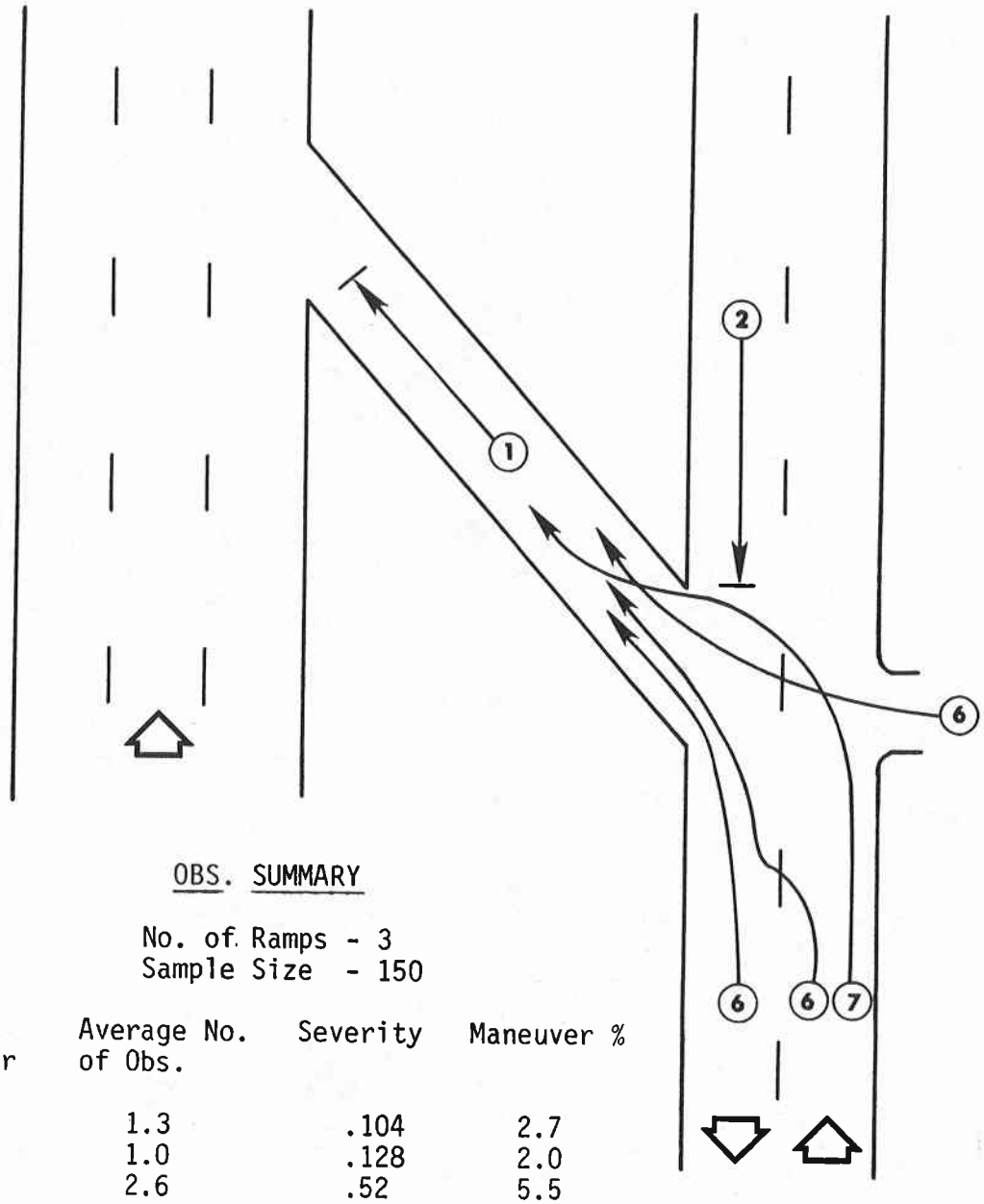


Figure 11

Erratic Maneuvers - Two-Way Operation
Slip On-Ramp from a Two-Way Frontage Road



OBS. SUMMARY

No. of Ramps - 3
Sample Size - 150

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
1	1.3	.104	2.7
2	1.0	.128	2.0
6	2.6	.52	5.5
7	4.0	.08	8.0
		0.832	18.1

Figure 12

Erratic Maneuvers - Two-Way Operation
Slip Off-Ramp to a Two-Way Frontage Road

OBS. SUMMARY

No. of Ramps - 2
Sample Size - 100

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
1	2.0	.16	4.0
2	3.5	.28	7.0
5	3.0	.60	6.0
		1.04	17.0

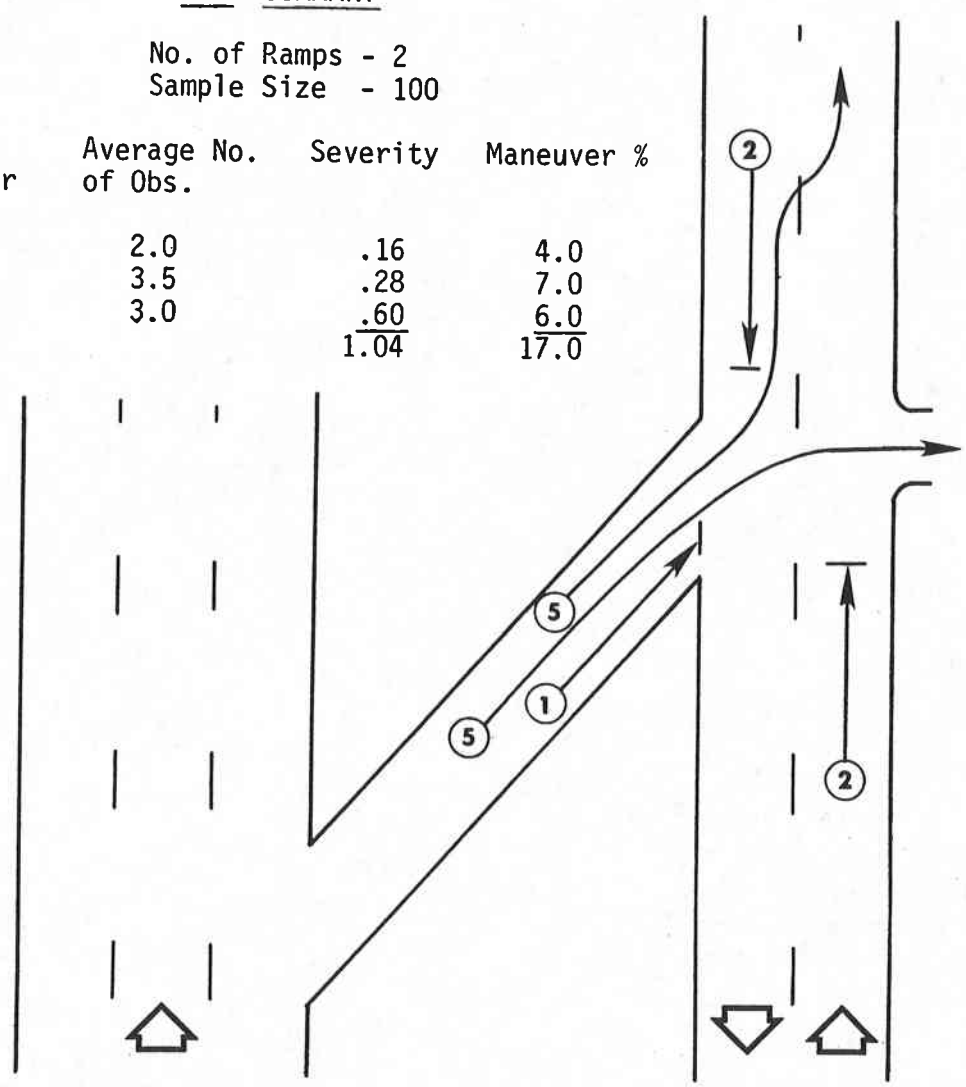
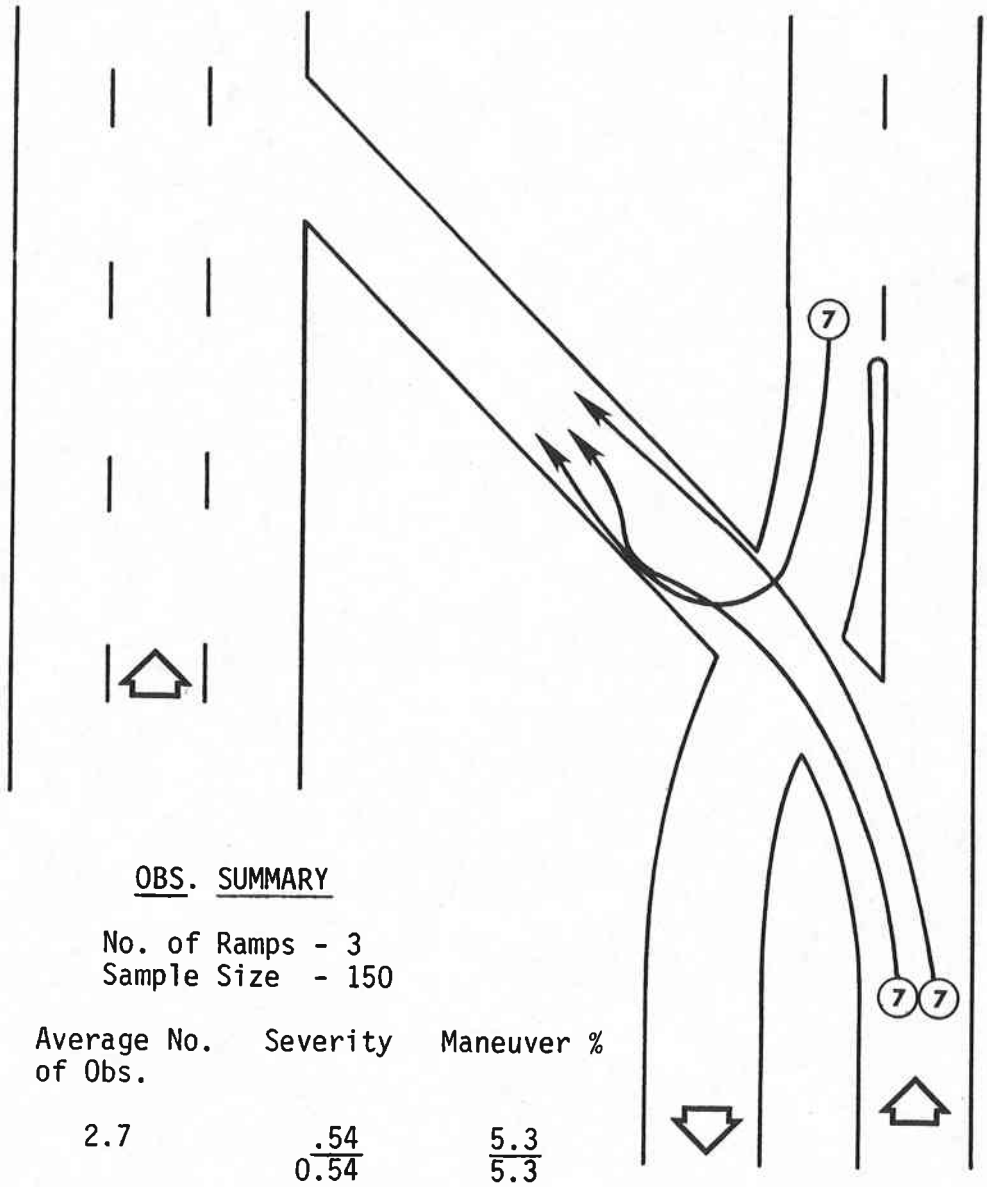


Figure 13

Erratic Maneuvers - Two-Way Operation
Braided On-Ramp from a Two-Way Frontage Road



OBS. SUMMARY

No. of Ramps - 3
Sample Size - 150

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
7	2.7	$\frac{.54}{0.54}$	$\frac{5.3}{5.3}$

Figure 14

Erratic Manuevers - Two-Way Operation
Braided Off-Ramp from a Two-Way Frontage Road

OBS. SUMMARY

No. of Ramps - 4
Sample Size - 200

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
1	1.5	0.12	3.0
2	1.2	0.01	2.5
5	1.2	0.02	2.5
7	0.2	0.04	0.5
8	0.2	0.03	0.5
9	0.2	0.04	0.5
		0.26	9.5

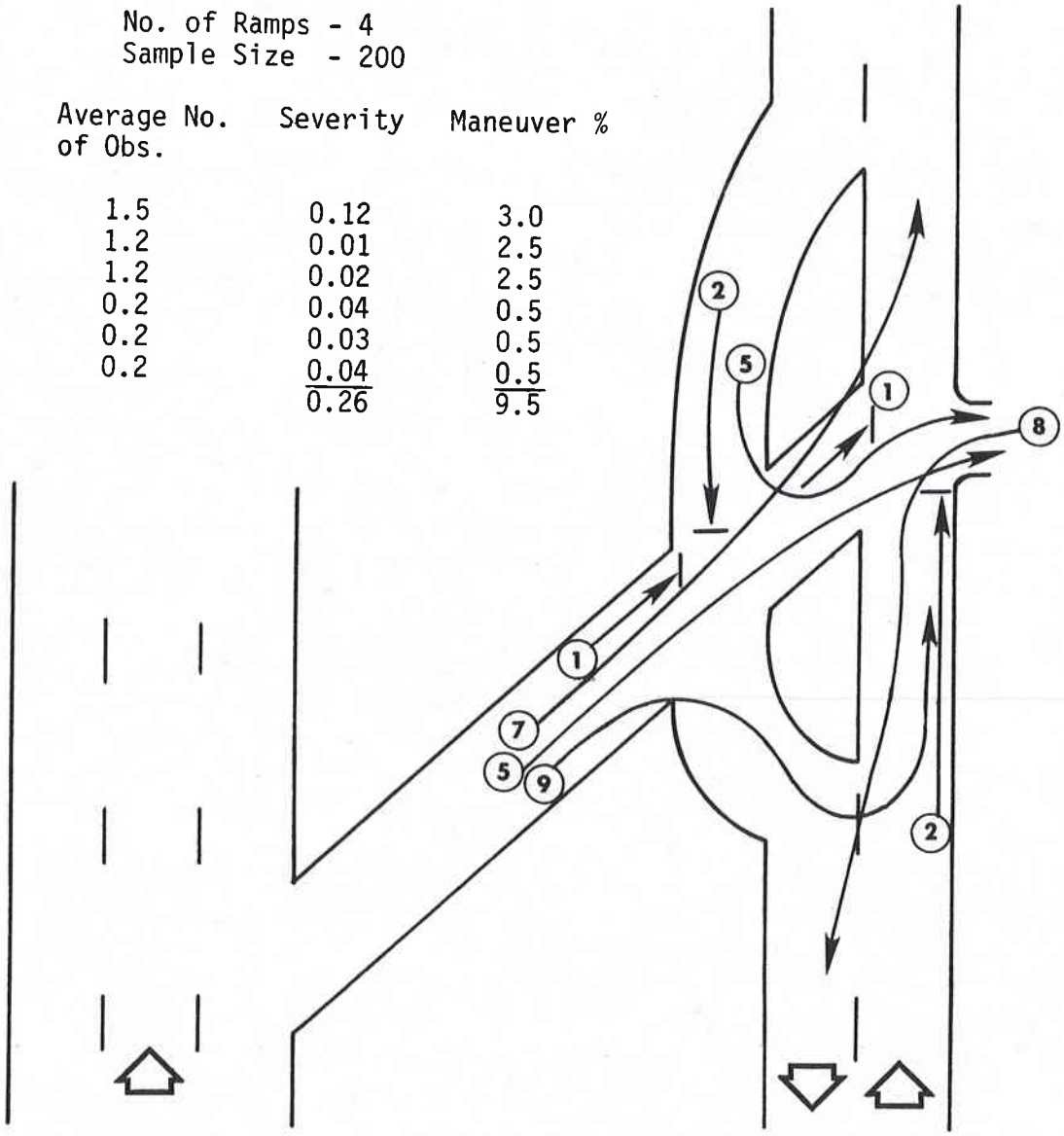
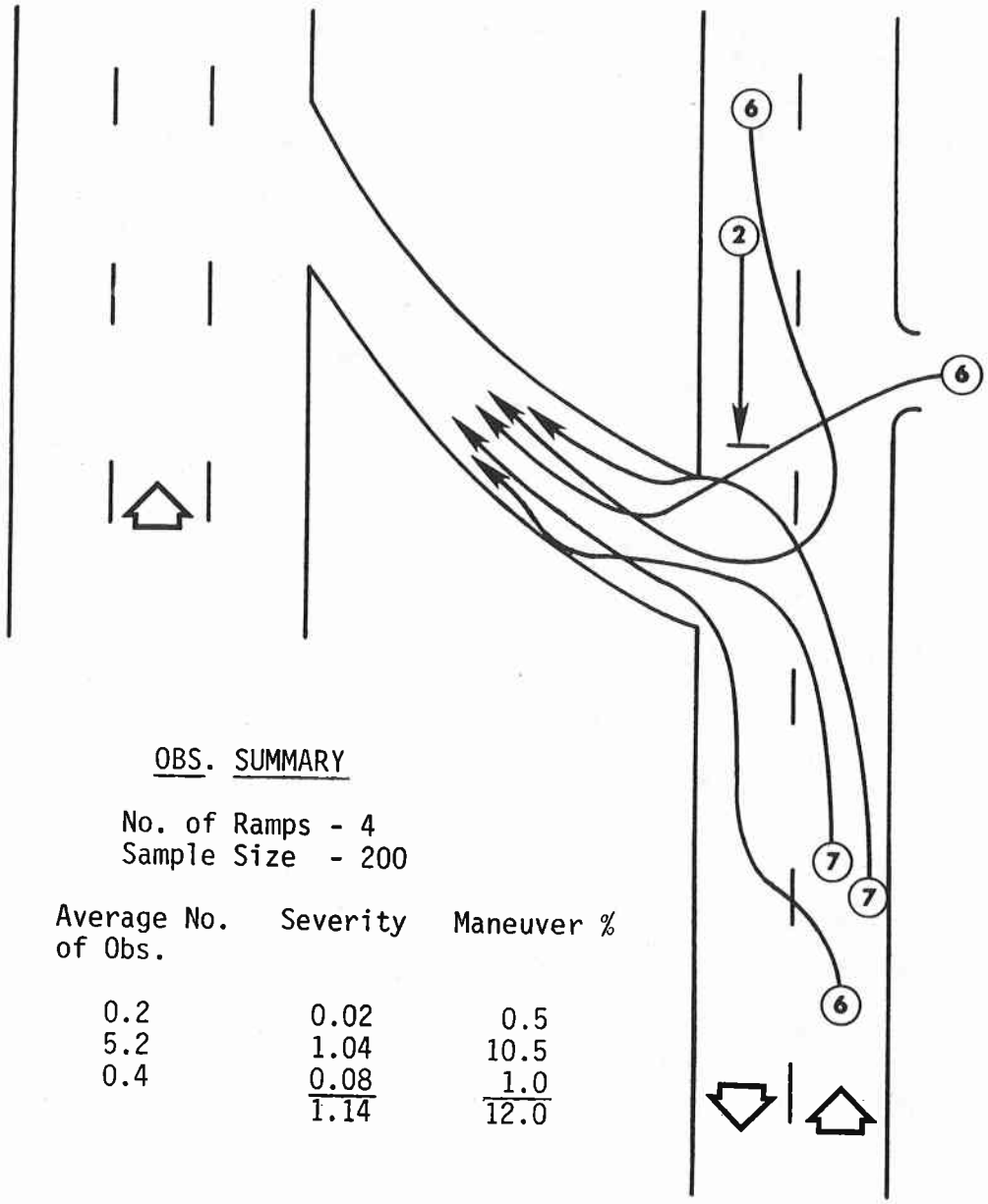


Figure 15

Erratic Manuevers - Two-Way Operation
Buttonhook On-Ramp from a Two-Way Frontage Road



OBS. SUMMARY

No. of Ramps - 4
Sample Size - 200

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
2	0.2	0.02	0.5
6	5.2	1.04	10.5
7	0.4	0.08	1.0
		1.14	12.0

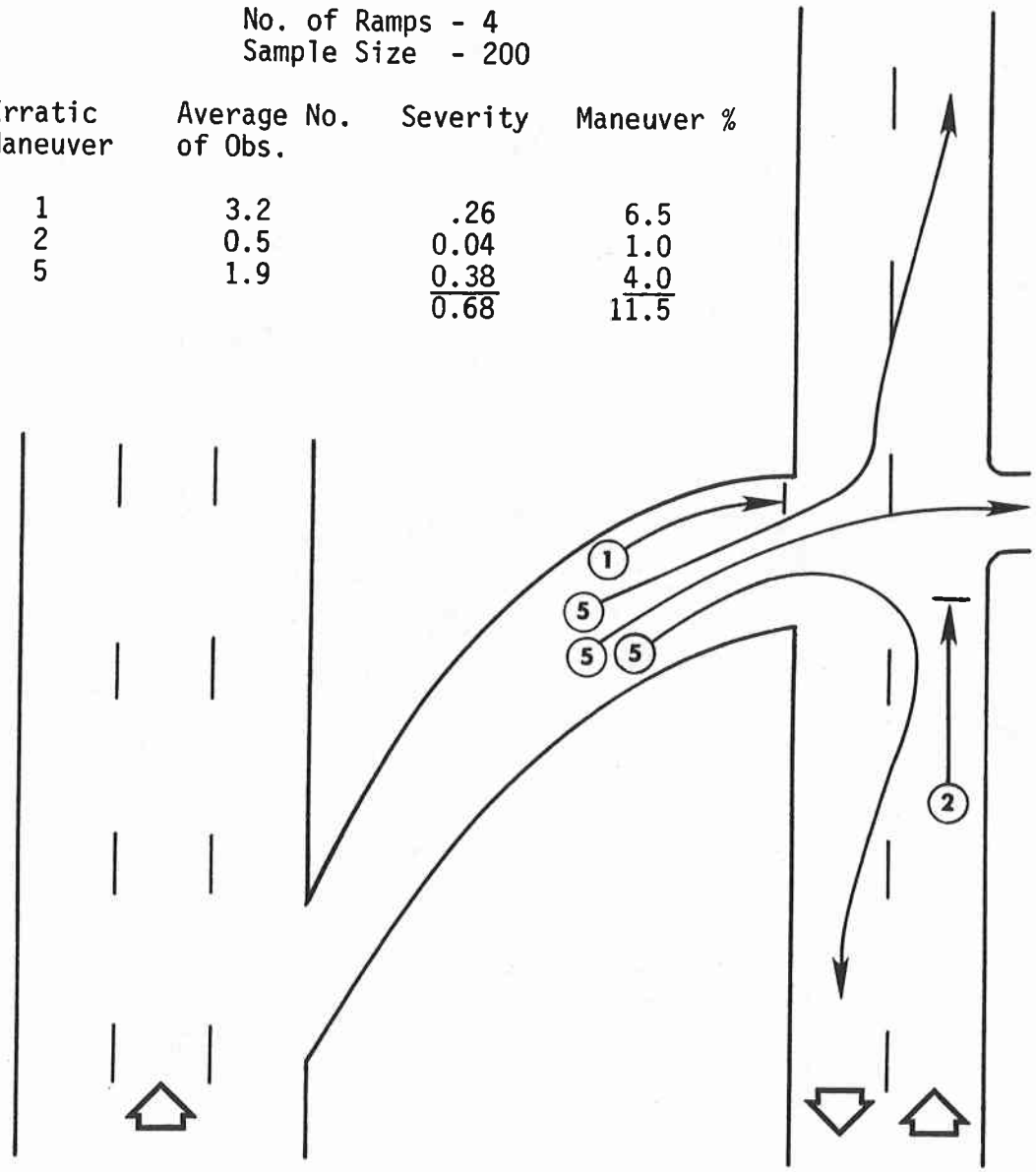
Figure 16

Erratic Maneuvers - Two-Way Operation
Buttonhook Off-Ramp to a Two-Way Frontage Road

OBS. SUMMARY

No. of Ramps - 4
Sample Size - 200

Erratic Maneuver	Average No. of Obs.	Severity	Maneuver %
1	3.2	.26	6.5
2	0.5	0.04	1.0
5	1.9	0.38	4.0
		0.68	11.5



Using the videotapes and the erratic maneuver classification, erratic maneuvers were counted and recorded for each site. The results are converted to percentages and tabulated below.

Table 3. Observed Total Percentage of Erratic Maneuvers by Ramp Type

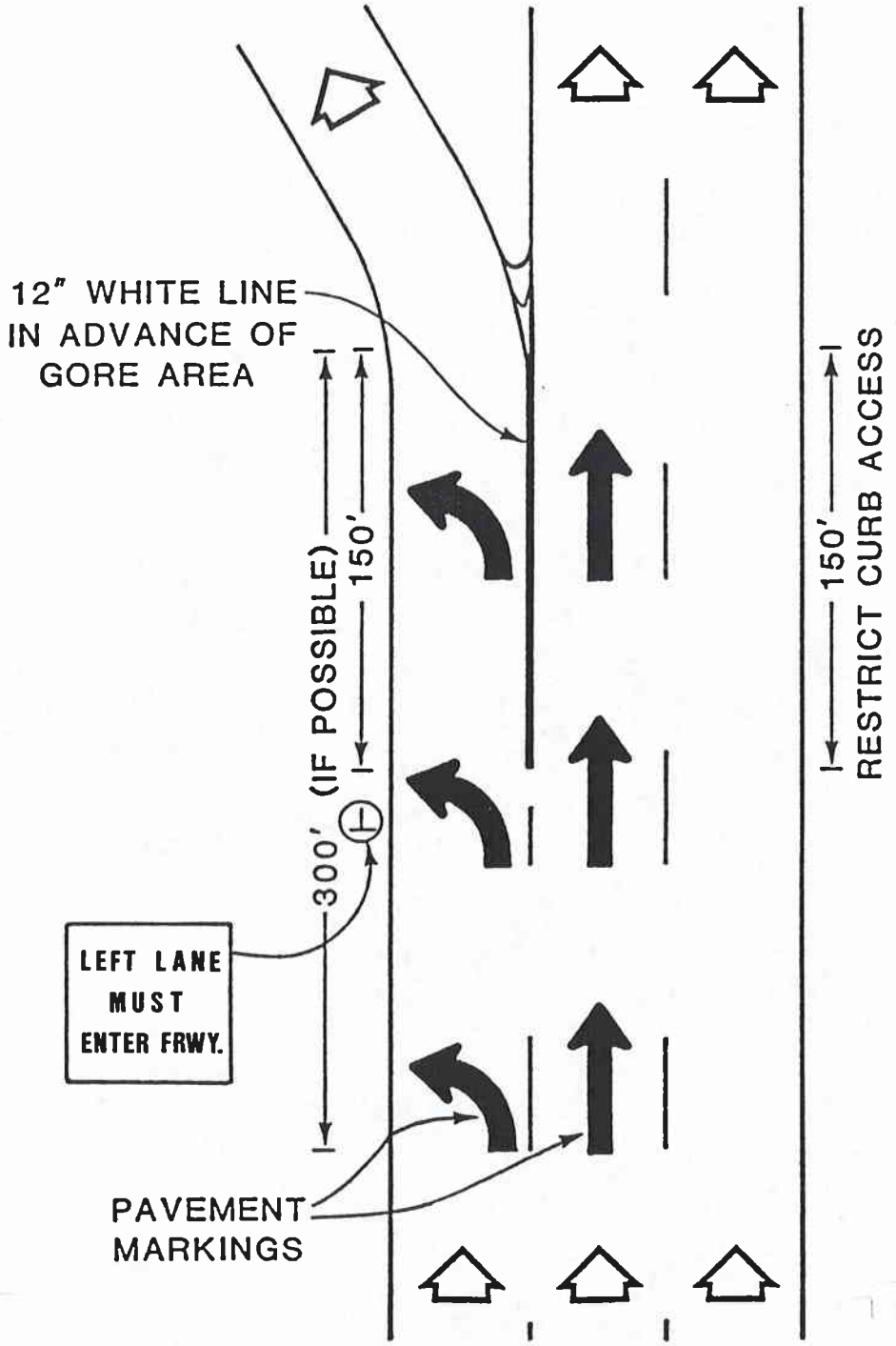
Type of Frontage Road Operation	Type of Ramp	Frontage Road Maneuver	
		Entrance From	Exit To
One-Way	Slip Ramp to or from a Separate Lane	19.0	41.6
	Slip Ramp to a Merge or from a Combined Use Lane	14.0	33.5
Two-Way	Buttonhook	12.0	11.5
	Slip	18.1	17.0
	Braided	10.6	9.5

From Table 3, it is obvious that the slip exit ramp had substantially higher percentages of erratic maneuvers. However, there was no general trend with increasing ramp-frontage road complexity, as was expected. It should also be noted that slip ramps provide a much greater opportunity to follow erratic paths because of the absence of channelization. The patterns suggest some changes in geometric design and traffic control in order to reduce the frequency of erratic maneuvers. These suggestions are presented in Figures 17 thru 24.

Figure 17

Suggested Design and Operational Improvements

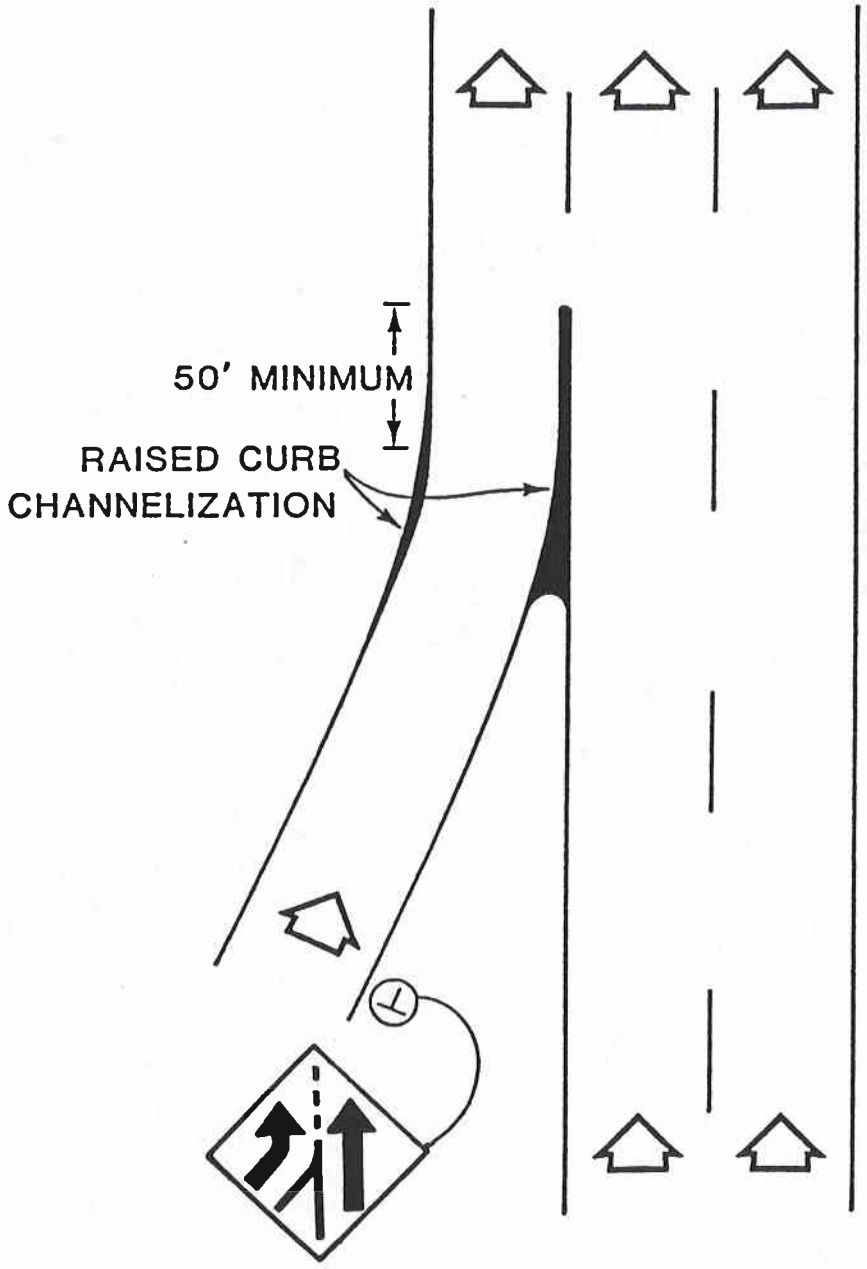
Slip On-Ramp from a One-Way Frontage Road with a Lane Drop



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 18

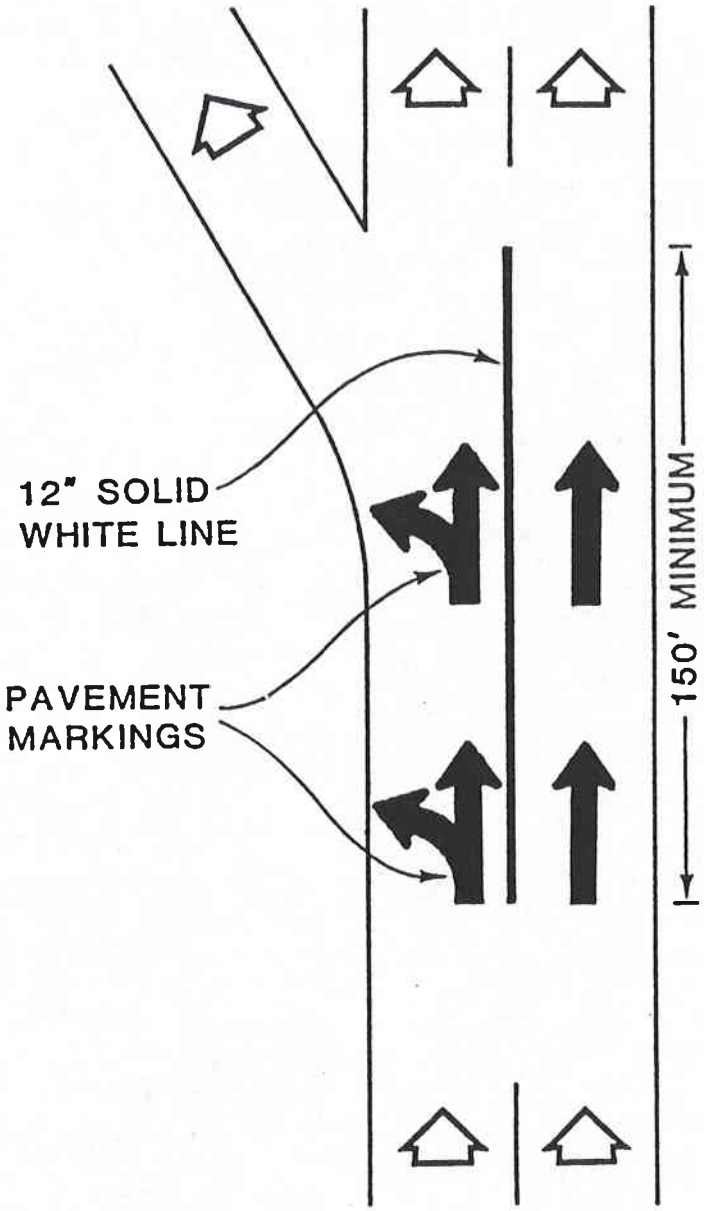
Suggested Design and Operational Improvements
Slip Off-Ramp to a Separate Lane on a One-Way Frontage Road



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 19

Suggested Design and Operational Improvements
Slip On-Ramp from a One-Way Frontage Road

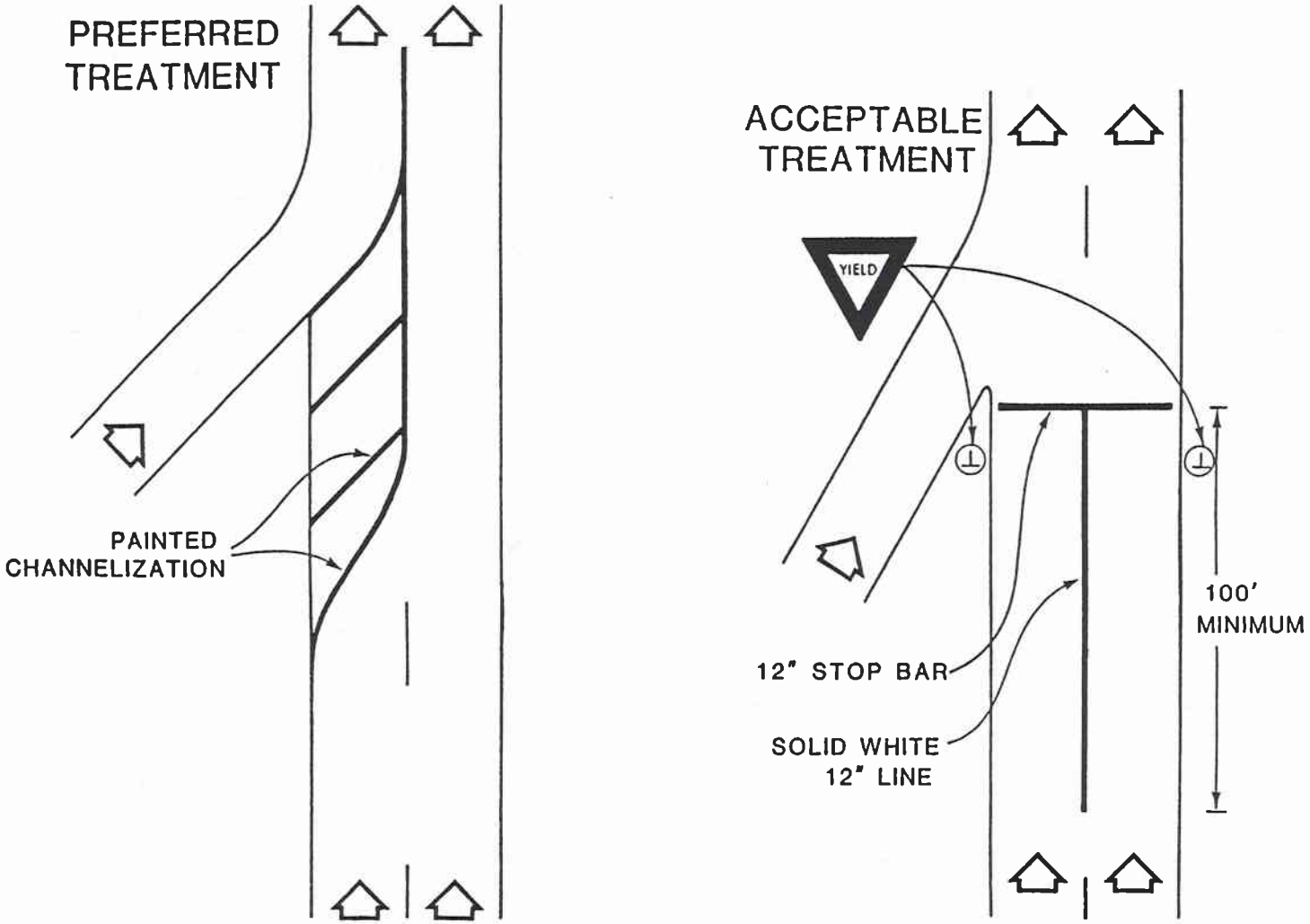


NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 20

Suggested Design and Operational Improvements

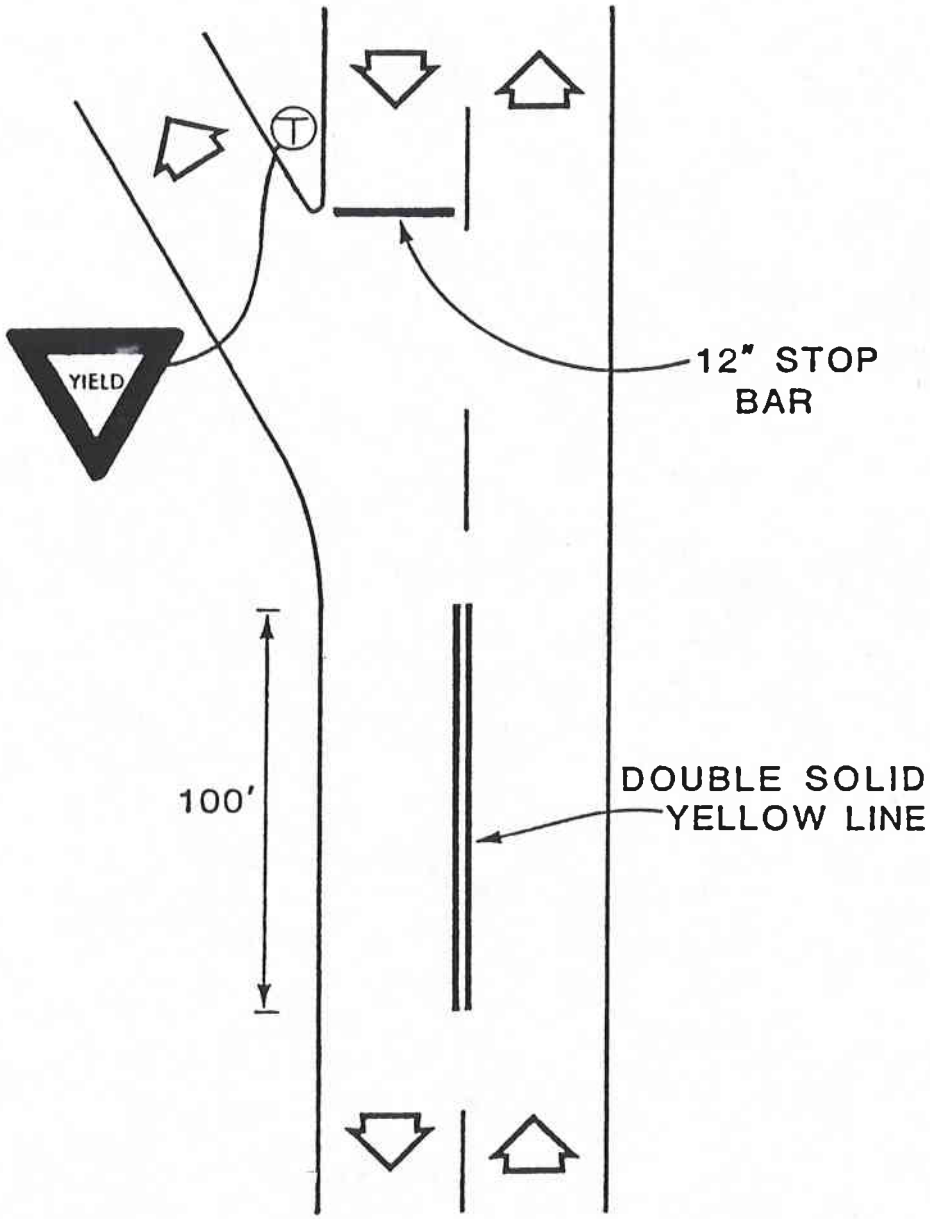
Slip Off-Ramp to a One-Way Frontage Road



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 21

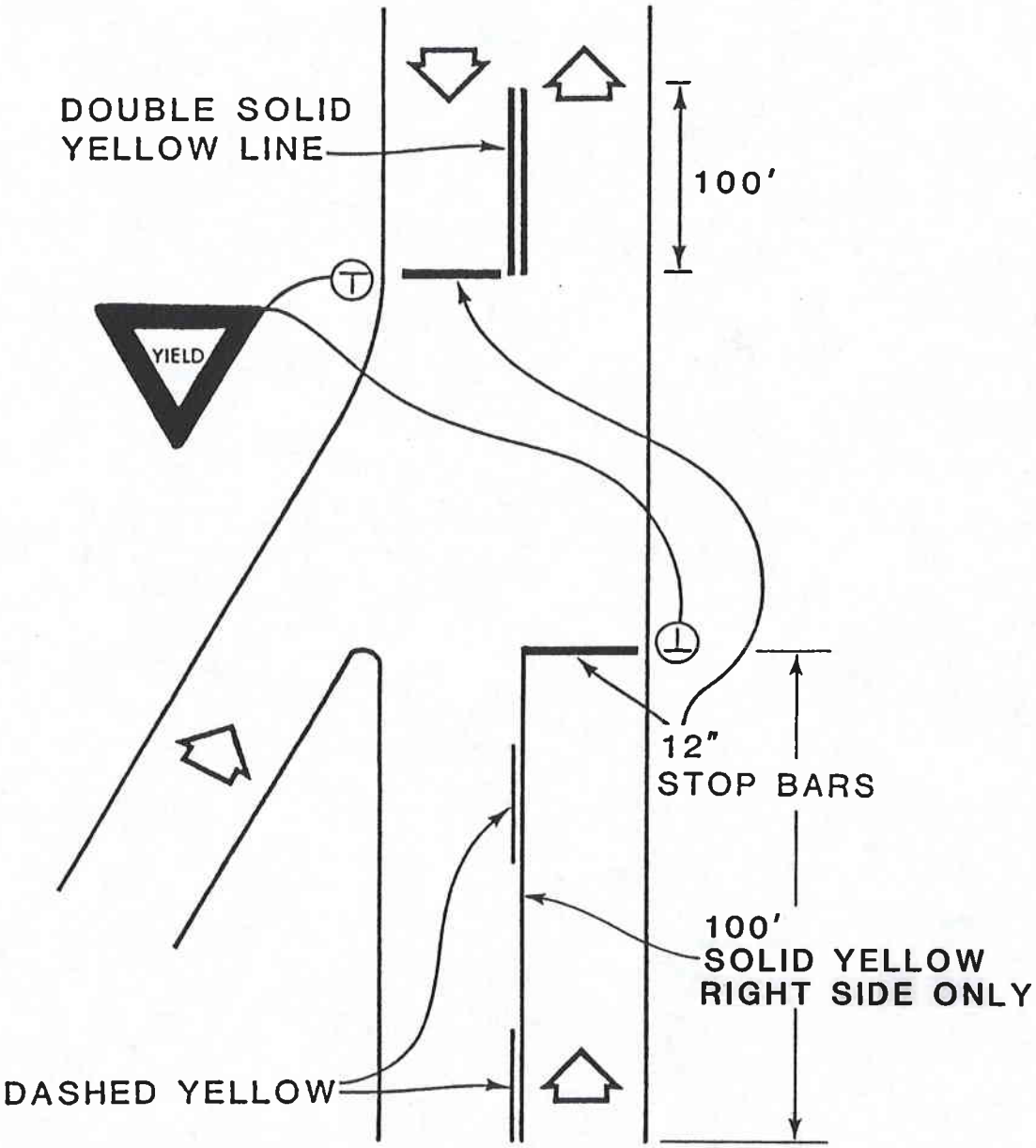
Suggested Design and Operational Improvements
Slip On-Ramp from a Two-Way Frontage Road



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 22

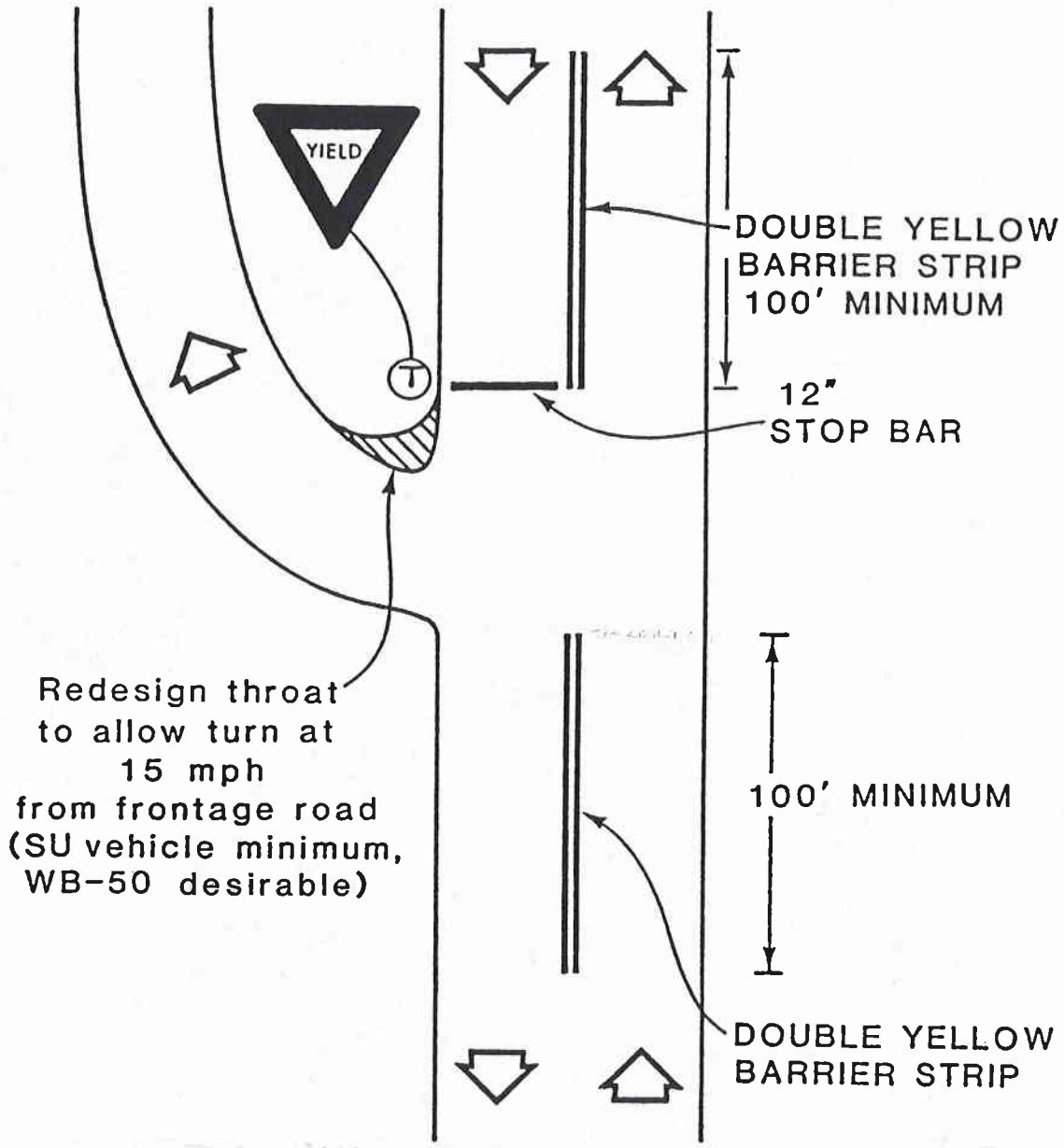
Suggested Design and Operational Improvements
Slip Off-Ramp to a Two-Way Frontage Road



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 23

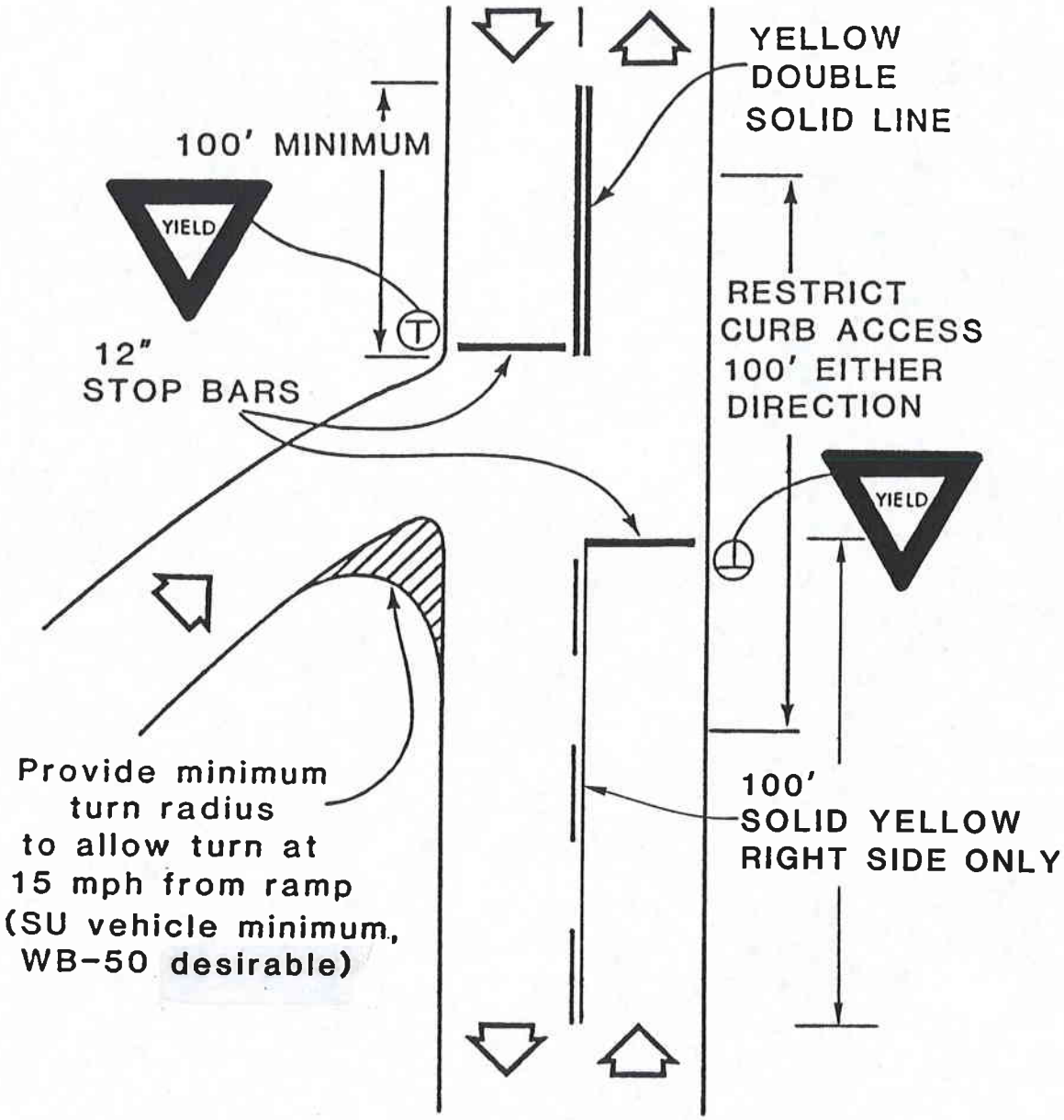
Suggested Design and Operational Improvements
Buttonhook On-Ramp from a Two-Way Frontage Road



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

Figure 24

Suggested Design and Operational Improvements
Buttonhook Off-Ramp to a Two-Way Frontage Road



NOTE: This is not a recommended design. Rather, it is a suggested improvement to reduce the magnitude of the erratic maneuvers observed.

3. RAMP AND TERMINAL SAFETY AND OPERATIONAL DATA

3.1 Methodology for Defining Ramp Related Accidents

The definition of a ramp terminal accident is somewhat difficult for many ramp types. For example, a slip ramp to a one-way frontage road is an ill-defined intersection, while the buttonhook ramp intersects a two-way frontage road at essentially 90 degrees. Likewise, a rear end collision on the frontage road from a high speed vehicle exiting the ramp could easily occur several hundred feet from the ramp intersection. Therefore, it is necessary to define the range over which an accident would be considered to be a ramp-related accident.

For the purposes of this study, the area bounded by a point 0.1 miles upstream and 0.1 miles downstream from the point of intersection of the centerline of the ramp and the centerline of the frontage road was defined as the "ramp terminal area". All reported accidents located within the "ramp terminal area" were considered to be potentially ramp-related.

The accident data revealed frequent accidents in the ramp area associated with turns into or out of adjacent property. These were identified by the "turning into driveway" code on the accident computer file and were not considered to be ramp-related accidents.

3.2 Basic Accident Data Period

The period over which the accident data are evaluated is critically important. In theory, the traffic and land development over the entire period being considered should be exactly the same. In practice, this is impossible. The development and the traffic movement are dynamic, changing from

day to day. The upward trend is usually rather slow and can be assumed to be reasonably constant over a several year period without a great loss of accuracy. It is essential that no obvious changes in land use patterns or traffic patterns be observed within the data collection period. These conditions were met by checking with District personnel to determine if a noticeable change in land use or traffic volumes occurred in 1979, 1980, or 1981. Data from these years were included in the basic data set.

3.3 Ramp Accident Frequency by Ramp Type

The average number of accidents per 1000 frontage road vehicles by ramp type and volume group are presented in Table 4.

Table 4. Table of Average Number of Accidents Per 1000 Frontage Vehicles Per Year

Frontage Road Operation	Ramp Type	Under 5000 VPD Moderate to Low Volume			5000 + VPD Moderate to High Volume		
		Rural	Inter-mediate	Urban	Rural	Inter-mediate	Urban
One-Way	Slip Ramp to Merge	0.17	1.0	NA	1.00	0.00	3.0
	Slip Ramp to a Separate Lane	0.50	0.0	NA	NA	1.5	5.0
Two-Way	Buttonhook	0.3	1.7	NA	0.5	0.0	5.0
	Slip Ramp	2.0	1.7	NA	0.0	0.7	NA
	Braided	NA	NA	NA	NA	1.0	0.0

A brief review of Table 4 suggests that volume on the frontage road and the degree of roadside development are both major influencing factors on accident frequency, regardless of the ramp type. For example, the highest accident rate shown occurs on slip and buttonhook ramps in moderate-to-high volume urban sites.

3.4 Analysis of Ramp and Frontage Road Accidents

To analyze the effect of how one-way and two-way operation interacted with ramp type, area development, and traffic volume, sites were selected and data on these sites were collected.

3.4.1 Data Collection

Twenty-two sites for each of one-way and two-way operation on frontage roads were selected and visited by members of the research team. Those factors which were believed to affect frontage road accidents were collected. Initially, all those factors were classified into categorized levels shown in Table 5.

The site characteristics encompassing these factors and factor levels are presented in Table 6. Due to not having some ramp types, the entire matrix could not be completed. Later, with the help of SDHPT, the 1980 traffic volumes observed on all 44 sites were obtained.

3.4.2 Accident Data

Reported accidents at the 44 selected sites in 1980 were also automatically retrieved from the master file in the Texas Department of Public Safety, using the statistical analysis system (SAS), a computer software package for statistical data analysis. Those accidents occurring within $\pm$ 0.1 miles of the ramp were included in the accident data set, which was abbreviated ACCA. Out of these, the intersection of ramp and frontage road

Table 5. List of Factors and Factor Levels Used for Accident Analysis

Factors			
Frontage Operational Mode	Ramp Type	Roadside Development	Frontage Road Volume
1) One-Way	1) SM*	1) Rural	1) LM**
2) Two-Way	2) SS	2) Intermediate	2) MH
	3) S	3) Urban	
	4) BR		
	5) BU		

*SM - Slip ramp to a merge with a frontage road lane.
SS - Slip ramp to a separate lane on the frontage road.
S - Slip ramp to a two-way frontage road.
BR - Braided ramp terminal to a two-way frontage road.
BU - Buttonhook ramp to a two-way frontage road.

**LM - Low to moderate frontage road volumes (Typically <5000 ADT).
MH - Moderate to high frontage road volumes (Typically >5000 ADT).

Table 6. Ramp and Frontage Road Information

Frontage Road Site No.	Ramp Type[a]	Frontage Road Information: Roadside Development[b]	Frontage Road Volume[c]	Directions of Travel
1	SM	R	LM	One-Way
2	S	R	LM	Two-Way
3	S	I	LM	Two-Way
4	SM	R	LM	One-Way
5	SM	R	LM	One-Way
6	S	I	LM	Two-Way
7	BU	R	LM	Two-Way
8	SS	U	MH	One-Way
9	SM	I	MH	One-Way
10	BU	R	LM	Two-Way
11	SM	R	LM	One-Way
12	SM	R	LM	One-Way
13	SM	R	LM	One-Way
14	SS	I	MH	One-Way
15	S	I	LM	Two-Way
16	BU	R	LM	Two-Way
17	SS	R	LM	One-Way
18	SS	I	MH	One-Way
19	SS	I	LM	One-Way
20	SS	U	MH	One-Way
21	SS	R	LM	One-Way
22	SM	I	LM	One-Way
23	SM	I	LM	One-Way
24	SM	R	MH	One-Way
25	SM	U	MH	One-Way
26	S	I	MH	Two-Way
27	S	I	MH	Two-Way
28	S	R	MH	Two-Way
29	S	I	MH	Two-Way
30	SM	U	MH	One-Way
31	SM	U	MH	One-Way
32	SM	U	MH	One-Way
33	BU	I	LM	Two-Way
34	SS	I	LM	One-Way
35	BU	R	MH	Two-Way
36	BU	I	MH	Two-Way
37	BR	U	MH	Two-Way
38	BR	I	MH	Two-Way
39	BU	R	MH	Two-Way
40	BU	R	LM	Two-Way
41	BU	I	LM	Two-Way
42	BU	U	MH	Two-Way
43	BU	I	MH	Two-Way
44	BU	U	MH	Two-Way
45	BU	I	LM	Two-Way

Note:
a - SM-Slip Merge
SS-Slip Separate
S -Slip (two-way frontage road)
BR-Braided
BU-Buttonhook

b - R-Rural
I-Intermediate
U-Urban

c - LM-Low-Medium
MH-Medium-High

accidents were abbreviated as ACCR. Thus, two data sets called ACCA and ACCR were created.

3.4.3 Accident Exposure Measure

Two accident exposure measures were used in this study. One is the total number of accidents per year, which may be called a null exposure measure. The other is the total number of accidents per million vehicle miles traveled (VMT), which uses the traffic volume multipled by section length as an exposure measure. Since section length is taken as constant, that is, 0.2 miles, this measure is equivalent to using traffic volume as an exposure measure. The accident rate per million vehicle miles traveled was abbreviated as ACCAR and ACCRR, creating two more data sets which are related to those previously discussed for accidents at the site (ACCA) and those which were ramp-related (ACCR).

3.4.4 Accident Experience

Table 7 shows the mean number of accidents per year (ACCR and ACCA) for all combinations of operational mode, ramp type, volume, and area. As expected, the mean number of accidents per year in an urban area serving high traffic volume appears to be higher than any of the other classes (See Table 7). The detailed annual mean number of accidents classified by the single, double, and triple combinations of factors for all sites is found in Appendix E. These combinations are usually products of the basic variable such as ADT x Operational Mode and are used to check for higher order interactions of the data.

3.5 Accident Analysis Results

The sites observed were found to be unbalanced because (1) not all possible combinations were included, and (2) the number of observations in each

Table 7. Mean Number of Accidents Per Year by the Combinations of Way, Ramp Type, Volume, and Area

Classes	Operational Mode	Ramp	Volume	Area	Mean ACCR	Mean ACCA
1	1	SM	LM	I	1.00	7.00
2	1	SM	LM	R	0.17	0.50
3	1	SM	MH	I	0.00	2.00
4	1	SM	MH	R	1.00	6.00
5	1	SM	MH	U	3.00	9.75
6	1	SS	LM	I	0.00	2.50
7	1	SS	LM	R	0.50	1.00
8	1	SS	MH	I	1.50	3.00
9	1	SS	MH	U	5.00	12.00
10	2	BR	MH	I	1.00	2.00
11	2	BR	MH	U	0.00	3.00
12	2	BU	LM	I	1.67	1.67
13	2	BU	LM	R	0.33	0.67
14	2	BU	MH	I	0.00	1.00
15	2	BU	MH	R	0.50	0.50
16	2	BU	MH	U	5.00	8.50
17	2	S	LM	I	1.67	3.67
18	2	S	LM	R	2.00	2.00
19	2	S	MH	I	0.67	2.33
20	2	S	MH	R	0.00	0.00

ACCR = Frequency of Ramp Accidents
ACCA = Total Frontage Accidents

class was not exactly the same. Further, it is a nested design because factor levels were not randomized on observation sites. Finally, since identical ramp types are not used in one-way and two-way operation, the effect of one-way and two-way operation on a given ramp type could not be analyzed.

Using SAS, analysis of variance (ANOVA) was performed for the observed categorized data. The nested ANOVA model including the interaction effects of way, given ramp type, and traffic volume was found to be insignificant at even = .15 level. Subsequently, the interaction terms were eliminated and only the main effects were tested.

Using the actual traffic volume in the form of average daily traffic (ADT), analysis of variance was performed for four accident groups: ACCR (Frequency of Ramp Accidents), ACCA (Frequency of Total Frontage Road Accidents), ACCRR (Ramp Accident Rate), and ACCAR (Total Accident Rate). As mentioned previously, all ramp types were not included in both one-way and two-way frontage road sites. Therefore, the two sets of independent variables were analyzed separately. The first set included the area, ADT, and operational frontage road mode (way), while the second set included the area, ADT, and ramp types as independent variables.

3.5.1 Accident Exposure Measure Comparison

Table 8 is a comparison of the different accident exposure measures applicable to this study. It reveals that the accident rate model using vehicle miles traveled as an exposure measure is inappropriate and results in a poor fit for both ACCRR and ACCAR. Specifically, the error level is extremely high and R^2 is extremely low. Accident rate models using VMT as an exposure measure have been found to be very poor. Thus, the accident rate model was excluded from further analysis.

Table 8. Accident Exposure Measure Comparison

Exposure Measure	Dependent Variable	Independent Variable	Significance Level	R^2
Number of Accidents Per Year	ACCR	Area, ADT, Way	0.01	0.48
		Area, ADT, Ramp	0.01	0.52
	ACCA	Area, ADT, Way	0.01	0.69
		Area, ADT, Ramp	0.01	0.70
Number of Accidents Per Million Vehicle Miles Traveled	ACCRR	Area, ADT, Way	0.82	0.04
		Area, ADT, Ramp	0.78	0.10
	ACCAR	Area, ADT, Way	0.10	0.18
		Area, ADT, Ramp	0.35	0.19

3.5.2 The Effects of Factors on Ramp Accidents

Table 9 is a summary of the analysis of variance for ramp accident models. Several hypotheses (listed below) were tested regarding the effect of these factors on ramp accidents.

Hypothesis 1: One-way or two-way operation does not significantly affect ramp accidents. The value of F with 1 and 38 degrees of freedom at the 5% significance is 4.10. The calculated value of F is:

$$F = \frac{SSE(3) - SSE(1)}{DF(3) - DF(1)} \div \frac{SSE(1)}{DF(1)}$$

$$= \frac{90.394 - 86.704}{39 - 38} \div \frac{86.704}{38}$$

$$= 1.617$$

Since F calculated at 1.617 is less than F (1, 38), α = 0.05, of 4.098, there is no statistical evidence that there is a difference in accidents on one-way and two-way operations.

Hypothesis 2: Both ADT and one-way and two-way operation do not significantly affect ramp accidents.

Similarly, $$F = \frac{SSE(4) - SSE(1)}{DF(4) - DF(1)} \div \frac{SSE(1)}{DF(1)}$$

$$= \frac{110,760 - 86,704}{40 - 38} \div \frac{86,704}{38}$$

$$= 5.272$$

Since F calculated at 5.272 is larger than the tabulated value, F(2, 38); α = 0.05 is 3.248 of the hypothesis that both ADT and way of operation are not significant is rejected at α = 0.05 level. There is a significant difference at the 5% level between high volume and low volume frontage road accident rates.

Table 9. Summary of ANOVA for Ramp Accident Models

Dependent Variable	Model Number	Independent Variables	Sum of Squares Error (SSE)	Error Degree of Freedom (DF)	Error Mean Square (MSE)	Coefficient of Determination (R^2)
ACCR	1	Area, ADT, Way	86.704	38	2.282	0.48
	2	Area, ADT, Ramp	80.901	35	2.311	0.52
	3	Area, ADT	90.394	39	2.318	0.46
	4	Area	110.760	40	2.769	0.34

Hypothesis 3: Ramp type does not significantly effect ramp accidents.

$$\text{Similarly, } F = \frac{SSE(3) - SSE(2)}{DF(3) - DF(1)} \div \frac{SSE(2)}{DF(1)}$$

$$= \frac{90.394 - 80.901}{39 - 35} \div \frac{80.901}{35}$$

$$= 1.027$$

Since the calculated value of F of 1.027 is smaller than the tabulated value of $F(4, 35)$: $\alpha = 0.05$ is 2.650, there is no effect of ramp type on ramp accidents. Ramp accidents appear to be randomly distributed across all ramp types at any confidence level.

3.5.3 Conclusion of Factor Effects on Ramp Accidents

From the three hypotheses tested, it is concluded that both area development and traffic volume significantly affect ($\alpha = 0.05$) ramp accidents. Specifically, accidents are observed to increase as the intensity of development increases. Accidents also increase as traffic volume increases.

3.5.4 The Effects of Factors on All Accidents

Table 10 is a summary of the analysis of variance for all accident models. Similar hypotheses were tested regarding the effect of the individual factors on all accidents.

Hypothesis 1: One-way and two-way operation does not significantly effect ramp accidents.

To test this hypothesis, the value of F is obtained as follows:

$$F = \frac{SSE(3) - SSE(1)}{DF(3) - DF(1)} \div \frac{SSE(1)}{DF(1)}$$

$$= \frac{297.224 - 297.153}{39 - 38} \div \frac{297.153}{38}$$

$$= 0.009$$

Table 10. Summary of ANOVA for All Accident Models

Dependent Variable	Model Number	Independent Variables	Sum of Squares Error (SSE)	Error Degree of Freedom (DF)	Error Mean Square (MSE)	Coefficient of Determination (R^2)
ACCA	1	Area, ADT, Way	297.153	38	7.820	0.69
	2	Area, ADT, Ramp	283.132	35	8.089	0.70
	3	Area, ADT	297.224	39	7.621	0.69
	4	Area	506.526	40	12.663	0.47

$F(1, 38)$: $\alpha = 0.05$ is 4.098, there is no one-way or two-way effect on all accidents at $\alpha = 0.05$ level.

Hypothesis 2: Both ADT and one-way or two-way operation do not significantly affect all accidents.

$$\text{Similarly, } F = \frac{SSE(4) - SSE(1)}{DF(4) - DF(1)} \div \frac{SSE(1)}{DF(1)}$$

$$= \frac{506.526 - 297.153}{40 - 38} \div \frac{297.153}{38}$$

$$= 13.387$$

Since the calculated value of 13.387 is greater than the tabulated value for $F(2, 38)$: $\alpha = 0.05$ is 3.248, the hypothesis that both ADT and way of operation are not significant is rejected at $\alpha = 0.05$ level. There is a significant effect.

Hypothesis 3: Ramp types do not significantly affect all accidents.

$$\text{Similarly, } F = \frac{SSE(3) - SSE(2)}{DF(3) - DF(1)} \div \frac{SSE(2)}{DF(1)}$$

$$= \frac{297.224 - 283.132}{39 - 35} \div \frac{283.132}{35}$$

$$= 0.436$$

Since the calculated value of 0.436 is smaller than the tabulated value at $\alpha = 0.05$ level for $F(4, 35)$ is 2.650, there is no statistical effect of ramp type on all accidents.

3.5.5 Conclusions from the Factor Effects Analysis on All Accidents

From the three hypotheses tested, it is concluded that both area development and traffic volume significantly affect ($\alpha = 0.05$) the accident rate on frontage roads within 0.1 mile from the ramp.

For both ramp accidents and all accidents, it is concluded that accidents increase in urban areas and also increase as a function of traffic volume. The regression (ANOVA) models were not of sufficient strength

(correlation) to justify their use for predictive purposes. The observed average of twenty percent reduction in accidents is the best estimate available at this time.

3.6 Limitations of the Study

It is cautioned that the findings regarding the insignificant effect of one-way or two-way operation and ramp type on accidents are limited: (1) the sites observed are involved in an unbalanced design with missing cells and an unequal number of observations, and (2) much of the information is qualitative in nature.

3.7 Summary of Erratic Maneuver Data for Ramps by Frontage Road Volume Levels

There is a possibility that erratic maneuvers may be related to the traffic level on the frontage road. In order to test this possibility, the data set summarized in Table 3 were stratified on the basis of frontage road traffic volume (ADT). Two broad categories were used: low volume (5000 ADT or less) and high volume (greater than 5000 ADT). The resulting data sets are presented in Table 11.

Table 11. Erratic Maneuver Data Stratified by Volume Level

Type of Frontage Road Operation	Type of Ramp	Driving Maneuver			
		Entrance		Exit	
		High Volume	Low Volume	High Volume	Low Volume
One-Way	Slip Ramp to or from a Separate Lane	21.2%	12.0%	40.0%	40.0%
	Slip Ramp to a Merge Situation	16.0%	12.7%	34.0%	22.0%
Two-Way	Buttonhook	18%	6%	NA	11.5%
	Slip Ramp	18%	6%	26%	8%
	Braided	NA	10.7%	2.0%	14%

Table 11 shows that for one-way operation, exit ramps constitute a far more significant problem than entrance ramps. In addition, the slip ramp in two-way operations tends to produce more erratic maneuvers on high volume than on low volume frontage roads. The buttonhook ramp also tends to produce a higher rate of erratic maneuvers on high volume frontage roads.

Braided ramp terminals with two-way frontage roads produced a relatively low frequency of erratic maneuvers compared to all ramps observed. This is probably the result of alternative paths being restricted by the traffic islands.

In general, the correlation of the percent erratic maneuvers and volume is very weak for exit ramps, if any correlation exists at all. However the entrance ramps of high volume frontage roads consistently exhibit a higher percentage of erratic maneuvers than low volume ones.

3.8 Erratic Maneuver Data for Terminals of Two-Way Operation

The one-way operation must be terminated at some point. Typically, this transition should take place at a point where the frontage roads are discontinuous, that is, where a tee-intersection exists. Frequently, however, there is no obvious location for a good transition from one-way to two-way operation. Many alternative treatments are being used for these transitions, but the question of operational efficiency still exists. This phase of the study addressed the terminal area of one-way frontage roads.

3.9 Study Sites For Terminal Study

Fourteen sites were located throughout the State of Texas with potential to meet the project's needs. Six were selected for field data collection. These sites were categorized by the type of traffic control system existing at the intersection. Erratic maneuvers were as previous defined for ramp intersections. Table 12 contains a summary of the site data.

Table 12. Summary of One-Way to Two-Way Terminal Sites

Type of Traffic Control	Number of Sites	Observed Number of Erratic Maneuvers	Total No. of Vehicles Observed
Signs Only	2	1	177
Signs with Channelization	2	0	139
Flashing Beacon and Signs	2	1	120
TOTAL	6	2	436

So few erratic maneuvers were observed that, for practical purposes, the terminals represent a minimal problem. This may well be the result of two factors: (1) the frontage road volumes are typically very low in the

two-way section, and (2) a high percentage of repeat drivers in the traffic stream make any deficiencies in the driver communication system less significant.

The following findings tend to suggest the desirable features of terminals for one-way frontage operation:

1. Low frontage road traffic on the two-way section, that is, less than 1000 VPD.
2. A relatively high percentage of repeat drivers, that is, 95% or more.
3. The standard MUTCD sign and marking complement should be used as a minimum.
4. A flashing beacon may be required under special conditions.

Accident experience at the terminal sites was also examined. Table 13 contains a summary of these data.

Table 13. Accident Experience at One-Way to Two-Way Terminal Sites

Traffic Control Type	Number of Sites	Observed Accidents in 1980	Average Number of Accidents Per Site
Signs Only	3	6	2.0
Signs and Channelization	5	2	0.4
Signals and Signs	4	14	3.5
TOTALS	12	22	m = 1.83

Kruskal-Wallis Test of Signed Rank Data of One-Way to Two-Way Transitions

Non-parametric statistics can be used to test the significance of the sum of the ranks of a group of data, assuming that all observations are independent of one another.

BASIC DATA MATRIX

	Observation					
	1	2	3	4	5	Mean
Signs Only	0	5	1	-	-	2.0
Signs and Channelization	0	0	1	1	0	0.4
Signals	2	4	8	0	-	3.5

Overall Mean = 1.83

RANK MATRIX

	Observation					
	1	2	3	4	5	Sum
Signs Only	3	11	7	--	--	21
Signs and Channelization	3	3	7	7	3	23
Signals	9	10	12	3	--	34

TEST STATISTIC

$$T = \frac{12}{N(N+1)} \sum R_i^2/N - 3(N^i + 1)$$

$$T = \frac{12}{12(13)} \left[\frac{(21)^2}{3} + \frac{(23)^2}{5} + \frac{(34)^2}{5} \right] - 3(13)$$

$$= 0.0769(541.8) - 39 = 2.66$$

$T(0.05, 5, 4, 3) = 5.63$ and therefore the Treatments are not significantly different. This finding suggests that the three types of control of one-way to two-way transitions are not significantly different.

Since volume data at each of the one-way to two-way transition points were not available, testing of accident rates was not possible. It is doubtful that such an analysis would provide any more insight into the safety problems of two-way to one-way transitions. The general finding is that

accidents at one-way terminals are relatively rare, and, therefore, the traffic control at these points should be selected on the basis of the individual site characteristics.

4. STUDY FINDINGS

Several findings from the study deserve to be highlighted.

1. Erratic maneuvers are more frequent on slip ramps than on other ramp types, primarily due to the available space to execute erratic maneuvers at slip ramp terminals.

2. Accidents at ramp-frontage road intersections are primarily influenced by frontage road traffic level (ADT) and area developmental intensity, and not by ramp type. Indeed, ramp type was not a statistically significant factor for either one-way or two-way operation.

3. Conversion from two-way to one-way reduces accidents significantly for high volume frontage roads, that is, over 5000 ADT total of both frontage roads.

4. A definite negative trend in the accident reduction with frontage road ADT was identified, but the correlation was too weak to use for predictive purposes. An average 20 percent reduction on conversion from two-way to one-way operations can be expected for ADT's over 5000 vehicles per day.

5. One-way termination points of frontage roads in Texas are apparently a minimal problem. Only two erratic maneuvers were observed in 436 vehicles included in the data. Accident data indicated an average of two accidents per year at the nine terminals studied, which is about the same as the national average for low volume intersections.

6. Again, findings on the insignificant effect of one-way or two-way operation and ramp type on accidents are limited because of missing cells and an unequal number of observations.

While the operational and safety studies documented in this report did not provide definitive warranting conditions, the accident reduction, traffic volumes, and degree of roadside development were statistically significant and indicate the factors which should be considered in establishing the warranting conditions.

REFERENCES

1. McFarland William F., John B. Rollins; Cost-Effectiveness Techniques For Highway Safety, Vol. III., Accident Costs (DRAFT); Texas Transportation Institute, Texas A&M University; November 1982.

APPENDIX A
TAPE REDUCTION SUMMARY
RAMP STUDY SITES

Sheet No. 1/6

Tape Reduction Summary

Tape No.: _____
Tape Dates: _____
Dates Reduced: _____
By: _____

Ramp No.	Movement 1	2	3	4	5	6	7	8	9	Frontage Rd. Site	Frontage* Rd. Oper.	Develop-ment**	Ramp Type	SR Volume R	Location (Gen.)	Time
1						11	1			33	2/2	I	Button Hook Entrance	L-m	I-45 @ Winter Green	7:45 AM
2	2	1							1	33	2/2	I	Braided Exit	L-m	Dowdy Ferry Rd @ I-45	1:40 P
5	1				25					25	2/1	U	Slip Exit w/ merging Lane	L-M	I-35 E @ Fox Ave Over Pass	11:35 A 12:05 A
6				3		3				25	2/1	U	Slip Entrance w/ merging Lane	L-m	I-35 E @ Fox Ave Over Pass	1:45 A
7		2								29	2/2	I	Slip Entrance	m-H	I-30 @ SH 205	9:30 A
8	4	5			4					29	2/2	I	Slip Exit	m-H	I-30 @ SH 205	9:30 A

Notes: *2/1: 2 lane - 1 way
2/2: 2 lane - 2 way
3/1: 3 lane - 1 way
**I = Intermediate
U = Urban
R = Rural

Comments:

09

Sheet No. 2/6

Tape Reduction Summary

Tape No.: _____

Tape Dates : _____

Dates Reduced : _____

By : _____

Ramp No.	Movement 1	2	3	4	5	6	7	8	9	Frontage Rd. Site	Frontage* Rd. Oper.	Develop-ment**	Ramp Type	SR Volume	R	Location (Gen.)	Time
9	2					5	3			15	2/2	I	Slip Entrance	L-m		I 35 ℄ FM 2114	10:45A
10		3			6					14	2/1	I	Slip Exit w/ MERGING LANE	m-H		I 35 ℄ Loop 340	2:35P
11					22					14	3/1	I	Slip Separate Exit	m-H		I 35 ℄ U.S. 84	3:45P 4:10P
12					21					8	3/1	U	Slip Merge Exit	m-H		I 35 ℄ OLTORF STR.	10:45A 11:00A
13				8		3				9	2/1	I	Slip Merge Entrance	m-H		I 35 ℄ BRAKER LANE	2:00P 2:30P
14			1	11						14	3/1	I	Slip Separate Entrance	m-H		I 35 ℄ US 84	4:00P 4:30P
15							6			37	2/2	U	Braided Entrance	L-m		I 35 ℄ O'CONNER RD	10:10A 10:26A
16							1			37	2/2	U	Braided Exit	L-m		I-35 ℄ WIEDNER RD.	10:30A 11:49A

Notes: *2/1: 2 lane - 1 way
2/2: 2 lane - 2 way
3/1: 3 lane - 1 way
**I = Intermediate
U = Urban
R = Rural

Comments: _____

Sheet No. 3/6

Tape Reduction Summary

Tape No.: _____
Tape Dates : _____
Dates Reduced : _____
By : _____

Ramp No.	Movement 1	2	3	4	5	6	7	8	9	Frontage Rd. Site	Frontage* Rd. Oper.	Develop-ment**	Ramp Type	Volume SR	Volume R	Location (Gen.)	Time
17	4	4			5			1		38	2/2	I	Braided Exit	M-H		I35 @ O'Conner Rd	12:05p 1:15p
18							2			38	2/2	I	Braided Entrance	M-H		I35 @ O'Conner Rd	3:50p
19										37	2/2	U	Braided Entrance	M-H		I35 @ O'Conner Rd	4:10p 4:52p
20										37	2/2	U	Braided Exit	M-H		I35 @ O'Conner Rd	5:10p
21				2							2/1	I	Slip Merge Entrance	L-M		W. Loop 410 @ Persail	8:20A 8:35A
22						1	1			39	2/2	R	Buttonhook Entrance w/y-Island	M-H		I35 @ Loop 1604	11:15A 11:35A
23	9	2								39	2/2	R	Buttonhook Exit w/y Island	M-H		I35 @ Loop 1604	12:50p 1:15A
24						3	3			40	2/2	R	Slip Merge ENTRANCE	L-M		I35 @ EVANS Rd.	1:55A

Notes: *2/1: 2 lane - 1 way
2/2: 2 lane - 2 way
3/1: 3 lane - 1 way
**I = Intermediate
U = Urban
R = Rural

Comments:

Sheet No. 4/16

Tape Reduction Summary

Tape No.: _____
Tape Dates: _____
Dates Reduced: _____
By: _____

Ramp No.	Movement 1	2	3	4	5	6	7	8	9	Frontage Rd. Site	Frontage* Rd. Oper.	Development**	Ramp Type	SR Volume R	Location (Gen.)	Time
25		1				5				42	2/2	U	Button Hook Entrance	L-M	I-35 @ 725	9: 15A — 9: 15A
26	2				3					42	2/2	U	Button Hook Exit	L-M	I-35 @ Far 1044 (Mackenzie)	9: 25P — 10: 15A
27						4				42	2/2	U	Button Hook Entrance	M-H	I-35 @ 725	10: 35A — 11: 10A
28	1				1					42	2/2	U	Button Hook Exit	M-H	I-35 @ For 1044 (Mackenzie)	11: 27A — 12: 07P
29			1	6		1				20	3/1	U	Slip Entrance	L-M	I-45 @ 61st St	11: 05A — 11: 15A
30			1		22					20	3/1	U	Slip Exit	L-M	I-45 @ 61st St	11: 50P — 12: 00N
31				8		7				20	3/1	U	Slip Entrance	M-H	I-45 @ 61st St	4: 00P — 4: 05A
32				10		2				21	3/1	R	Slip Entrance	L-M	I-45 @ FM 517	8: 10A — 8: 40A

Notes: *2/1: 2 lane - 1 way
2/2: 2 lane - 2 way
3/1: 3 lane - 1 way
**I = Intermediate
U = Urban
R = Rural

Comments: _____

Sheet No. 5/6

Tape Reduction Summary

Tape No.: _____
Tape Dates : _____
Dates Reduced : _____
By : _____

Ramp No.	Movement 1	2	3	4	5	6	7	8	9	Frontage Rd. Site	Frontage* Rd. Oper.	Develop-ment**	Ramp Type	SR Volume	R	Location (Gen.)	Time
33				1		5				19	3/1	I	slip Entrance	L-M		I-45 @ FM 517	9:25A 9:40A
34			1		18					21	3/1	R	slip Exit	L-M		I-45 @ FM 517	10:40A 11:07A
35			11		6					19	3/1	I	slip Exit	L-M		I-45 @ FM 517	11:40A 12:05A
36	1				4					45	2/2	I	Buttonhook Exit	L-M		I-35 @ Brahter Ln.	1:30P 2:30P
37				7						17	2/1	R	slip Entrance	L-M		I-45 @ choate Rd.	1:55P 2:15P
38		2			9					17	2/1	R	slip Exit	L-M		I-45 @ choate Rd	3:00 3:25
39				6						4	3/1	R	slip Entrance	M-H		I-10 @ SH 6	11:30 11:40
40		3			14					4	2/1	R	slip Exit	M-H		I-10 @ Park 10 Rd.	12:10P 12:19P

Notes: *2/1: 2 lane - 1 way
2/2: 2 lane - 2 way
3/1: 3 lane - 1 way
**I = Intermediate
U = Urban
R = Rural

Comments: _____

Sheet No. 6/6

Tape Reduction Summary

Tape No.: _____
Tape Dates : _____
Dates Reduced : _____
By : _____

Ramp No.	Movement 1	2	3	4	5	6	7	8	9	Frontage Rd. Site	Frontage* Rd. Oper.	Develop-ment**	Ramp Type	SR	Volume	R	Location (Gen.)	Time
41					23					4	3/1	R	Slip separate Exit	m-H			I-10 @ SH6	—
42			1	6		1				4	2/1	R	Slip Merge Entrance	m-H			I-10 @ Barker Rd.	—
43		2			2					2	2/2	R	Slip Exit	m-H			I-45 @ Tamina Rd. Exit RAMP	—
																		—
																		—
																		—
																		—
																		—

Notes: *2/1: 2 lane - 1 way
2/2: 2 lane - 2 way
3/1: 3 lane - 1 way
**I = Intermediate
U = Urban
R = Rural

Comments: TOTAL E.A. - 402
TOTAL VEHICLES 2050
DO NOT USE RAMPS 3+4

APPENDIX B

ONE-WAY TO TWO-WAY TRANSITION INTERSECTION DESCRIPTIONS

SITE 1 I-10 South Frontage Road and Akerman Road
Signs with Channelization Islands
1980 Volume - 2-Way Frontage Road Section Only
South Frontage Road - 242 Veh/Day Total - 692 Veh/Day
No Erratic Maneuvers

SITE 2 US90 North Frontage Road and Cupples Road
Signals with Signs
1980 Volume - Not Available
No Erratic Maneuvers

SITE 3 I-35 West Frontage Road and SH123 (South Loop 82)
Signals with Signs
1980 Volume - 2-way Frontage Road Section Only
West Frontage Road - 5908 Veh/Day Total - 9632 Veh/Day
1 Erratic Maneuver - in One-Way Direction
66 Vehicles Surveyed (43 in One-Way Direction, 13 in Two-Way)
Percent Erratic Maneuvers
One-Way 1/43 = 2.3%
Total 1/66 = 1.5%

SITE 4 Not Used

SITE 5 I-35 West Frontage Road and SH-6 (South Loop 340)
Signs with Channelization Islands
1980 Volume - Not Available
No Erratic Maneuvers

SITE 6 I-35 East Frontage Road and Braker Lane
Signs Only
1980 Volumes - Both Frontage Road Sections
Two-Way Section - East Frontage Road - 4150 Veh/Day--Total 6687 Veh/Day
One-Way Section - East Frontage Road - 1140 Veh/Day--Total 3430 Veh/Day
No Erratic Maneuvers

SITE 7 I-45 East Frontage Road and Tamina Road
Signs Only
1980 Volumes - Two-Way Frontage Road Section Only
East Frontage Road - 2100 Veh/Day--Total 3500 Veh/Day
One Erratic Maneuver - in One-Way Direction
88 Vehicles Surveyed (64 in One-Way Direction, 24 in Two-Way)
Percent Erratic Maneuvers
One-Way Direction 1/64 = 1.6%
Total 1/88 = 1.1%

APPENDIX C

FRONTAGE ROAD ONE-WAY TO TWO-WAY TRANSITIONS

LOCATION DESCRIPTIONS, VOLUME DATA

AND ERRATIC MANEUVER DATA

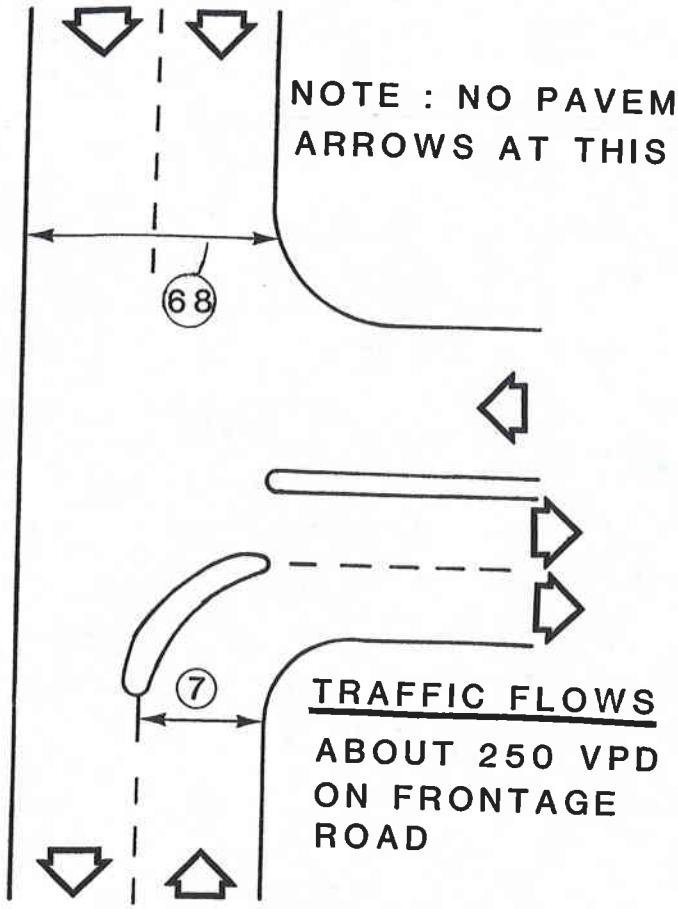
APPENDIX C

One-Way to Two-Way Transition Intersections

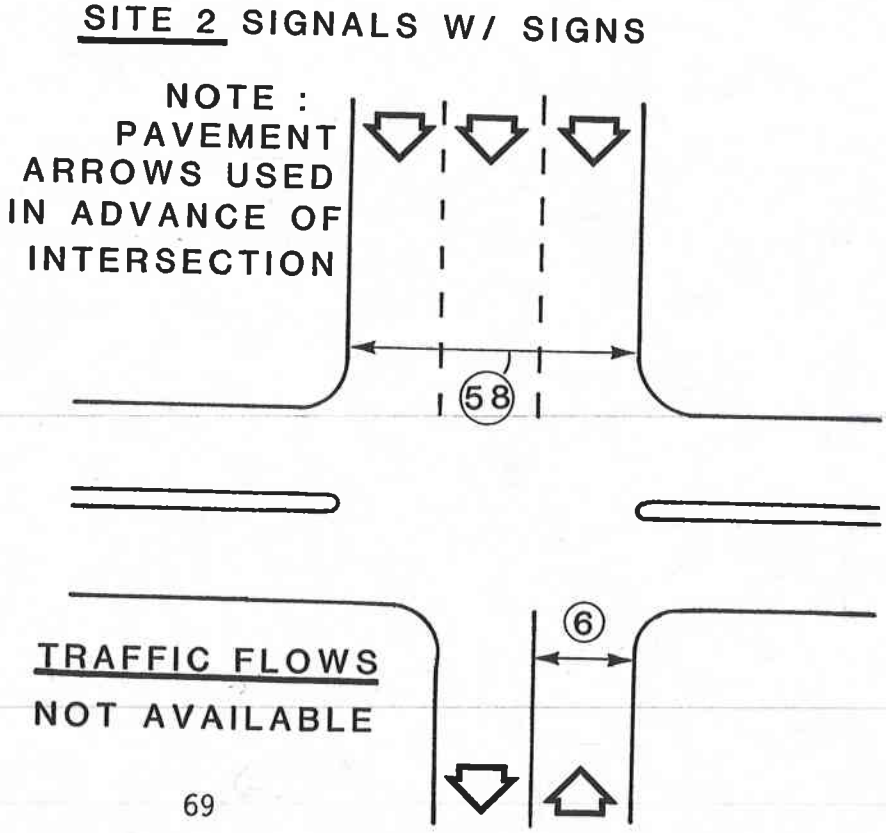
VOLUME DATA

Location	No. Vehicles Traveling One-Way	No. Vehicles Traveling Two-Way	Total No. Vehicles	Number of Erratic Maneuvers	%
Site 1: Signs w/Island	68	7	75	0	0
Site 2: Signals w/Sign	58	6	64	0	0
Site 3: Signals w/Sign	43	13	56	1	1.8
Site 5: Signs w/Island	56	8	64	0	0
Site 6: Signs	75	14	89	0	0
Site 7: Signs	64	24	88	1	1.1
Type Location	364	72	436	2	0.46
Signs w/Island Sites 1 & 5	124	15	139	0	0
Signals w/Sign Sites 2 & 3	101	19	120	1	0.83
Signs Only Sites 6 & 7	139	38	177	1	0.56

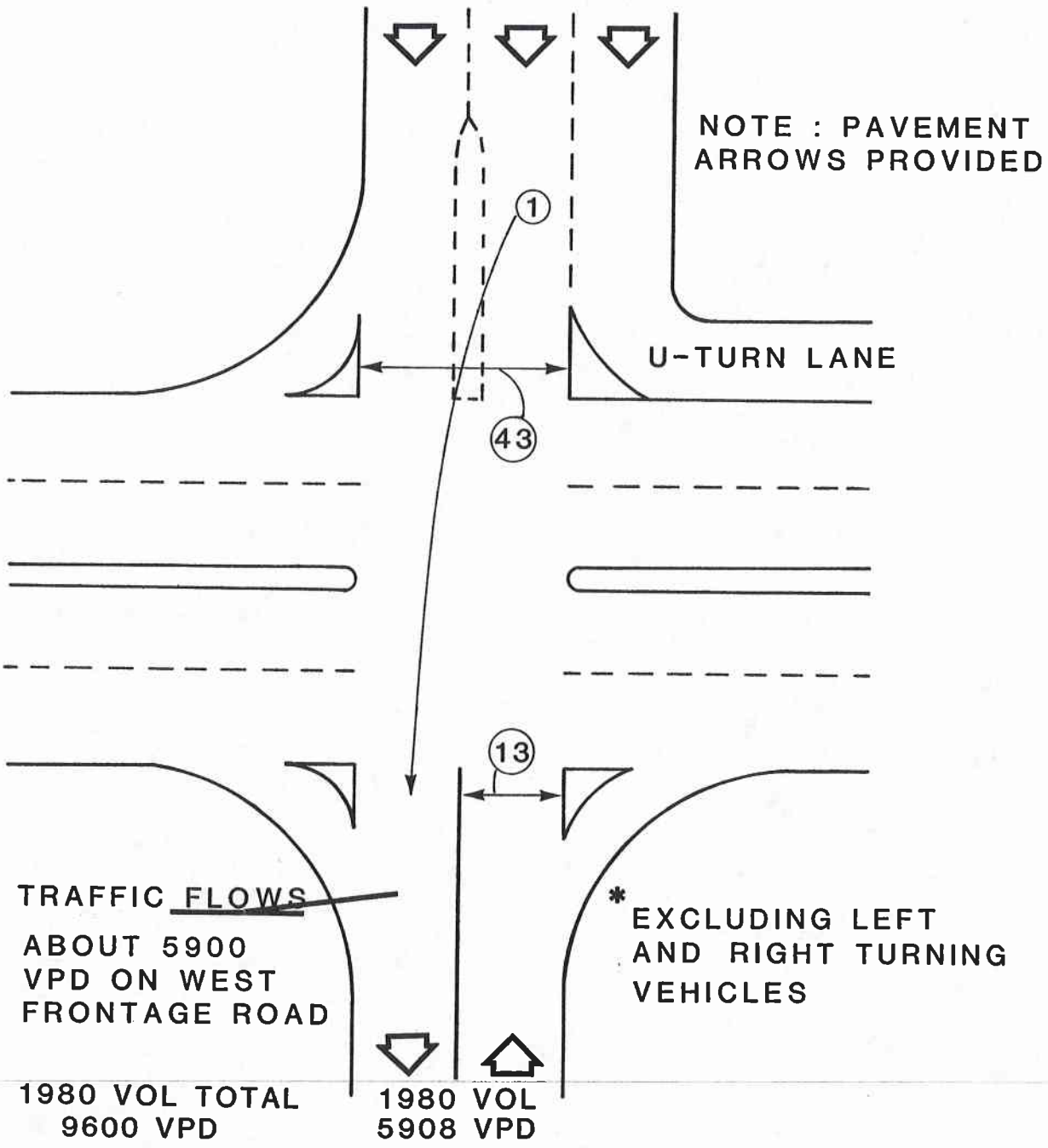
SITE 1 SIGNS W/ ISLANDS



SITE 2 SIGNALS W/ SIGNS

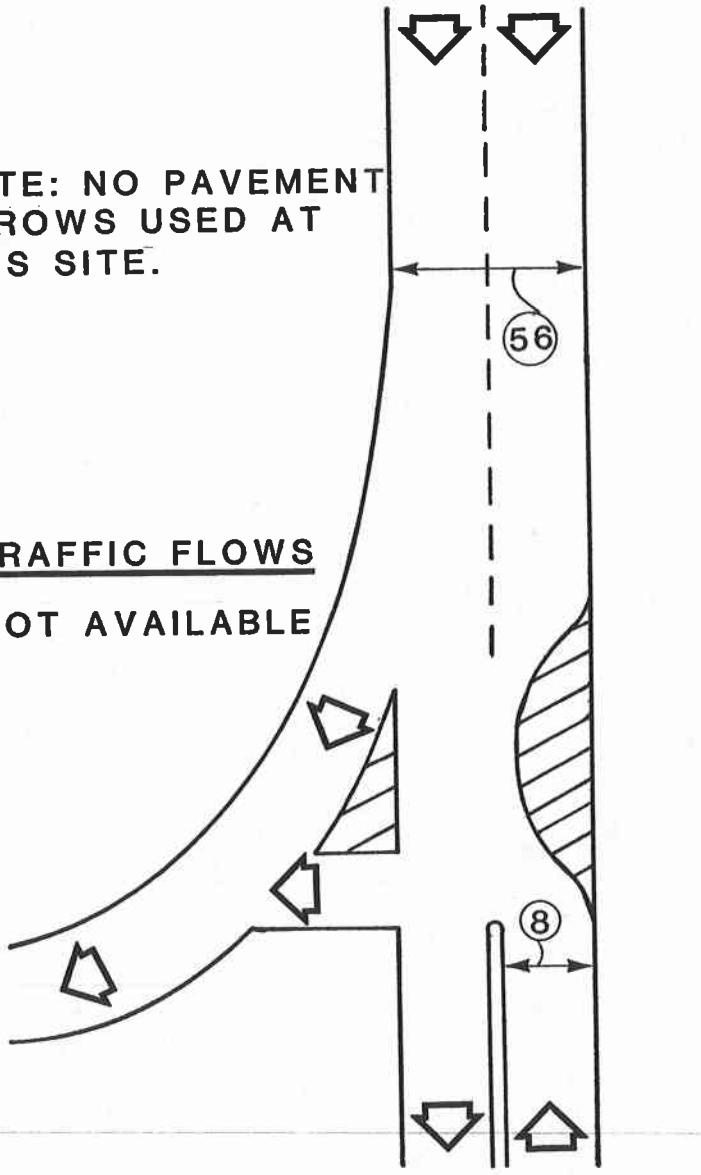


SITE 3 SIGNALS W/ SIGNS *



SITE 5 SIGNS W/ ISLANDS

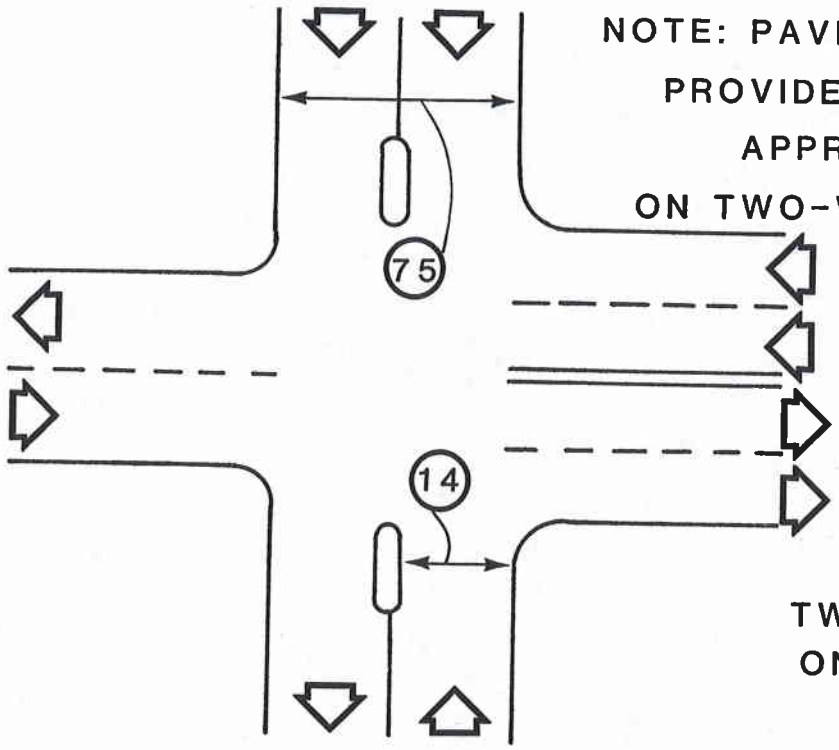
NOTE: NO PAVEMENT ARROWS USED AT THIS SITE.



TRAFFIC FLOWS

NOT AVAILABLE

SITE 6 SIGNS

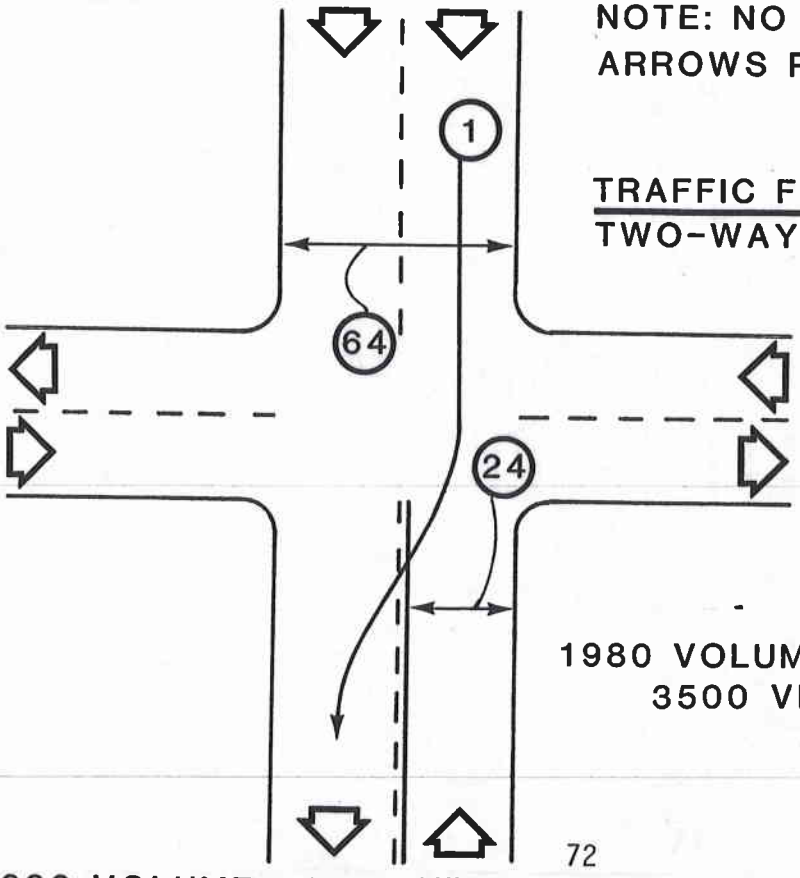


NOTE: PAVEMENT ARROWS PROVIDED ON ONE-WAY APPROACH BUT NOT ON TWO-WAY APPROACH

FRONTAGE ROAD TRAFFIC FLOWS

TWO-WAY 4150 VPD
ONE-WAY 1140 VPD

SITE 7 SIGNS



NOTE: NO PAVEMENT ARROWS PROVIDED

TRAFFIC FLOWS
TWO-WAY SECTION - 2100 VPD

1980 VOLUME TOTAL
3500 VPD

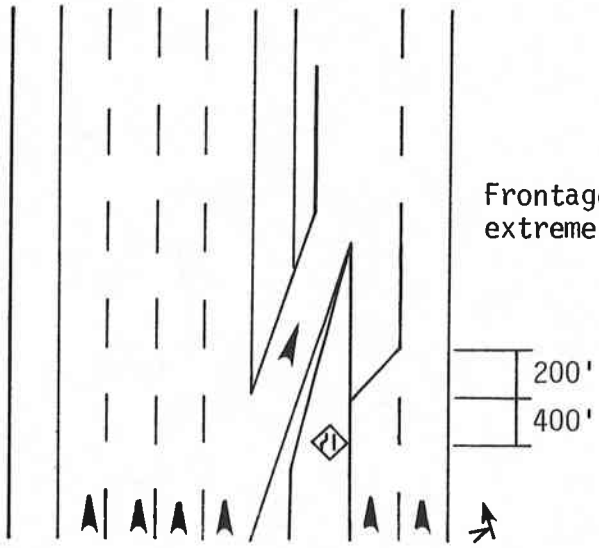
1980 VOLUME 2100 VPD

APPENDIX D

EXIT RAMP SITES

EXIT RAMPS (PROJECT 2288)

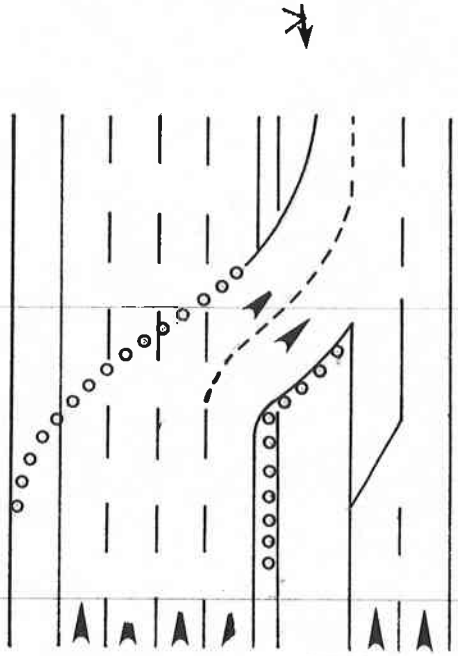
1. U.S. 290 WB @ 34th St. 7-29-80
10:25 AM - 10:30 AM 000-100



Frontage road traffic extremely light.

Filming site & direction

2. U.S. 290 WB @ 43rd St. (Freeway end) 7-29-80
11:00 AM - 100-150



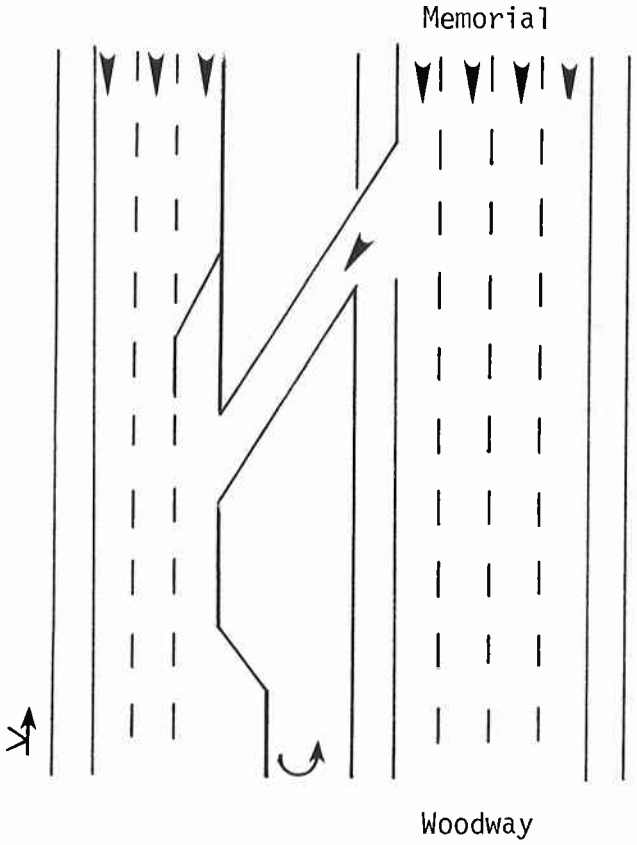
Frontage road traffic extremely light.

Filming Site & Direction

3. I-610W SB @ WOODWAY
11:25 AM

7-29-80

150-240



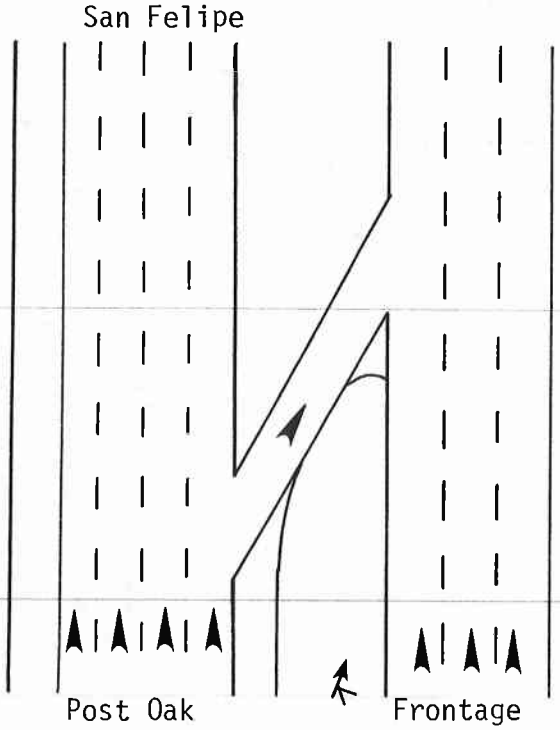
Very light frontage road traffic, platooned due to Memorial St. signalization

Filming Site & Direction

4. I-610W SB @ SAN FELIPE/WESTHEIMER
12:00 Noon - 12:11 PM

7-29-80

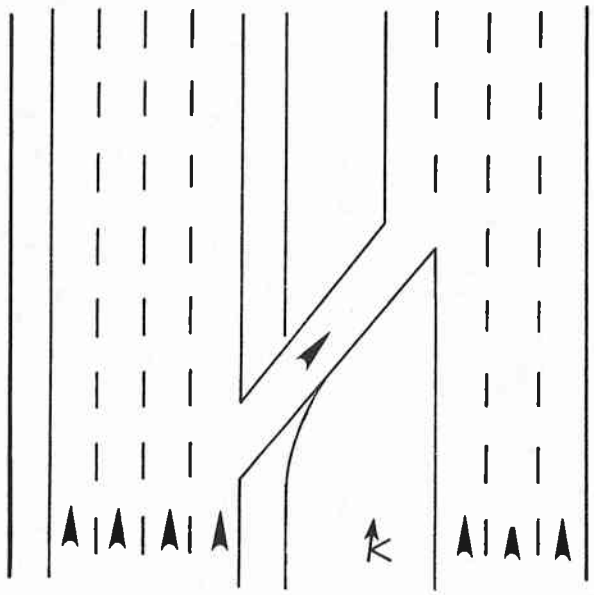
240-336



Exiting traffic was moderate while frontage road traffic was light. Frontage road traffic was spuratic.

Filming Site & Direction

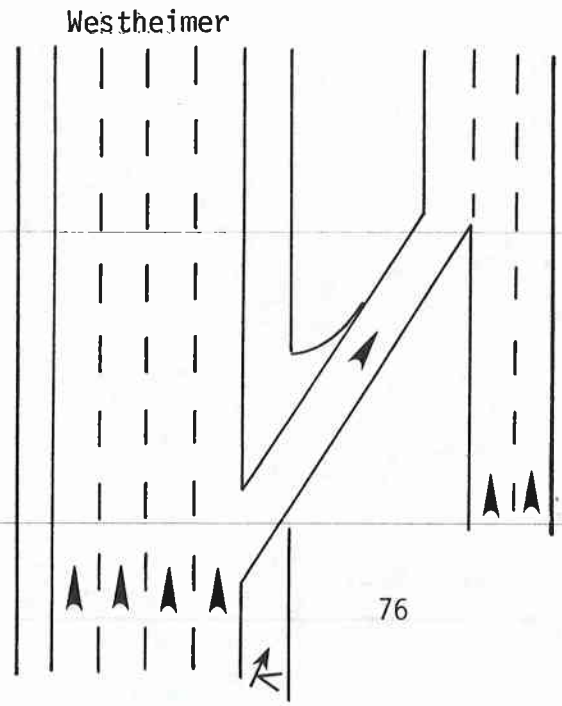
5. U.S. 59 SB @ BEECHNUT/GESSNER 7-29-80
12:50 PM - 12:55 PM 337-376



Frontage road traffic light while exiting traffic was moderate.

Filming Site & Direction

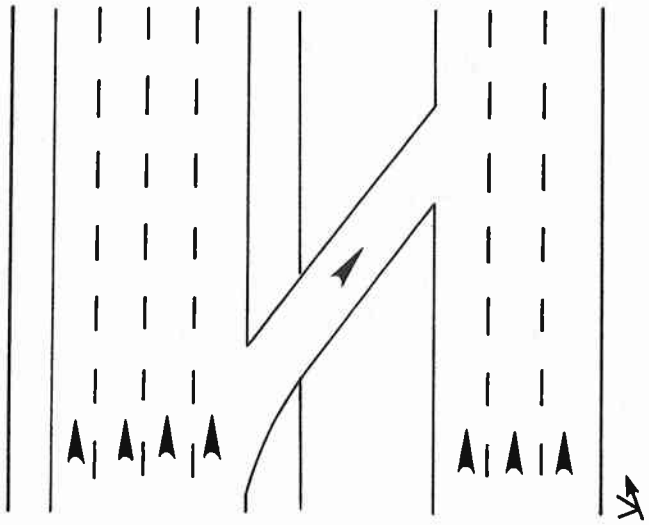
6. I-610W NB @ WESTHEIMER RD. 7-29-80
1:27 PM - 1:35 PM 378-420



Frontage road traffic was light while exiting traffic was extremely heavy.

Filming Site & Direction

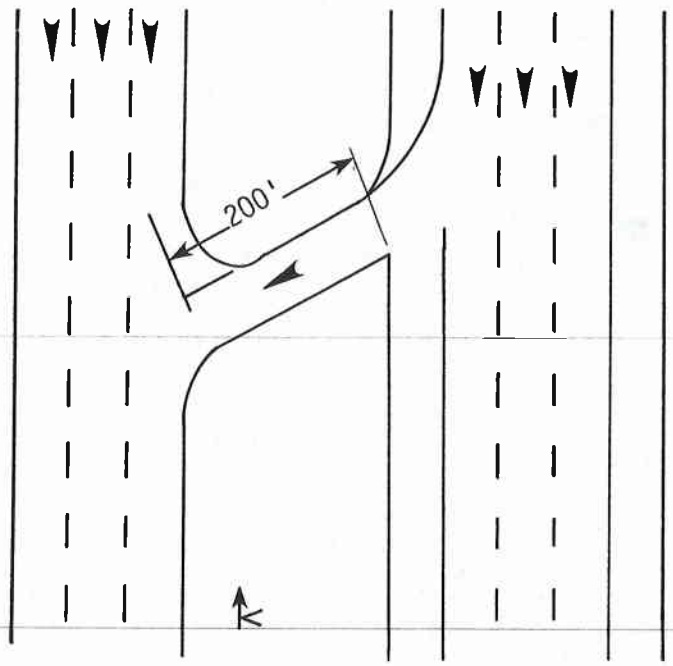
7. I-10 EB @ BLALOCK/CAMPBELL RD. 7-31-80
12:00 Noon - 12:10 PM 420-493



Filming Site & Direction

From shopping center parking lot.

8. I-10W EB @ ANTOINE Zoom on Ramp & Gore 7-31-80
12:35 PM - 12:47 PM 493-567



Short bottom hook ramp-moderate to heavy Main lane traffic-consistant frontage road traffic

Filming Site & Direction

APPENDIX E

Annual Mean Number of Accidents Classified by the Combinations of Factors for 44 Sites

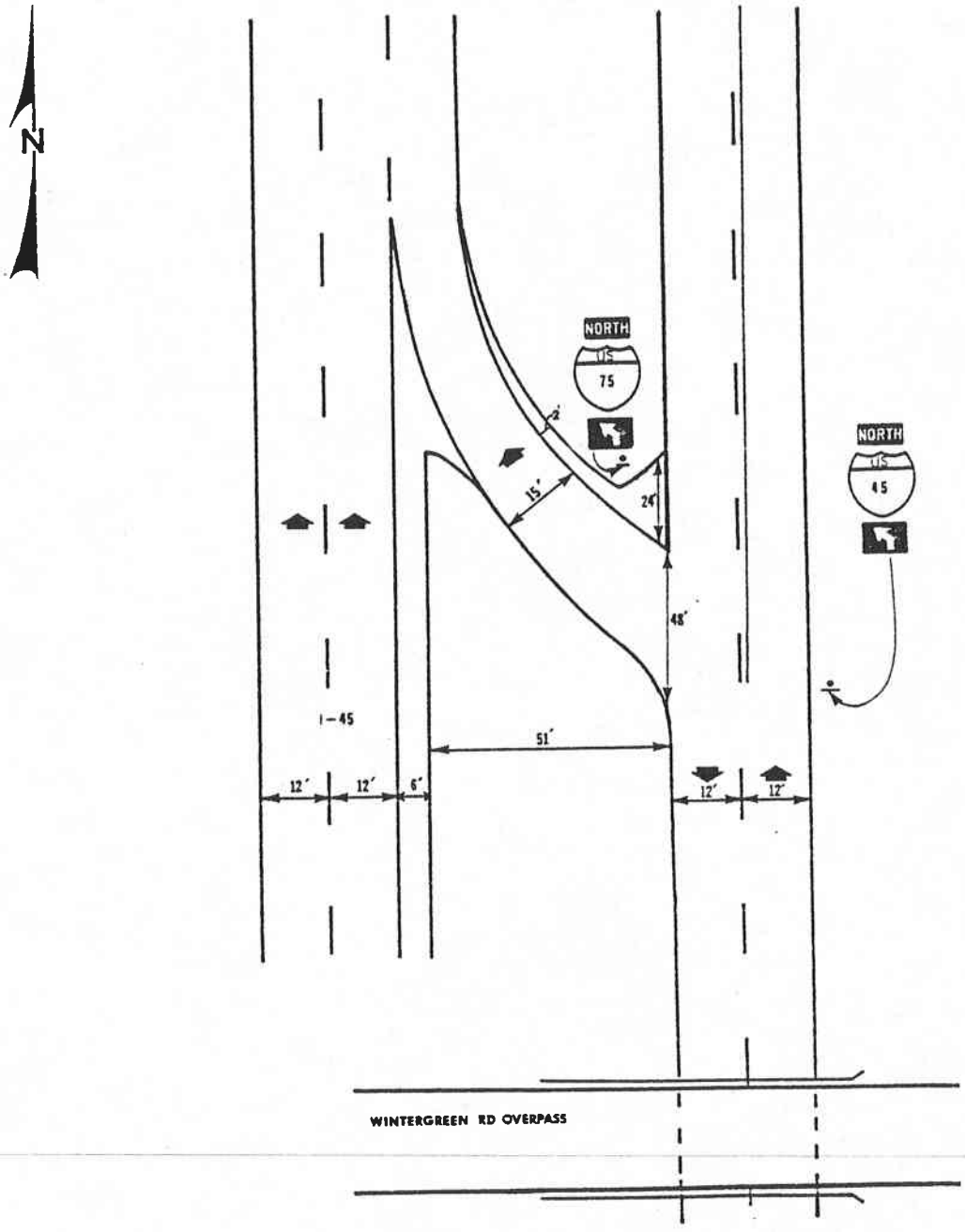
Classes	Way	Ramp	Volume	Area	N	Mean Annual Number of Accidents
1	1	--	--	--	22	4.59
2	2	--	--	--	22	2.36
1	--	BR	--	--	2	2.50
2	--	BU	--	--	12	2.25
3	--	S	--	--	8	2.50
4	--	SM	--	--	14	4.57
5	--	SS	--	--	8	4.63
1	--	--	LM	--	22	2.00
2	--	--	MH	--	22	4.95
1	--	--	--	I	19	2.84
2	--	--	--	R	16	1.00
3	--	--	--	U	9	9.22
1	1	SM	--	--	14	4.57
2	1	SS	--	--	8	4.63
3	2	BR	--	--	2	2.50
4	2	BU	--	--	12	2.25
5	2	S	--	--	8	2.50
1	1	--	LM	--	12	2.00
2	1	--	MH	--	10	7.70
3	2	--	LM	--	10	2.00
4	2	--	MH	--	12	2.67
1	1	--	--	I	7	3.86
2	1	--	--	R	9	1.22
3	1	--	--	U	6	10.50
4	2	--	--	I	12	2.25
5	2	--	--	R	7	0.71
6	2	--	--	U	3	6.67
1	--	BU	LM	--	6	1.17
2	--	S	LM	--	4	3.25
3	--	SM	LM	--	8	2.13
4	--	SS	LM	--	4	1.75
5	--	BR	MH	--	2	2.50
6	--	BU	MH	--	6	3.33
7	--	S	MH	--	4	1.75
8	--	SM	MH	--	6	7.83
9	--	SS	MH	--	4	7.50
1	--	BR	--	I	1	2.00
2	--	BU	--	I	5	1.40
3	--	S	--	I	6	3.00

APPENDIX E (Continued)

Classes	Way	Ramp	Volume	Area	N	Mean Annual Number of Accidents
4	--	SM	--	I	3	5.33
5	--	SS	--	I	4	2.75
6	--	BU	--	R	5	0.60
7	--	S	--	R	2	1.00
8	--	SM	--	R	7	1.29
9	--	SS	--	R	2	1.00
10	--	BR	--	U	1	3.00
11	--	BU	--	U	2	8.50
12	--	SM	--	U	4	9.75
13	--	SS	--	U	2	12.00
1	--	--	LM	I	10	3.50
2	--	--	MH	I	0	2.11
3	--	--	LM	R	12	0.75
4	--	--	MH	R	4	1.75
5	--	--	MH	U	9	9.22
	1	SM	LM	--	8	2.13
	1	SM	MH	--	6	7.83
	1	SS	LM	--	4	1.75
	1	SS	MH	--	4	7.50
	2	BR	MH	--	2	2.50
	2	BU	LM	--	6	1.17
	2	BU	MH	--	6	3.33
	2	S	LM	--	4	3.25
	2	S	MH	--	4	1.75
	1	SM	--	I		5.33
	1	SM	--	R		1.29
	1	SM	--	U		9.75
	1	SS	--	I		2.75
	1	SS	--	R		1.00
	1	SS	--	U		12.00
	2	BR	--	I		2.00
	2	BR	--	U		3.00
	2	BU	--	I		1.40
	2	BU	--	R		0.60
	2	BU	--	U		8.50
	2	S	--	I		3.00
	2	S	--	R		1.00
	1	--	LM	I		4.75
	1	--	LM	R		0.63
	1	--	MH	I		2.67
	1	--	MH	R		6.00
	1	--	MH	U		10.50
	2	--	LM	I		2.67
	2	--	LM	R		1.00
	2	--	MH	I		1.83
	2	--	MH	R		0.33
	2	--	MH	U		6.67

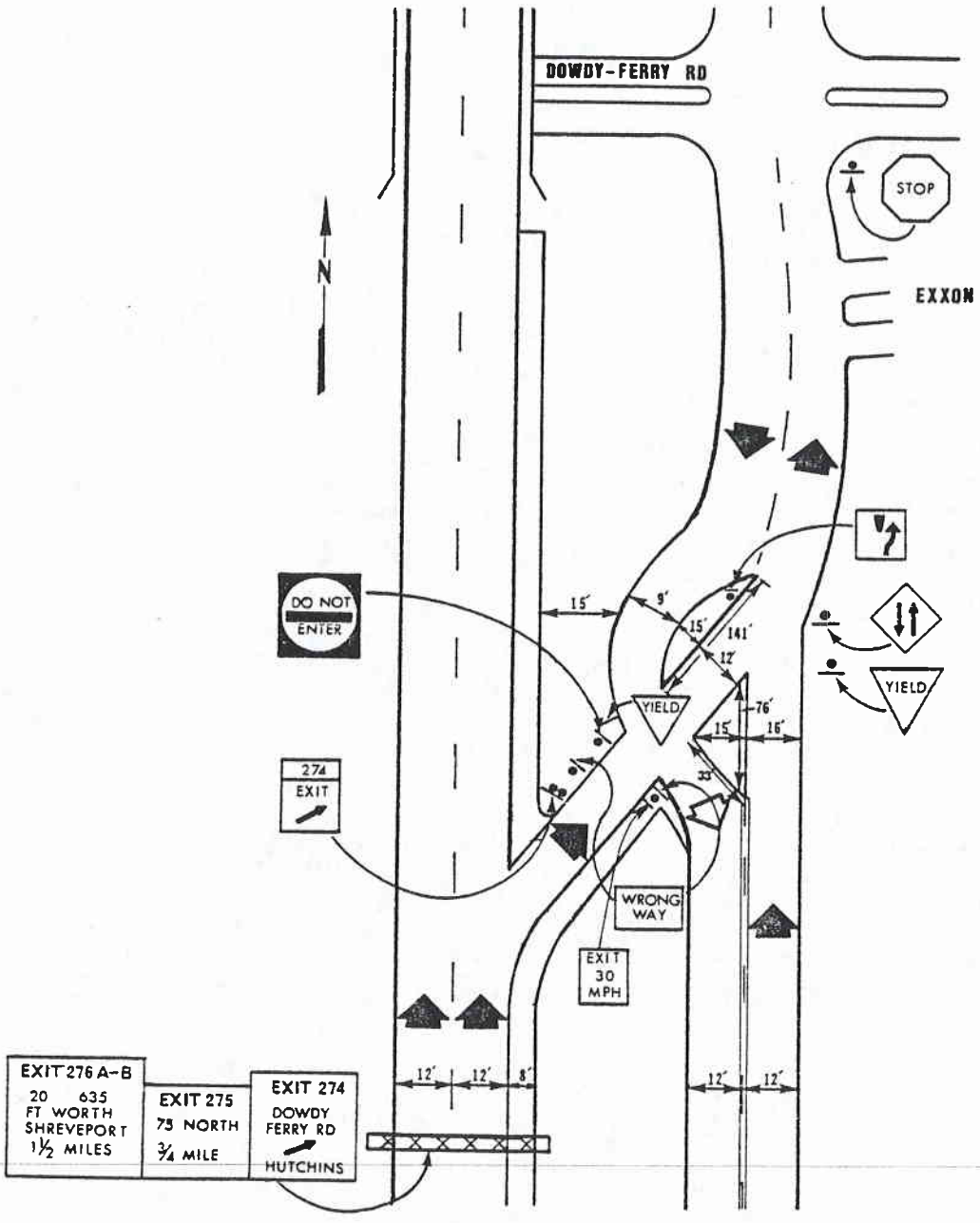
APPENDIX F

STUDY RAMP DIAGRAMS



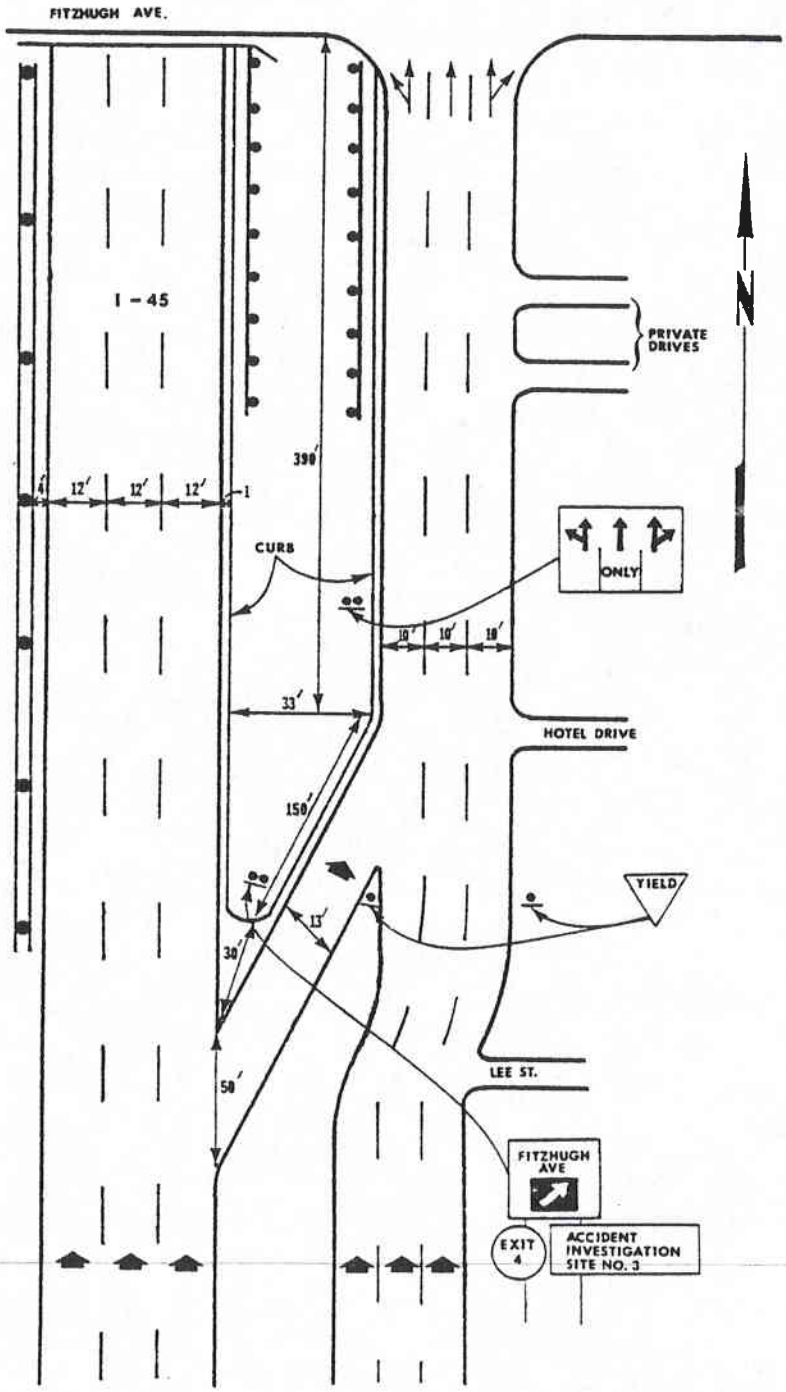
RAMP STUDY NO. 1

FRONTAGE ROAD SITE NO. 33



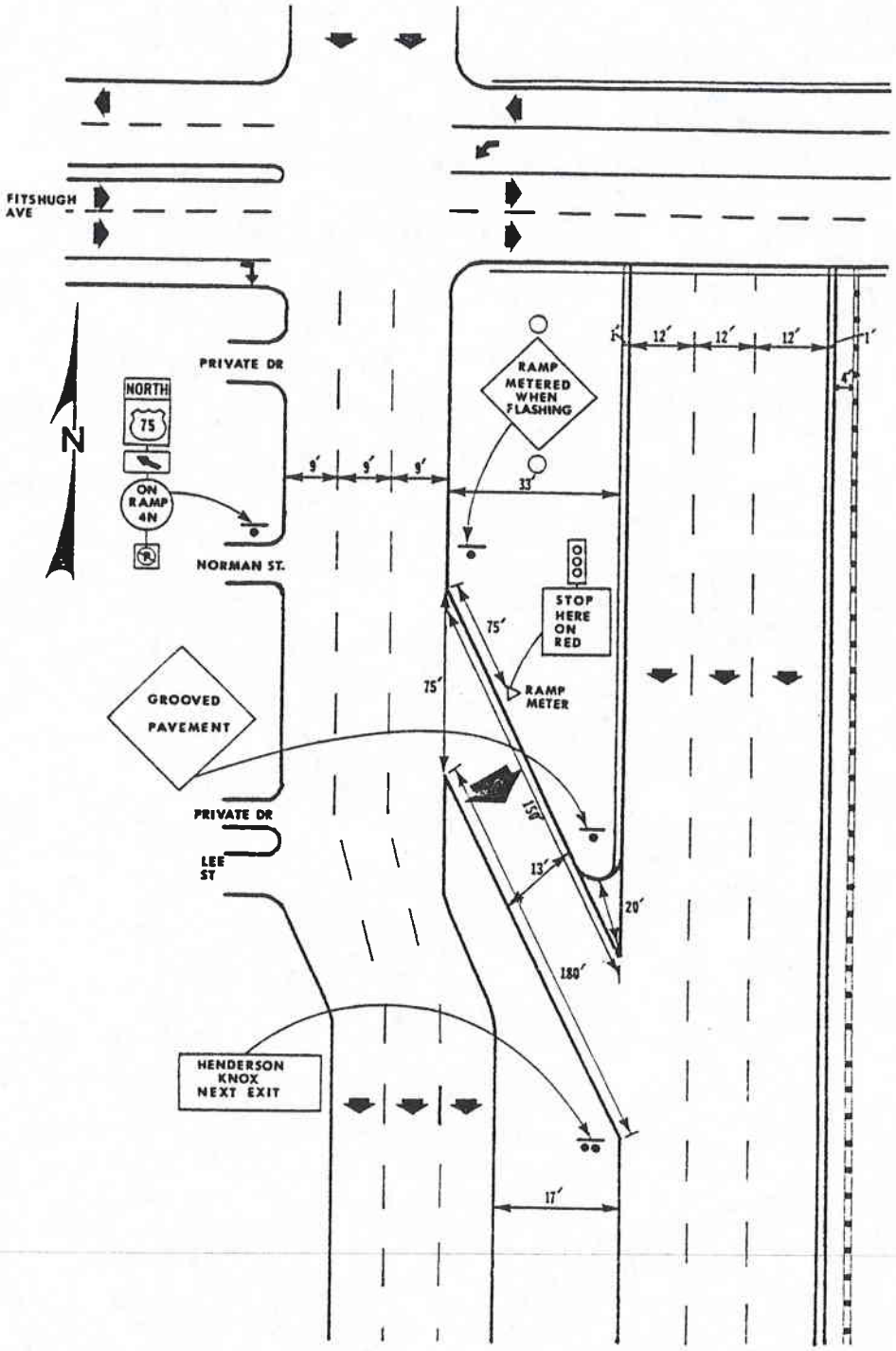
RAMP STUDY NO. 2

FRONTAGE ROAD SITE NO. 33



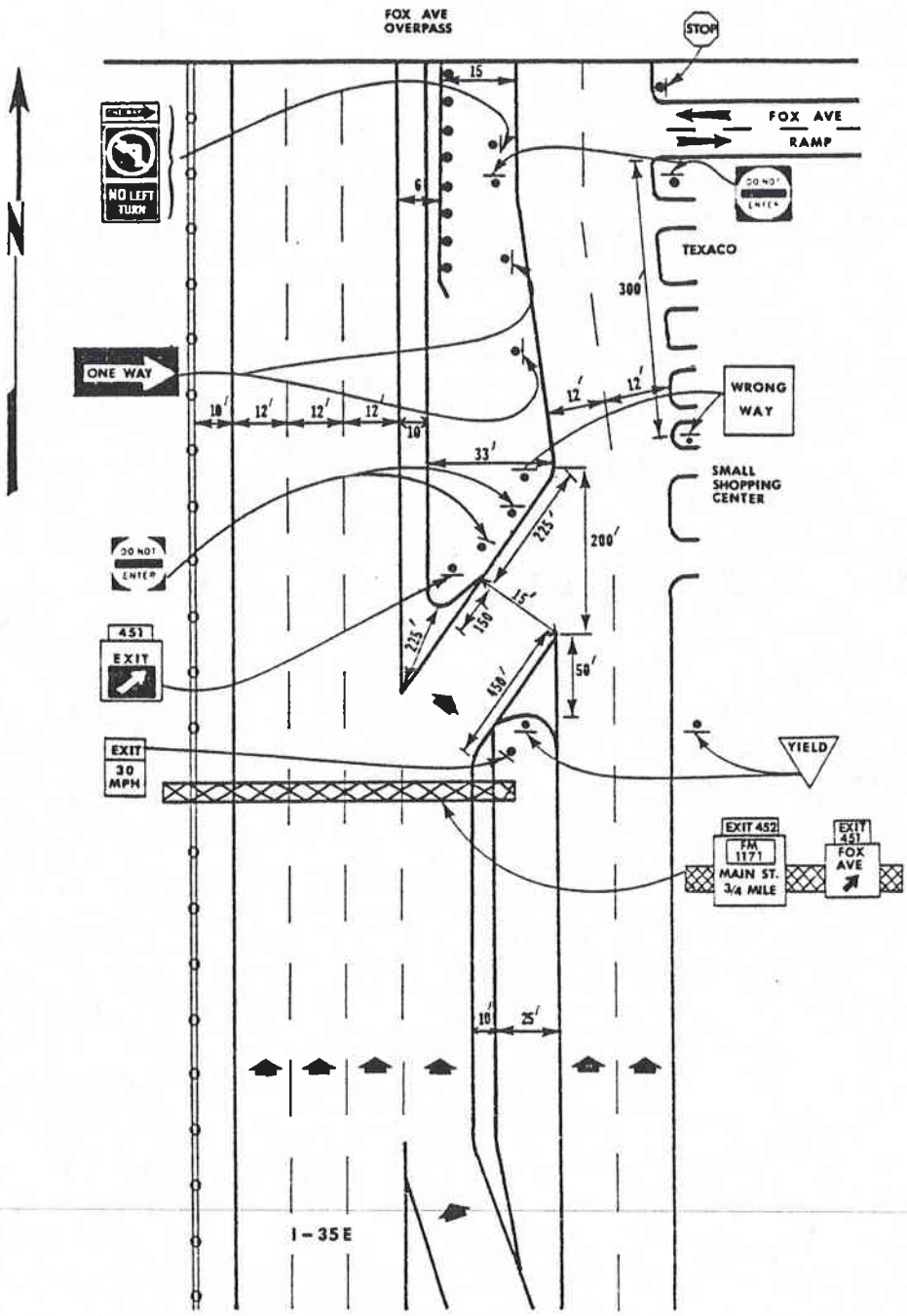
RAMP STUDY NO. 3

FRONTAGE ROAD SITE NO. 31



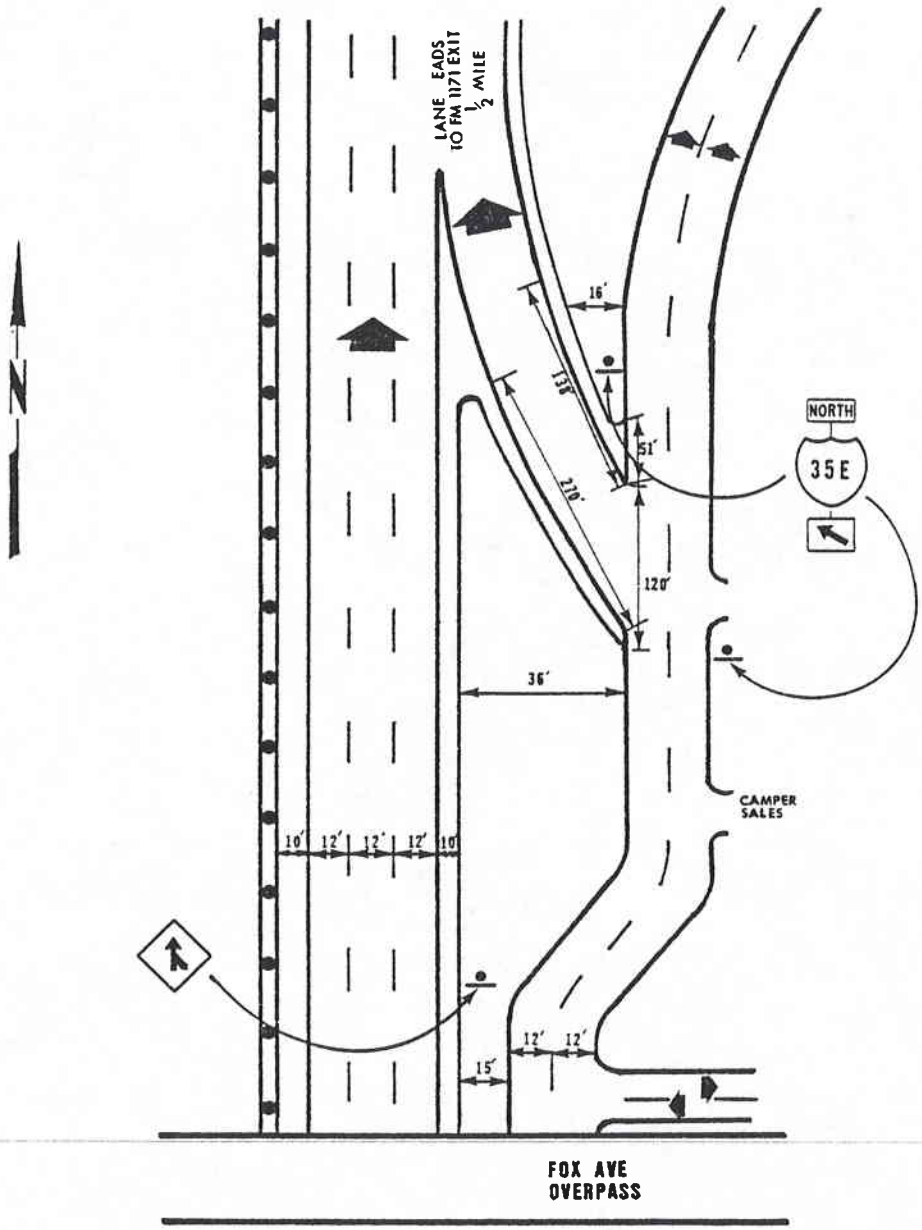
RAMP STUDY NO. 4

FRONTAGE ROAD SITE NO. 31



RAMP STUDY NO. 5

FRONTAGE ROAD SITE NO. 25



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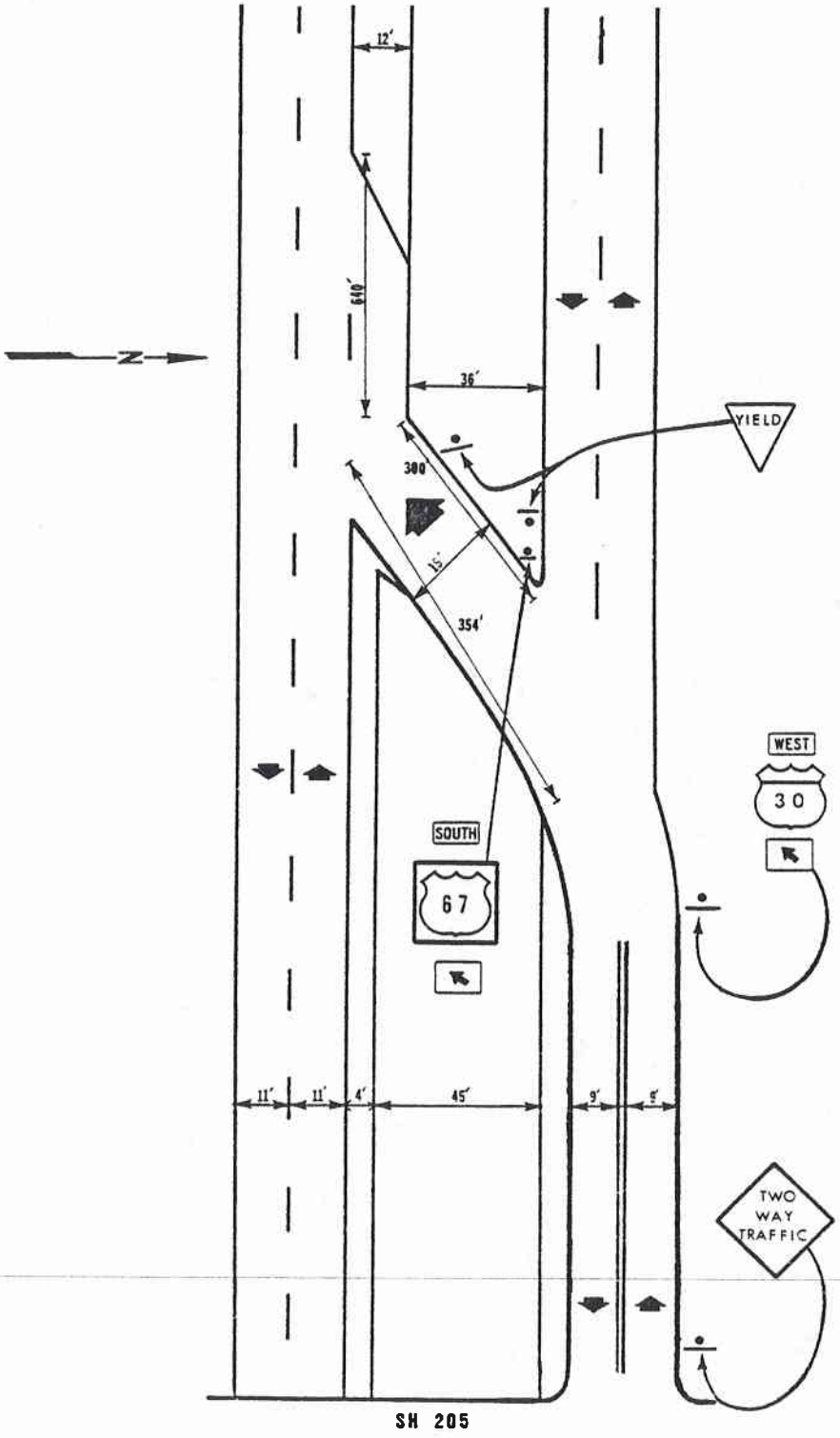
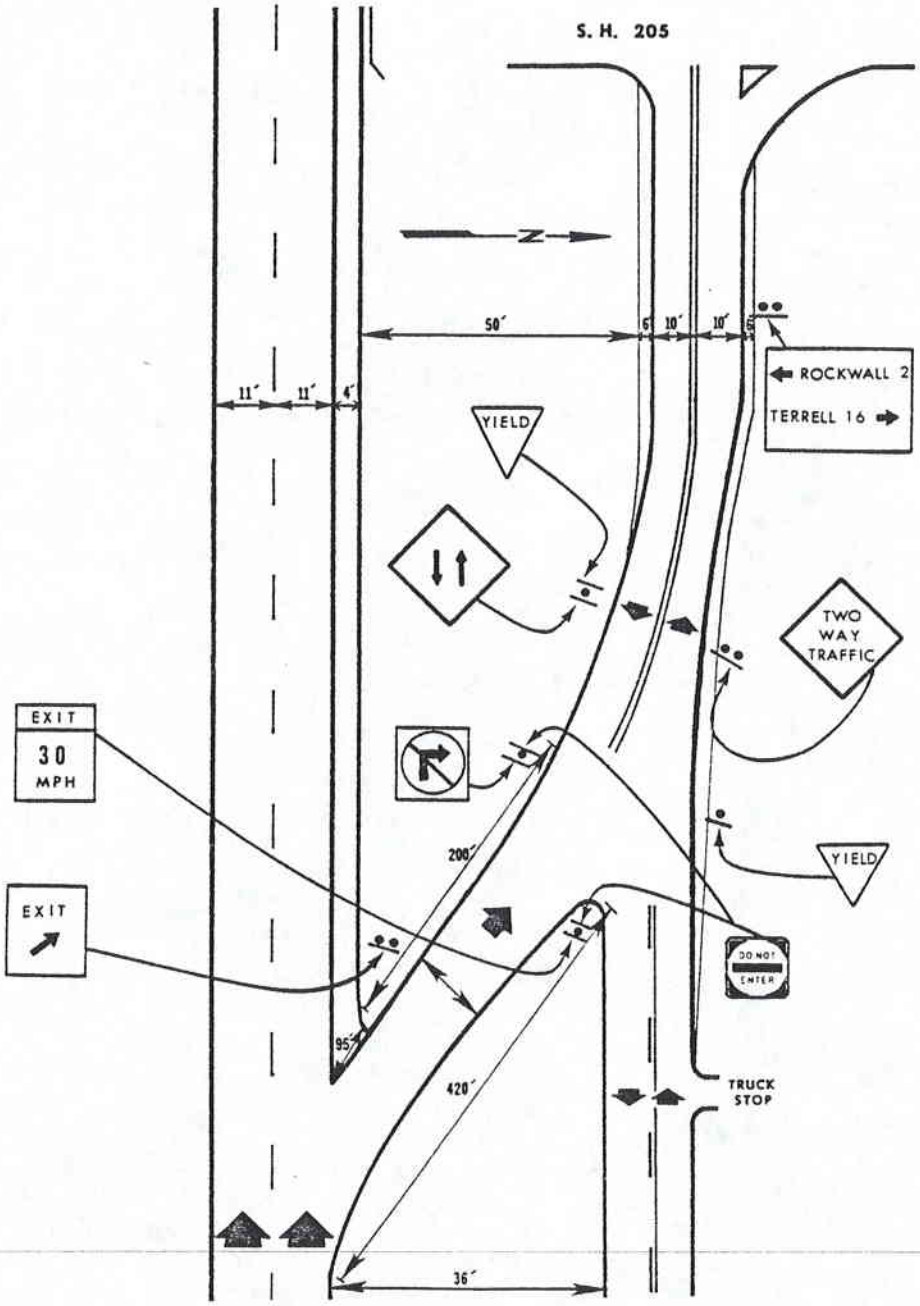
FRONTAGE ROAD SITE NO. 25



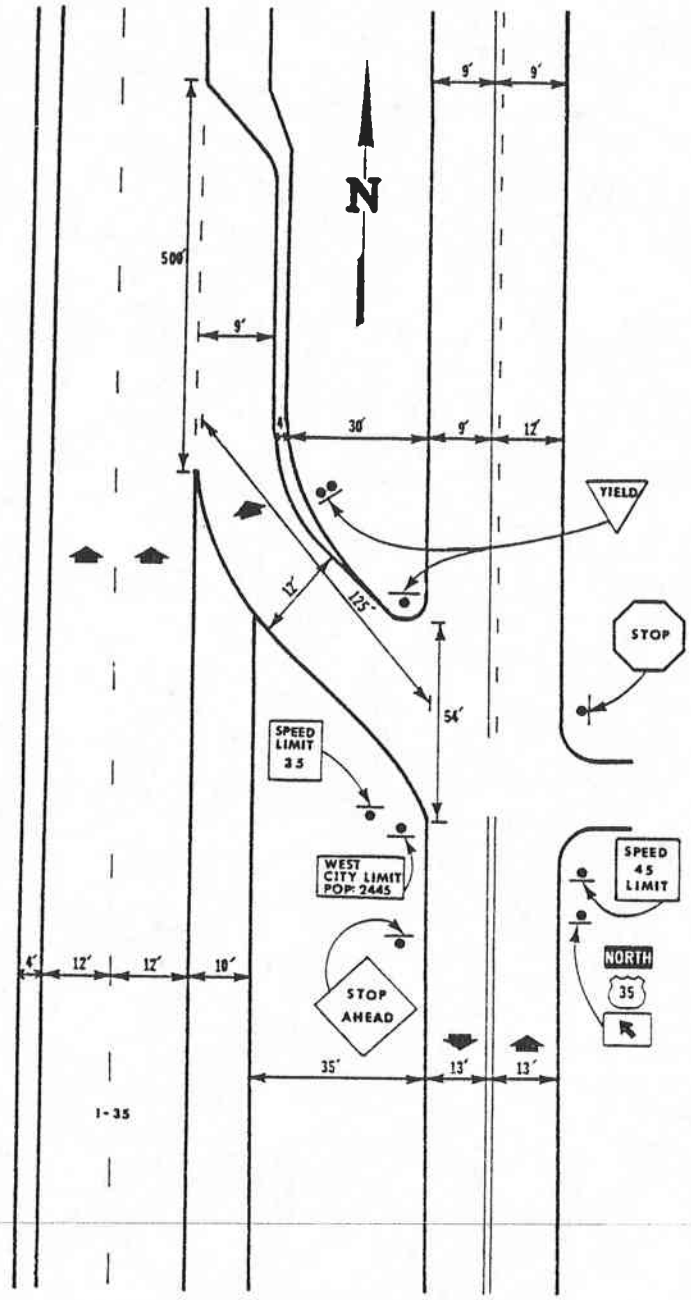
RAMP STUDY NO. 7

FRONTAGE ROAD SITE NO. 29



RAMP STUDY NO. 8

FRONTAGE ROAD SITE NO. 29



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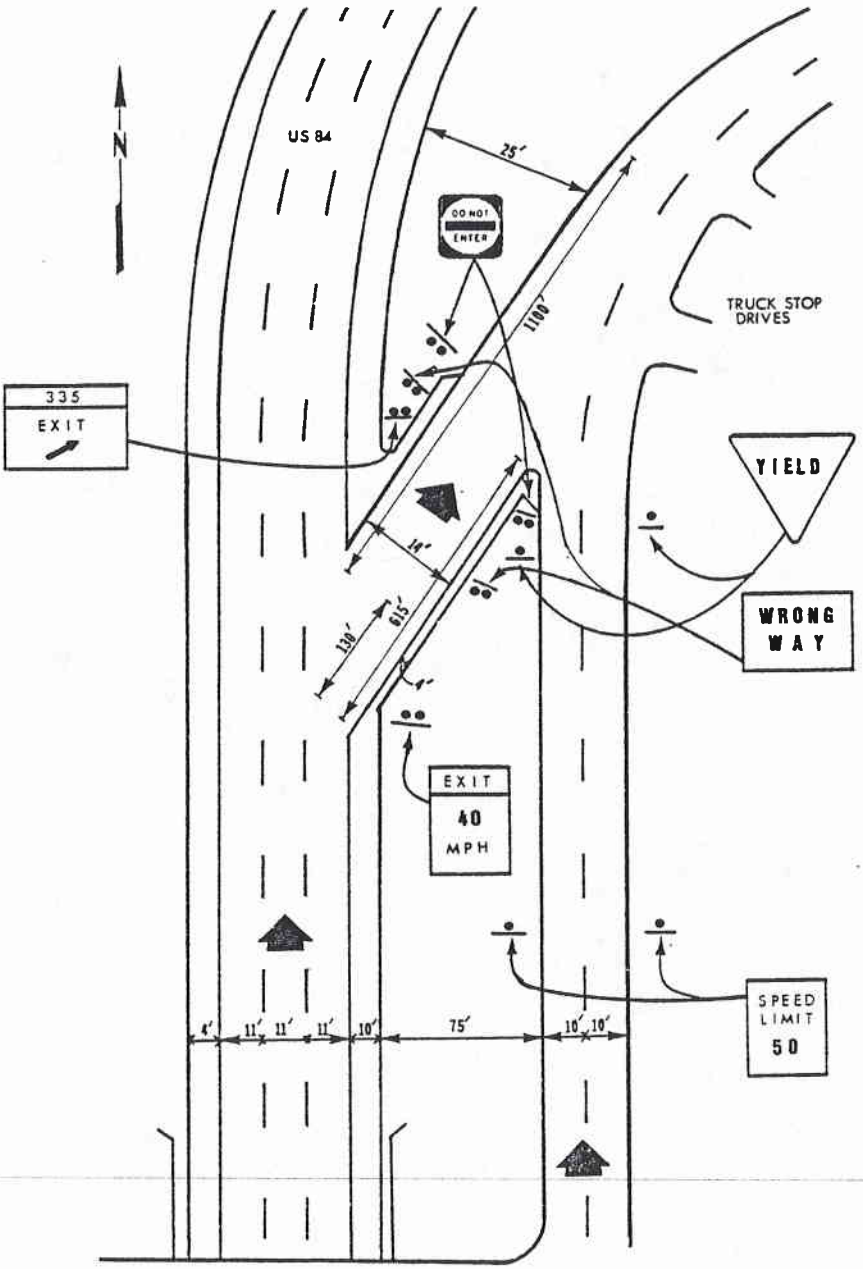
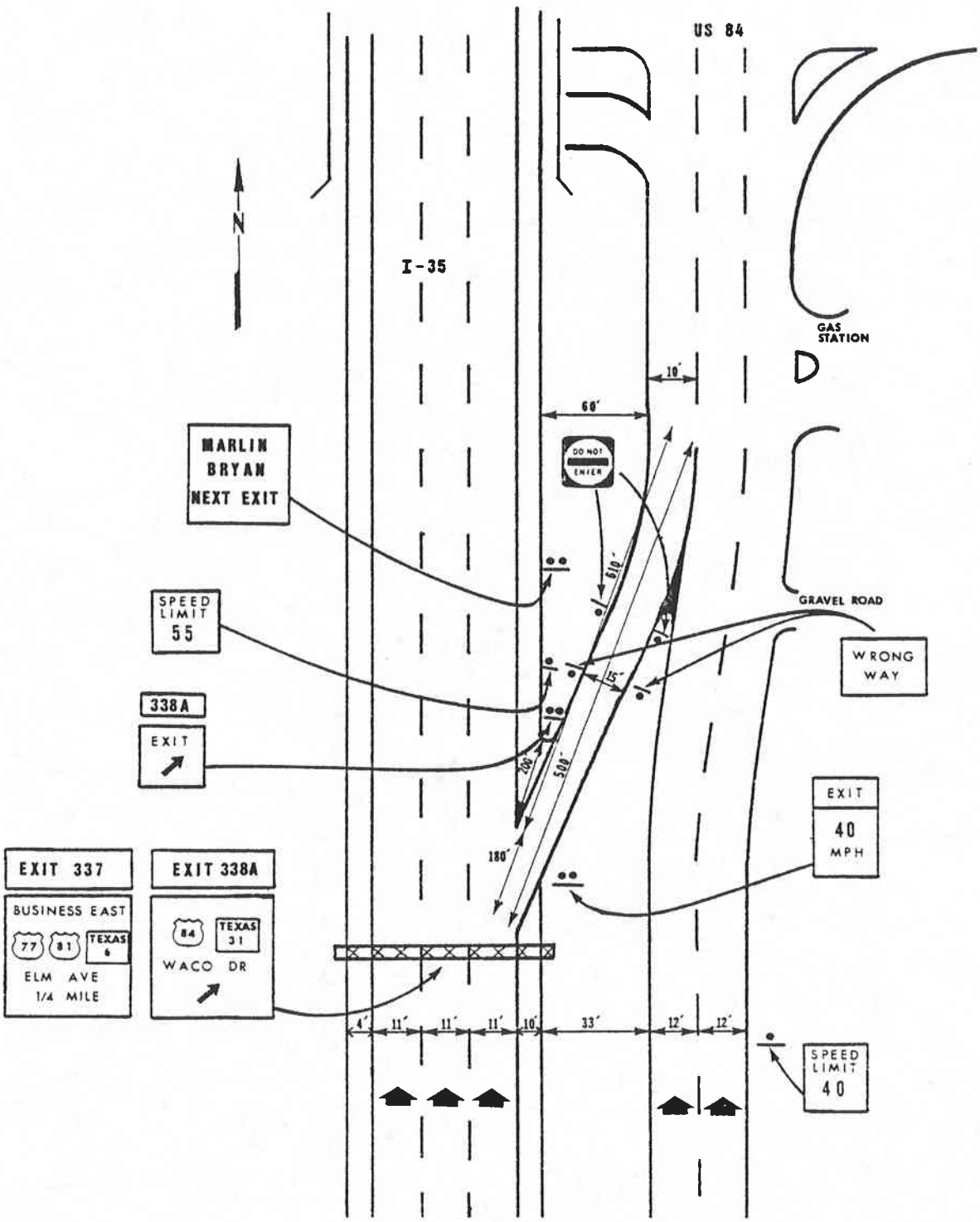
FRONTAGE ROAD SITE NO. 15



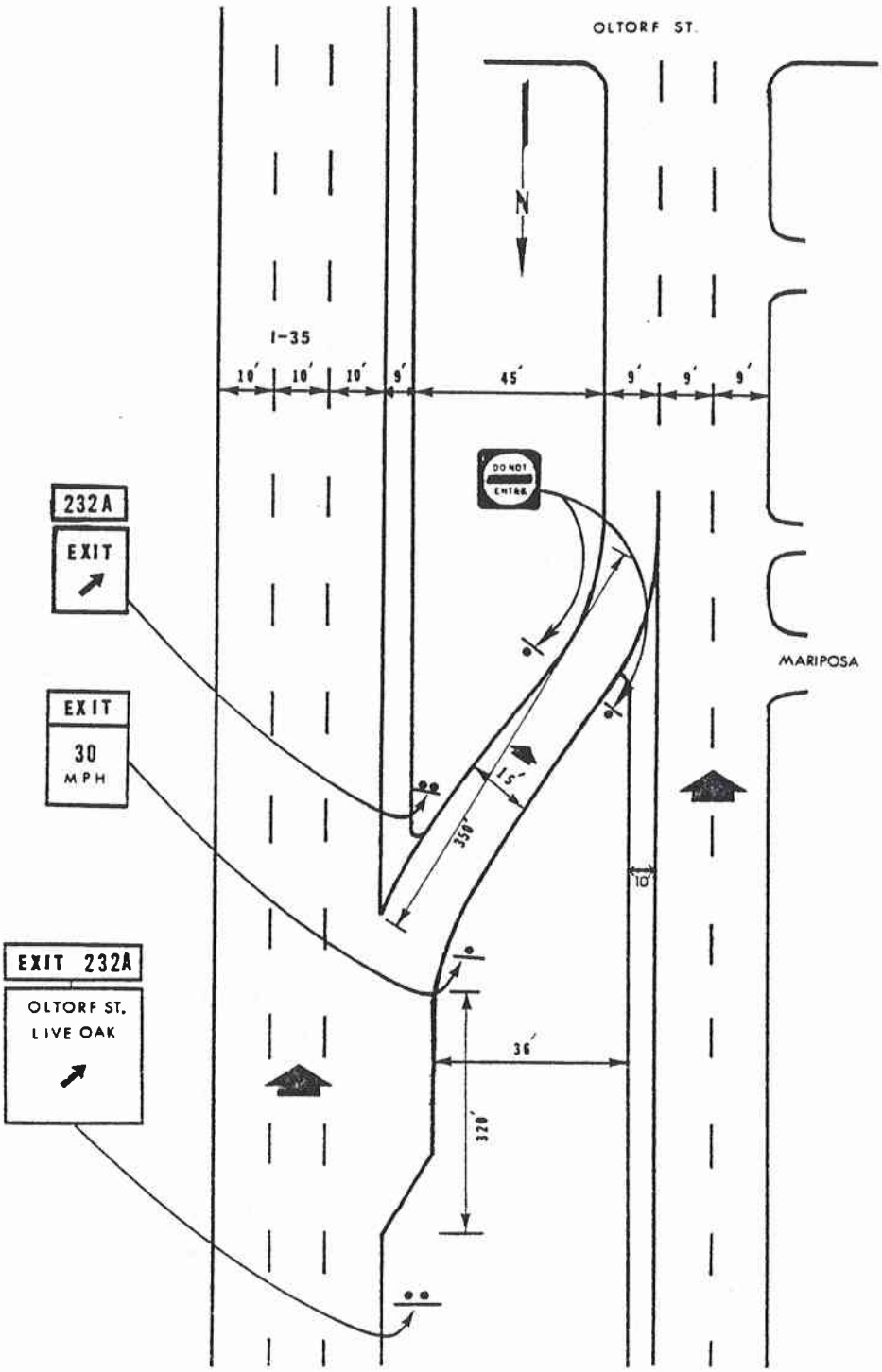
RAMP STUDY NO. 10

FRONTAGE ROAD SITE NO. 14



RAMP STUDY NO.11

FRONTAGE ROAD SITE NO.14



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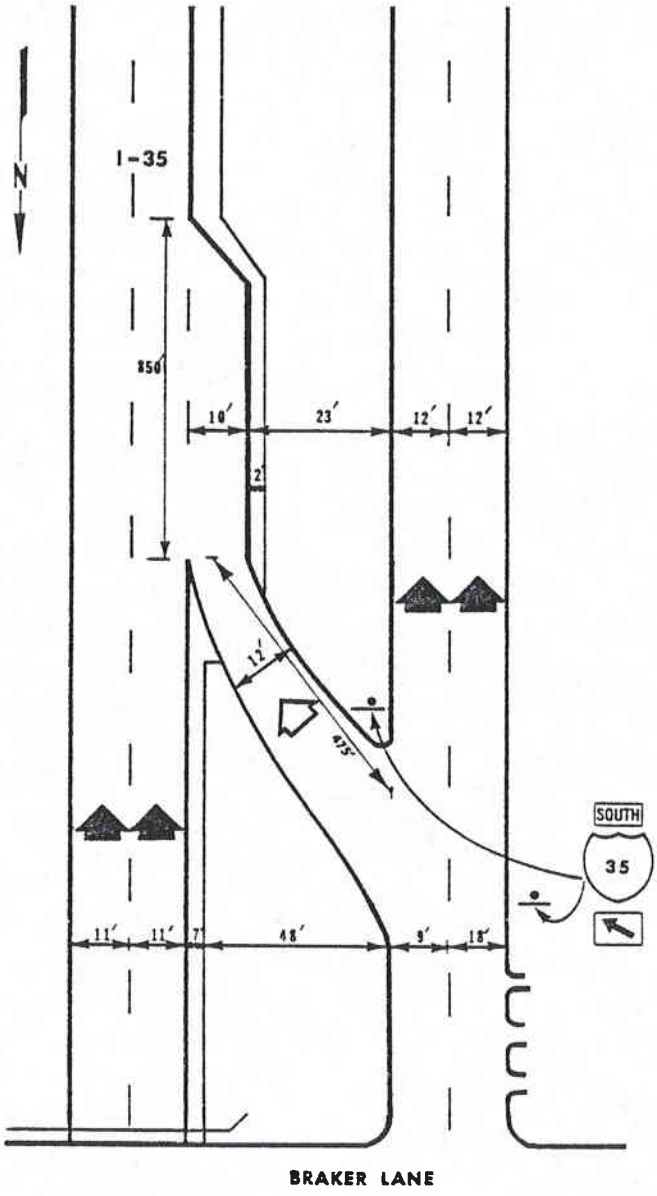
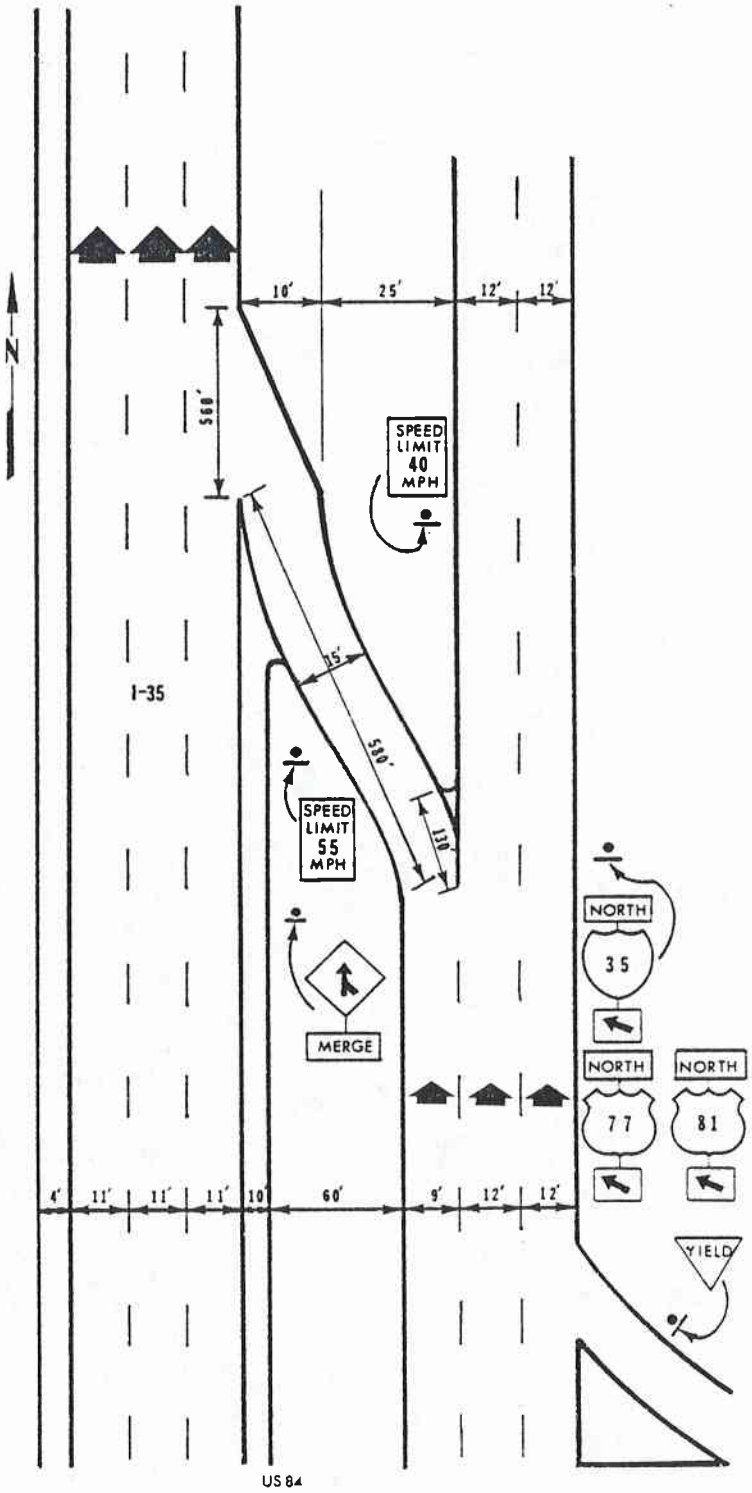
FRONTAGE ROAD SITE NO. 8



RAMP STUDY NO. 13

FRONTAGE ROAD SITE NO. 9



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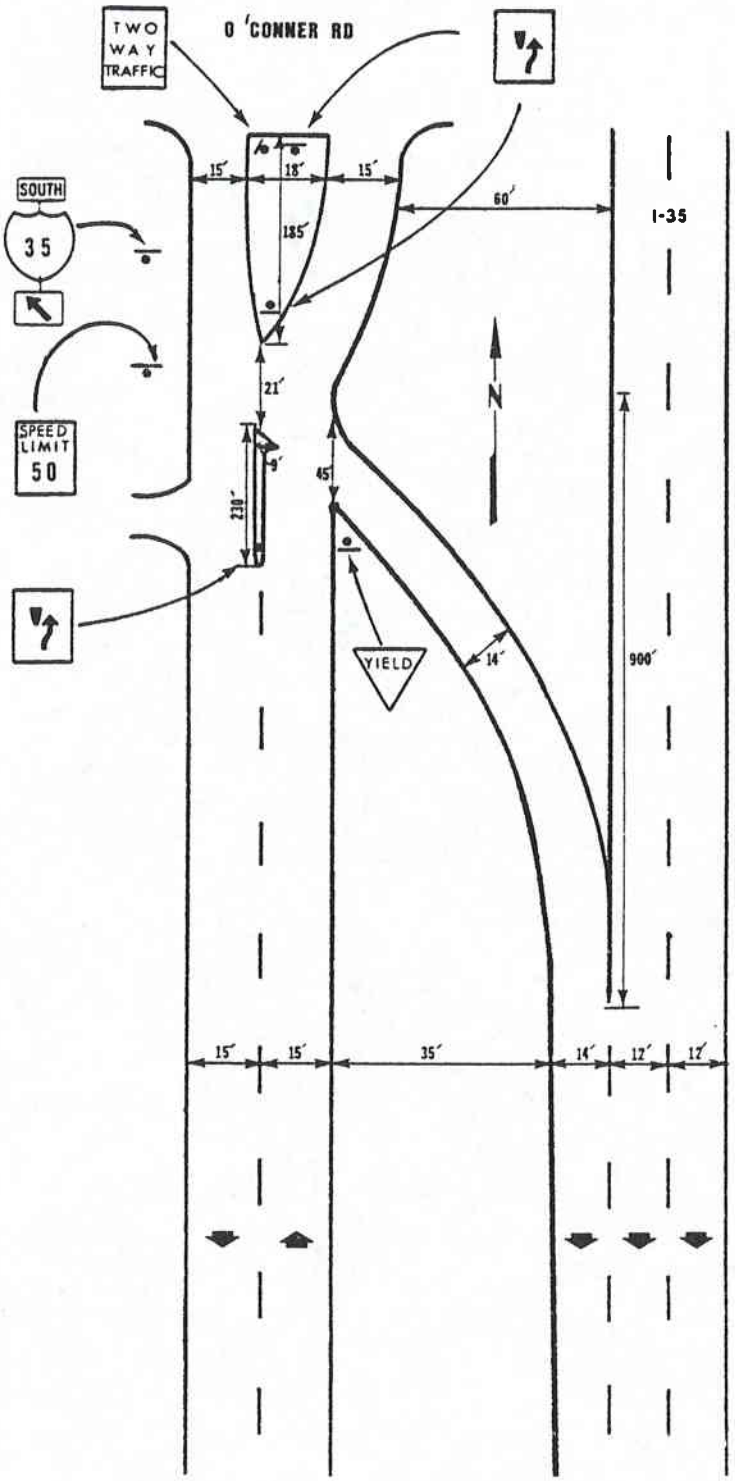
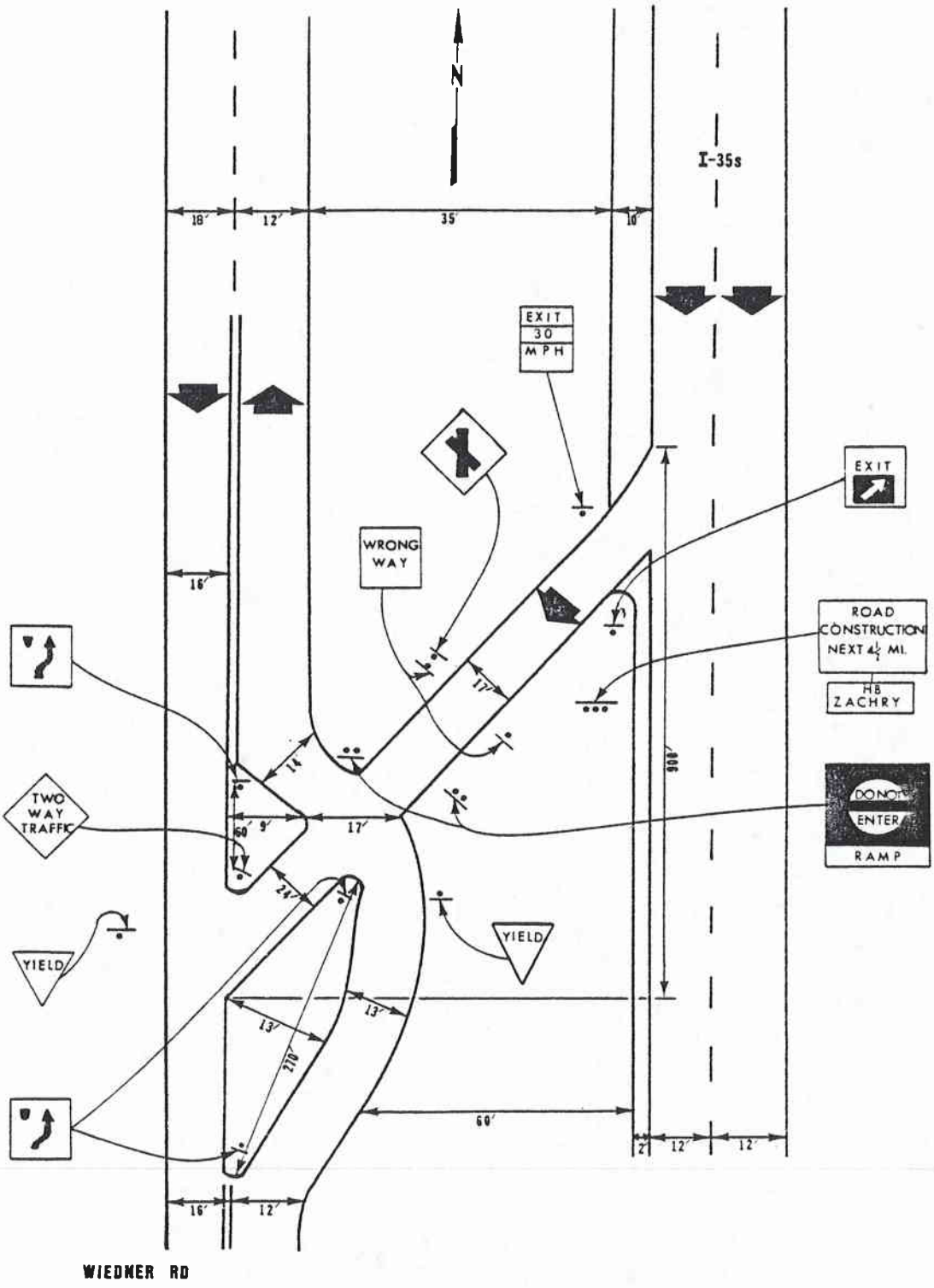


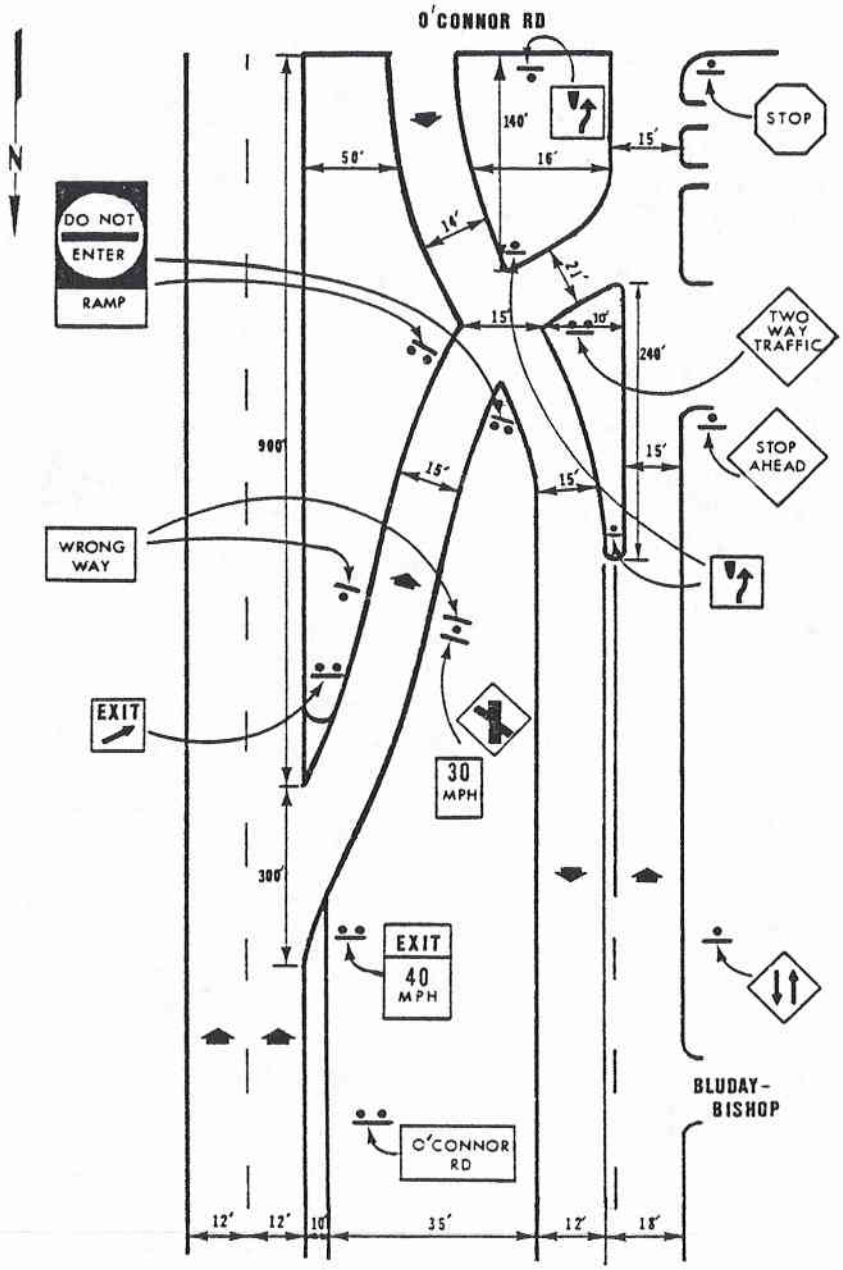
RAMP STUDY NO. 19&15

FRONTAGE ROAD SITE NO. 37



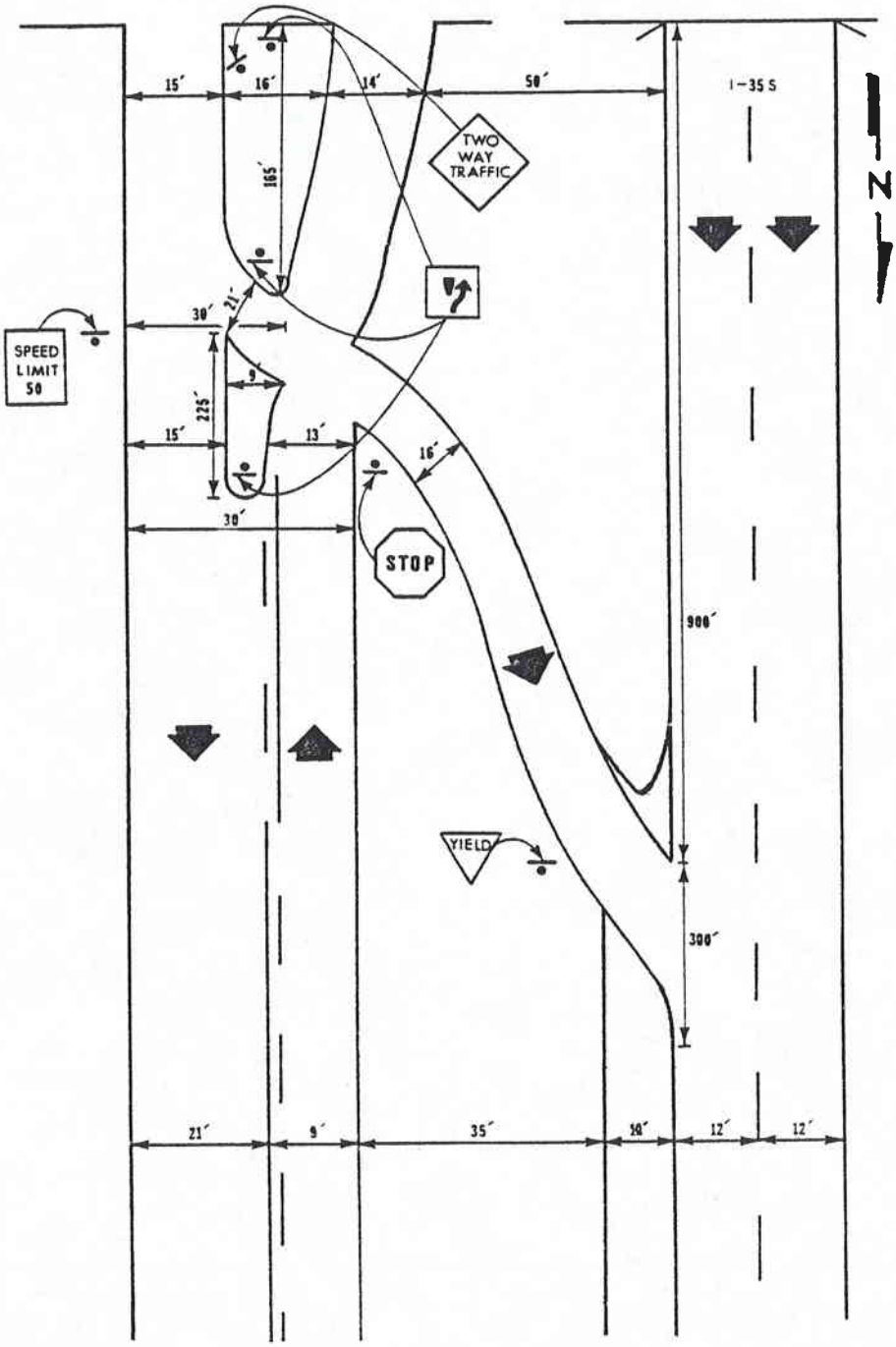
RAMP STUDY NO. 16&20

FRONTAGE ROAD SITE NO. 37



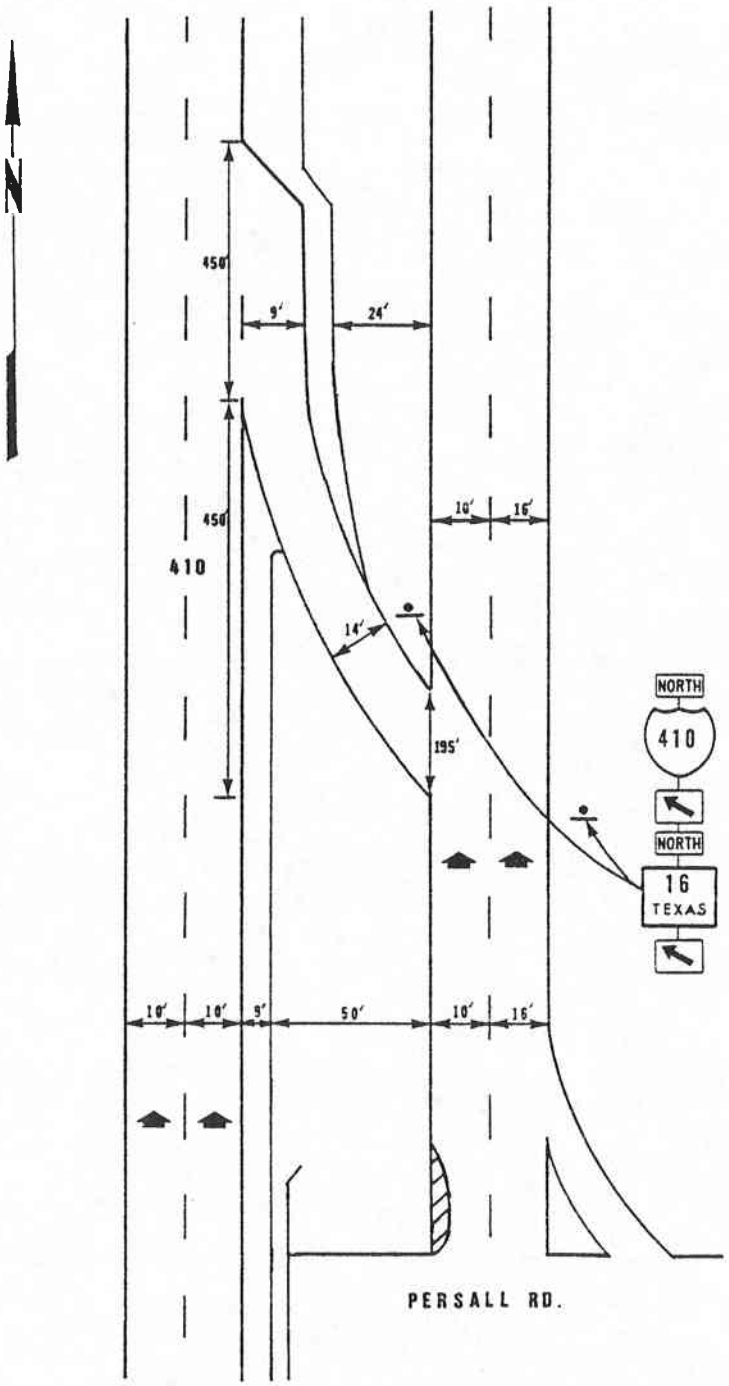
RAMP STUDY NO. 17

FRONTAGE ROAD SITE NO. 38



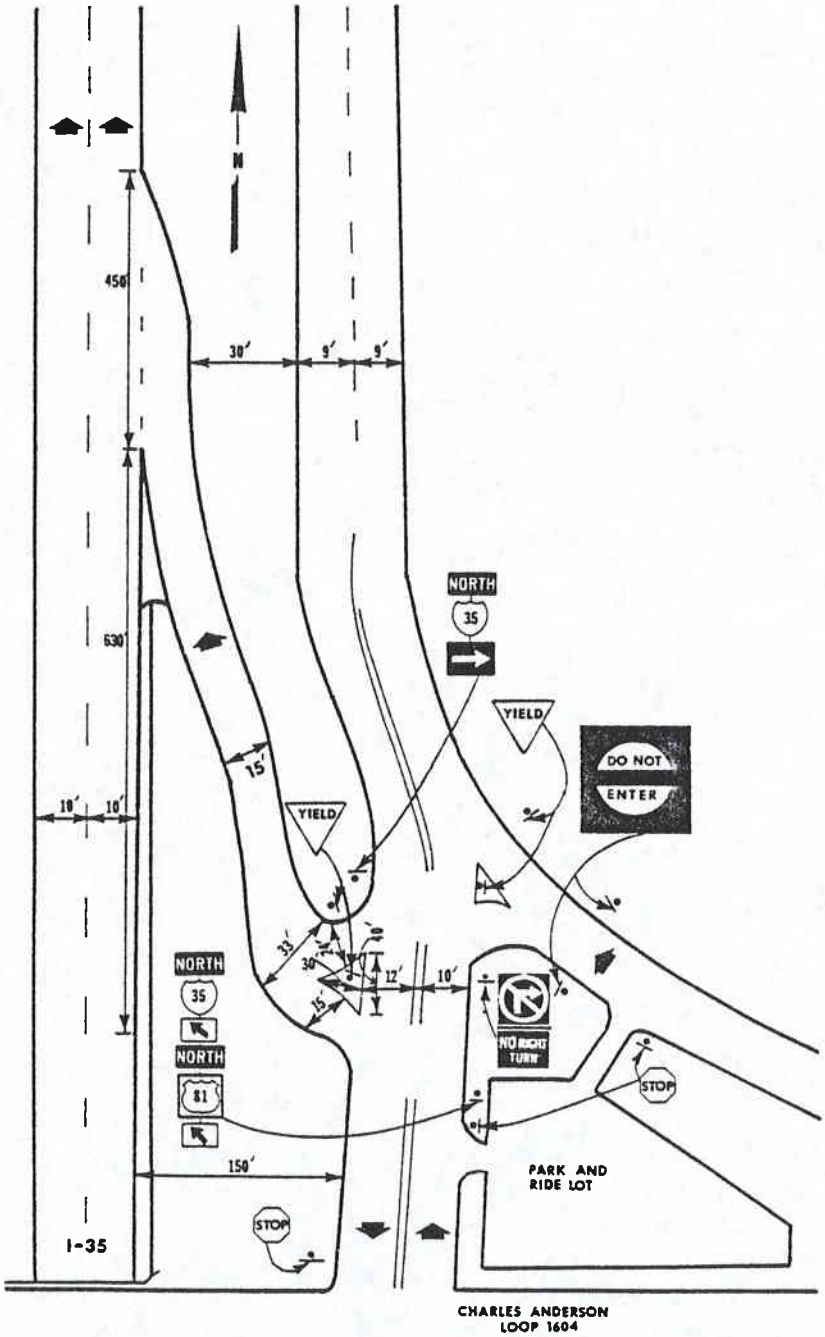
RAMP STUDY NO. 18

FRONTAGE ROAD SITE NO. 38



RAMP STUDY NO. 21

FRONTAGE ROAD SITE NO. 34



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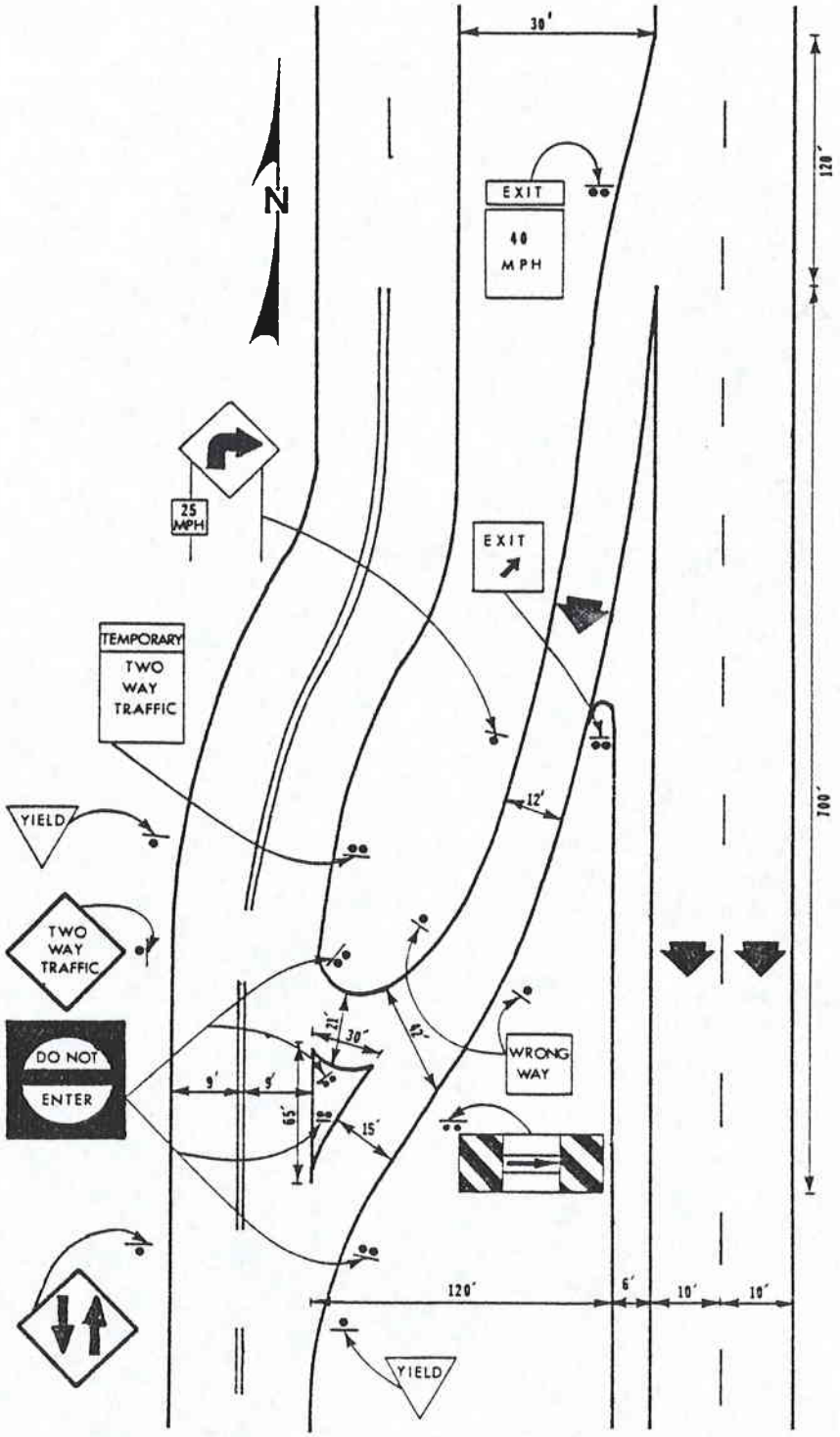
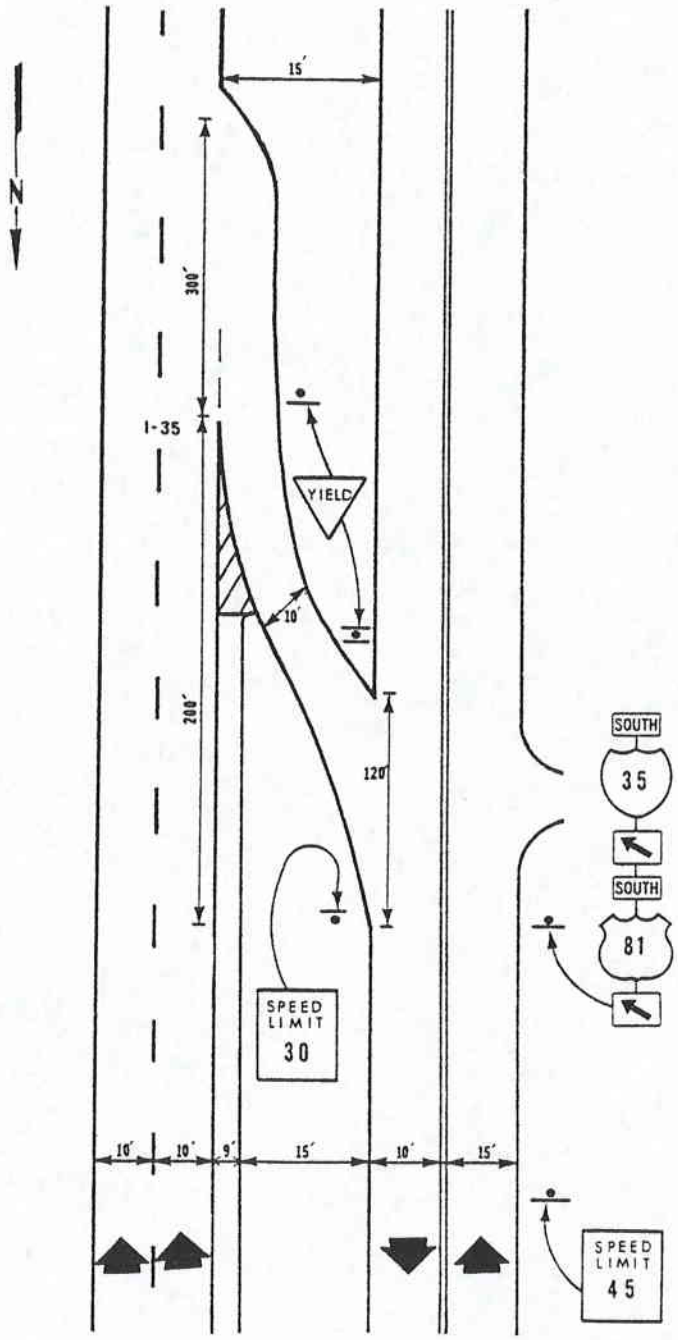
FRONTAGE ROAD SITE NO. 39



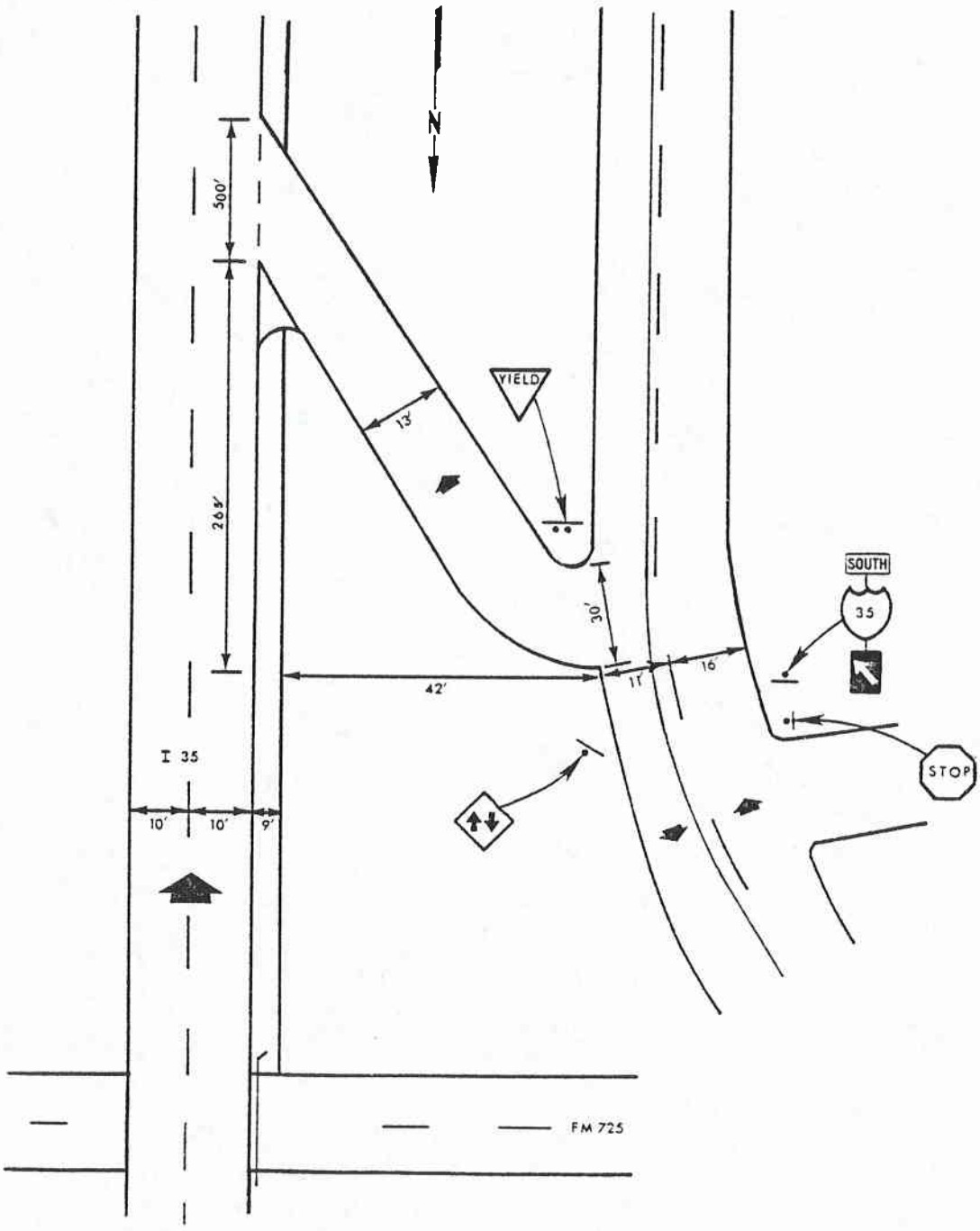
RAMP STUDY NO. 23

FRONTAGE ROAD SITE NO. 39



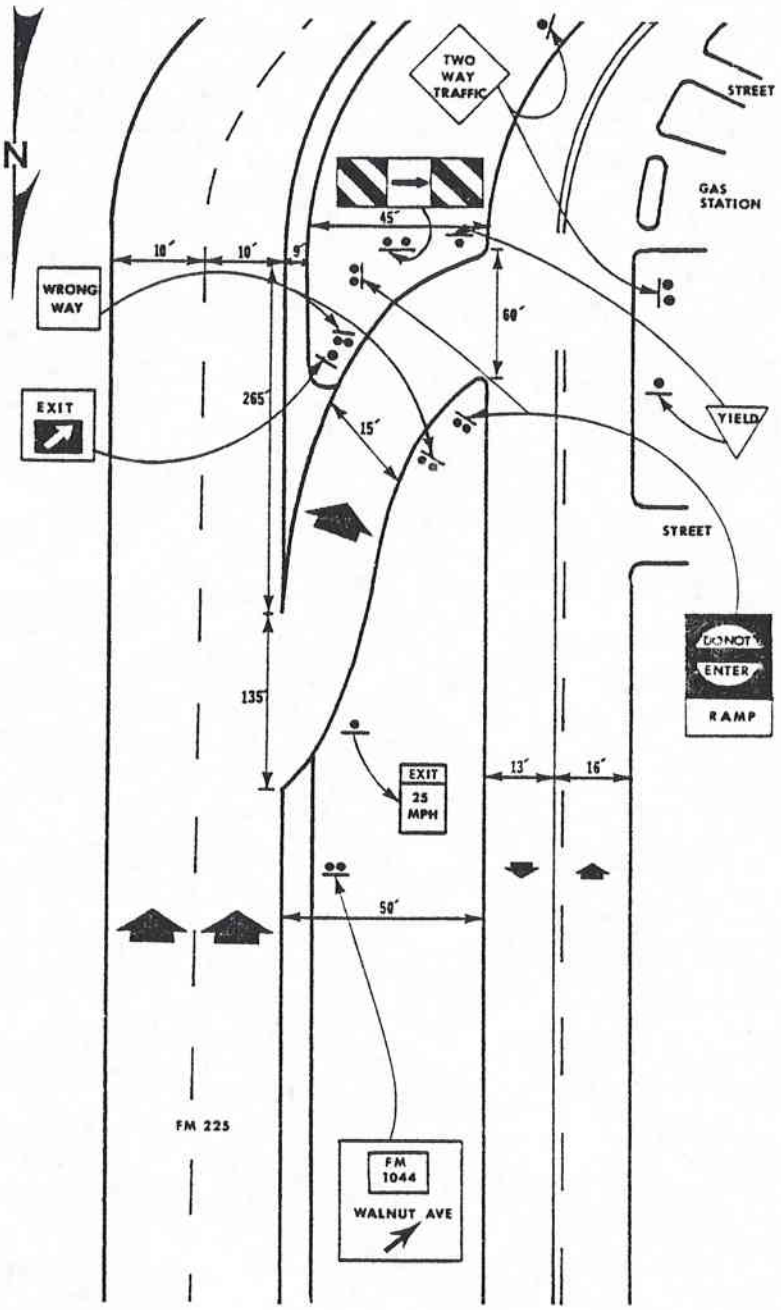
RAMP STUDY NO. 24

FRONTAGE ROAD SITE NO. 40



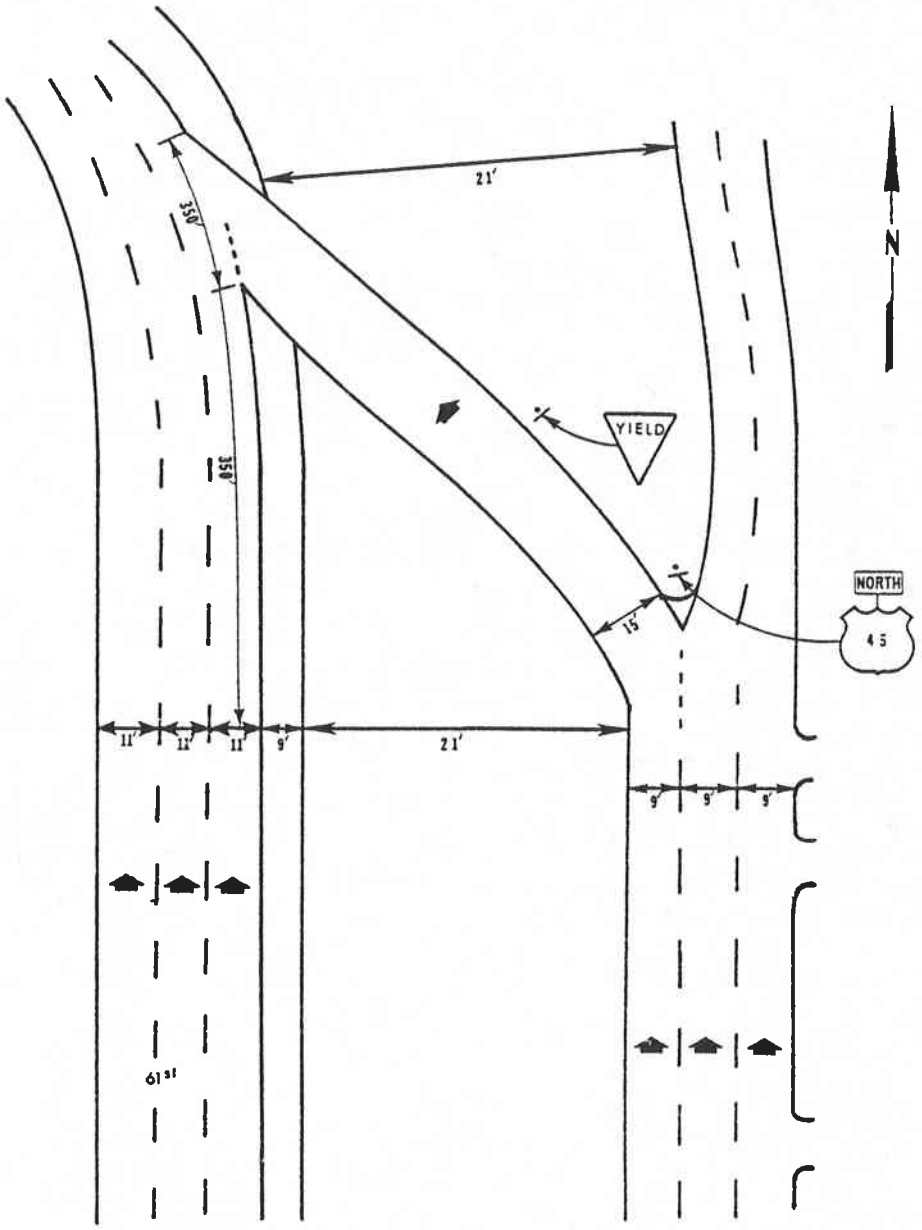
RAMP STUDY NO. 25

FRONTAGE ROAD SITE NO. 42



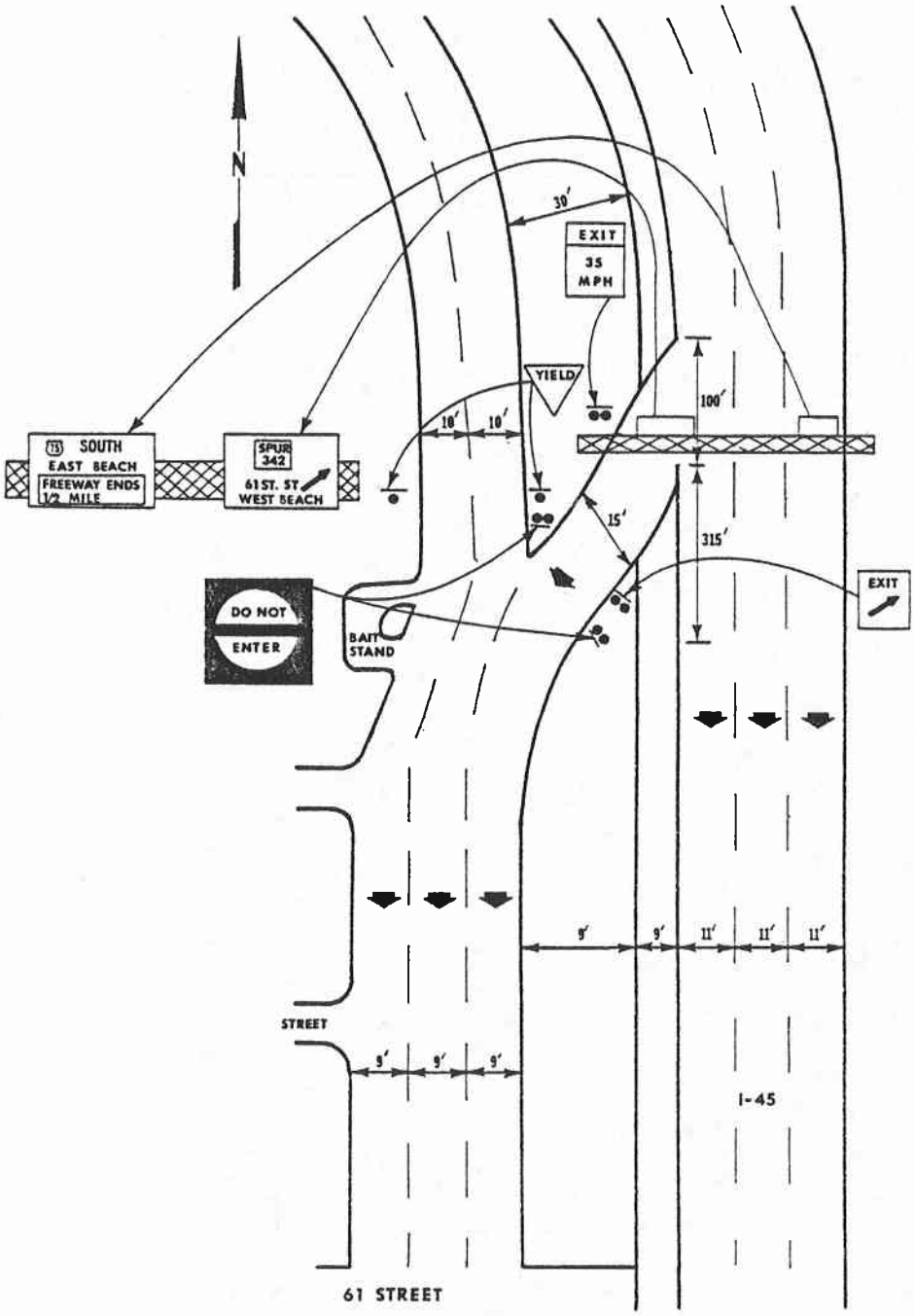
RAMP STUDY NO. 28&26

FRONTAGE ROAD SITE NO. 42



RAMP STUDY NO. 31&29

FRONTAGE ROAD SITE NO. 20



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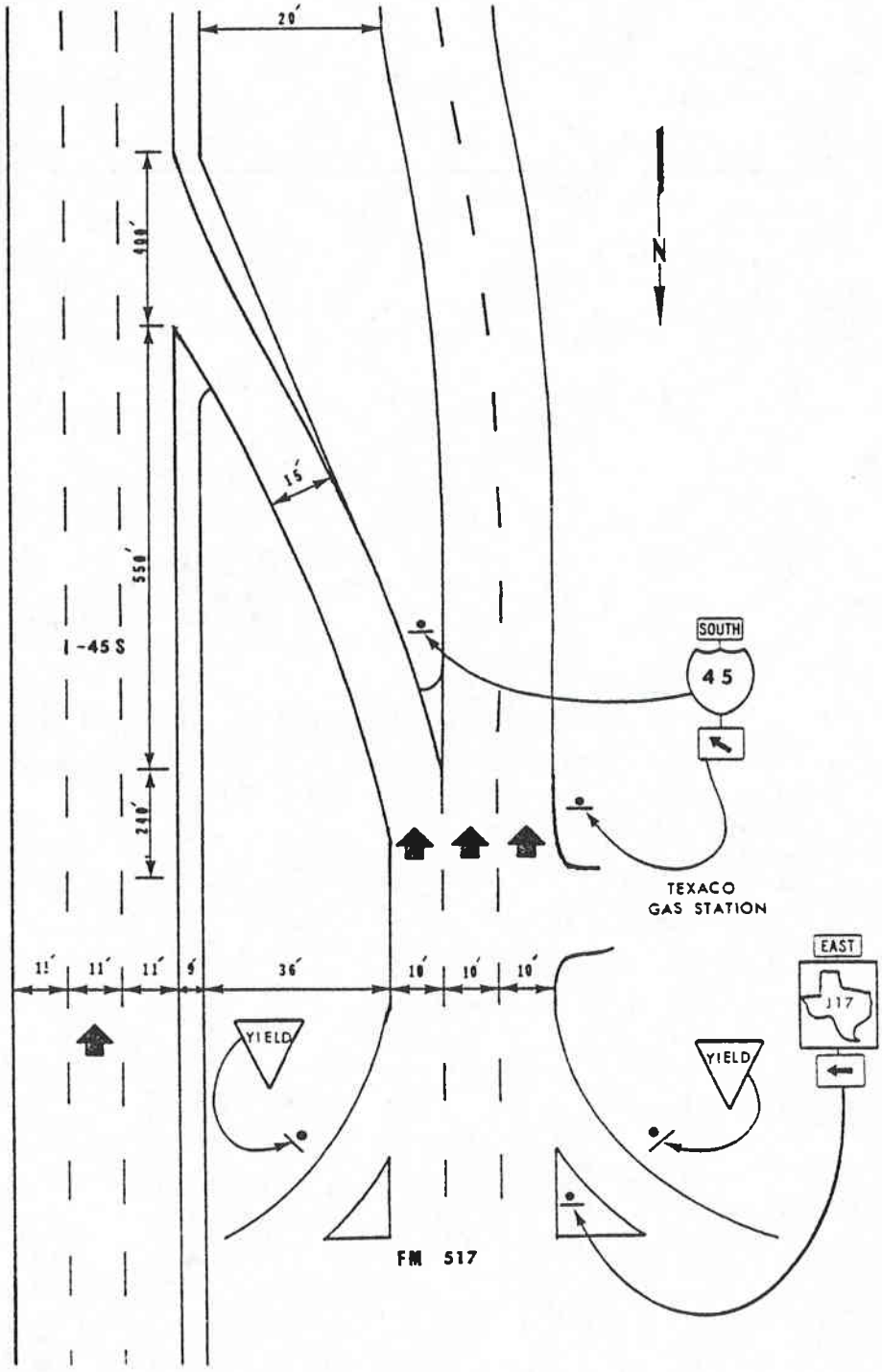

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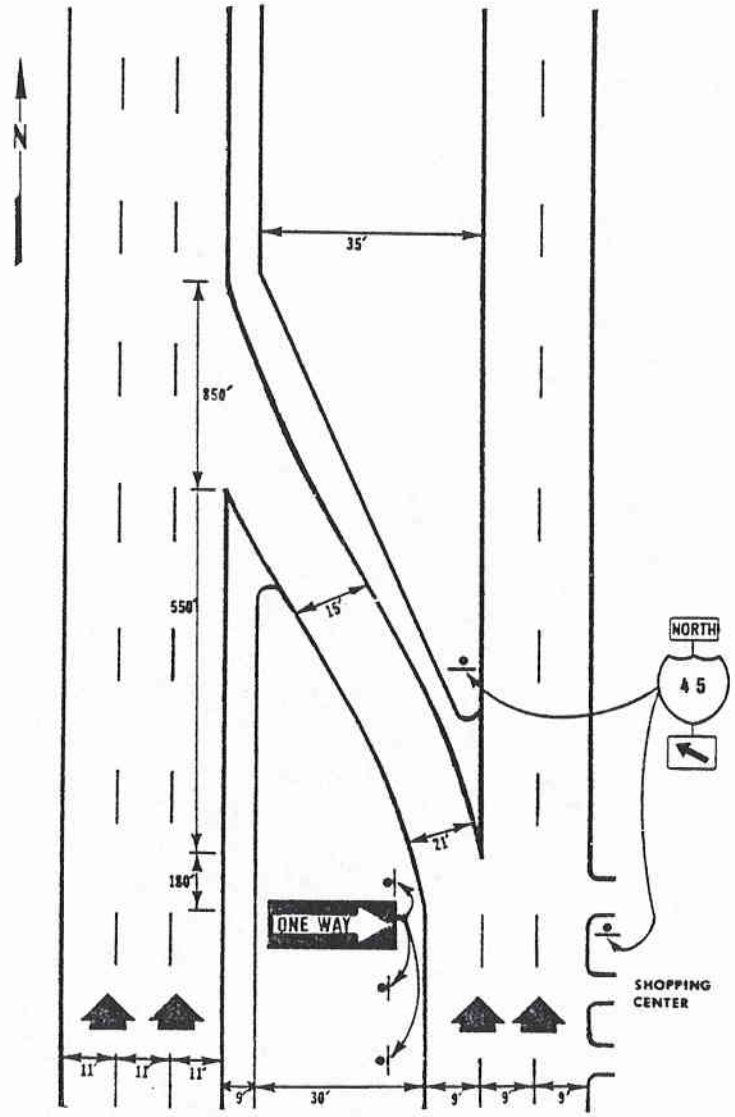

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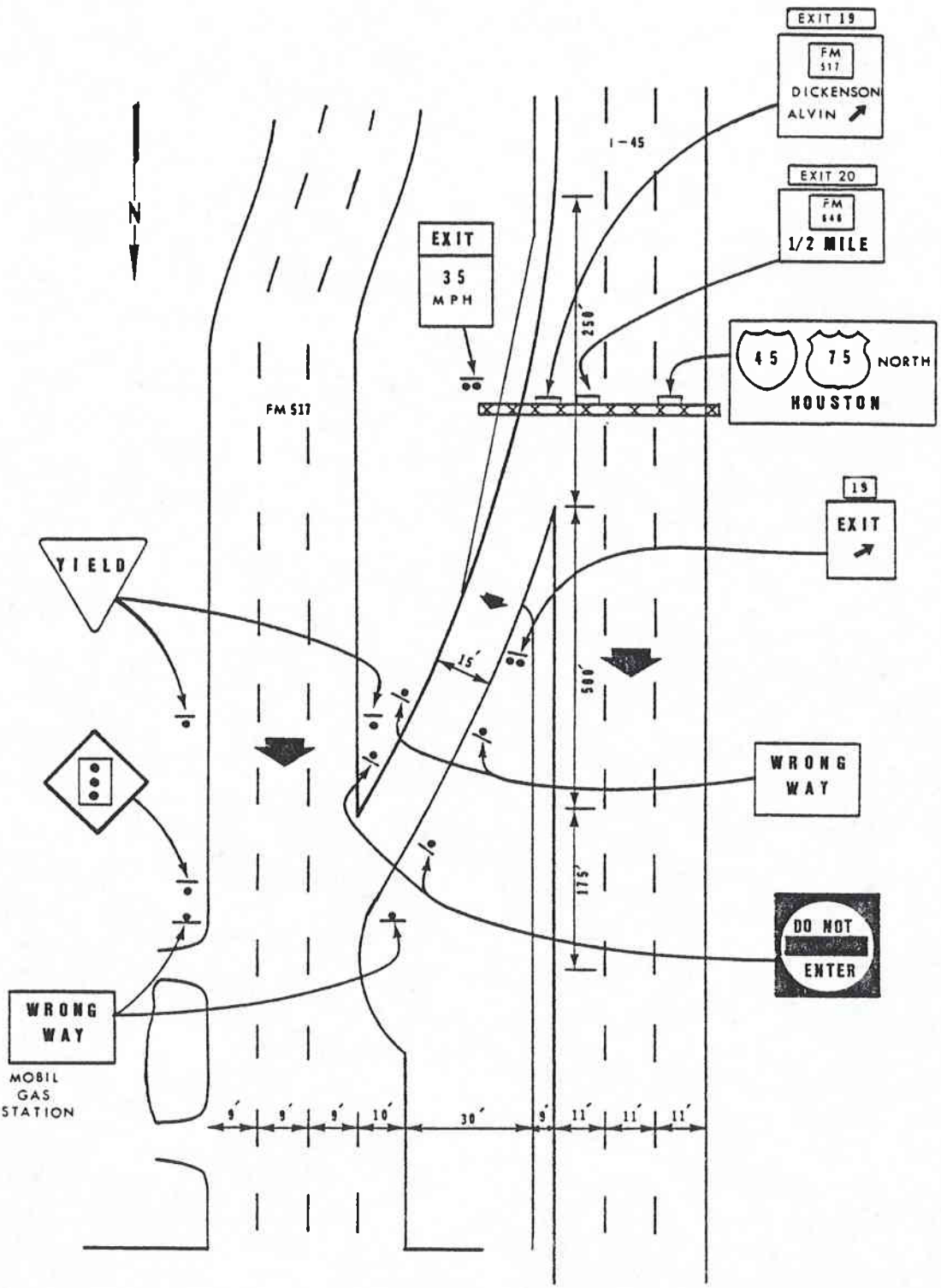
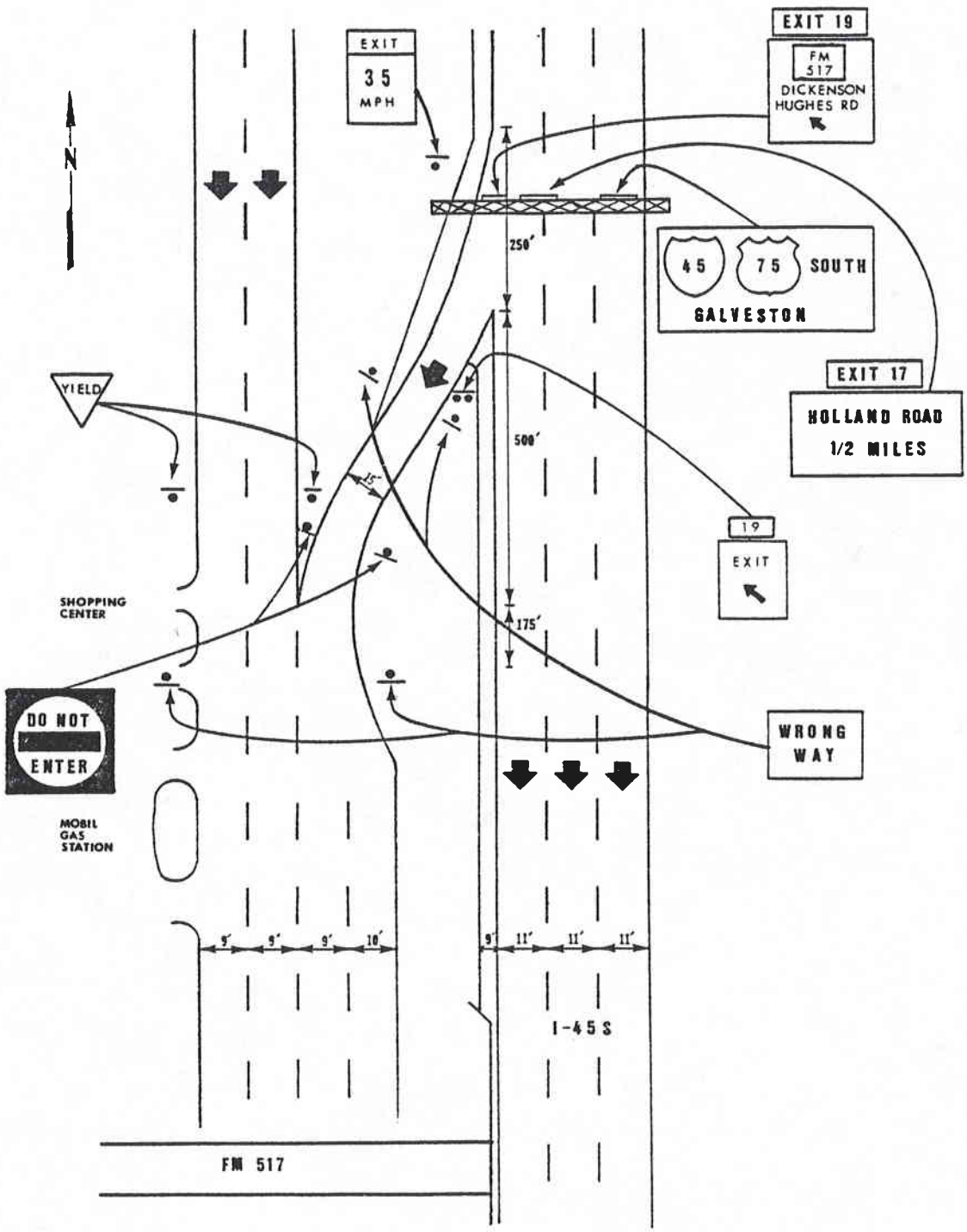


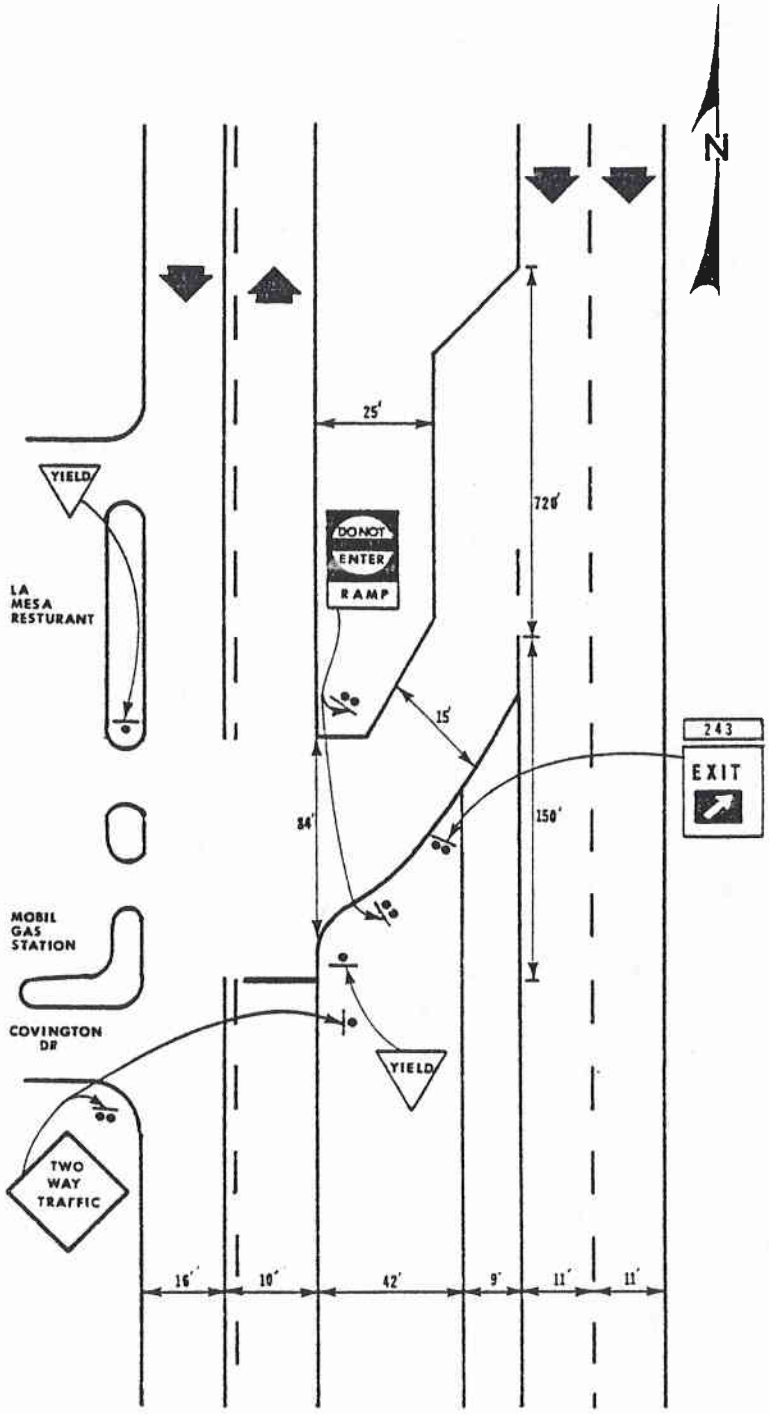
RAMP STUDY NO. 34

FRONTAGE ROAD SITE NO. 21



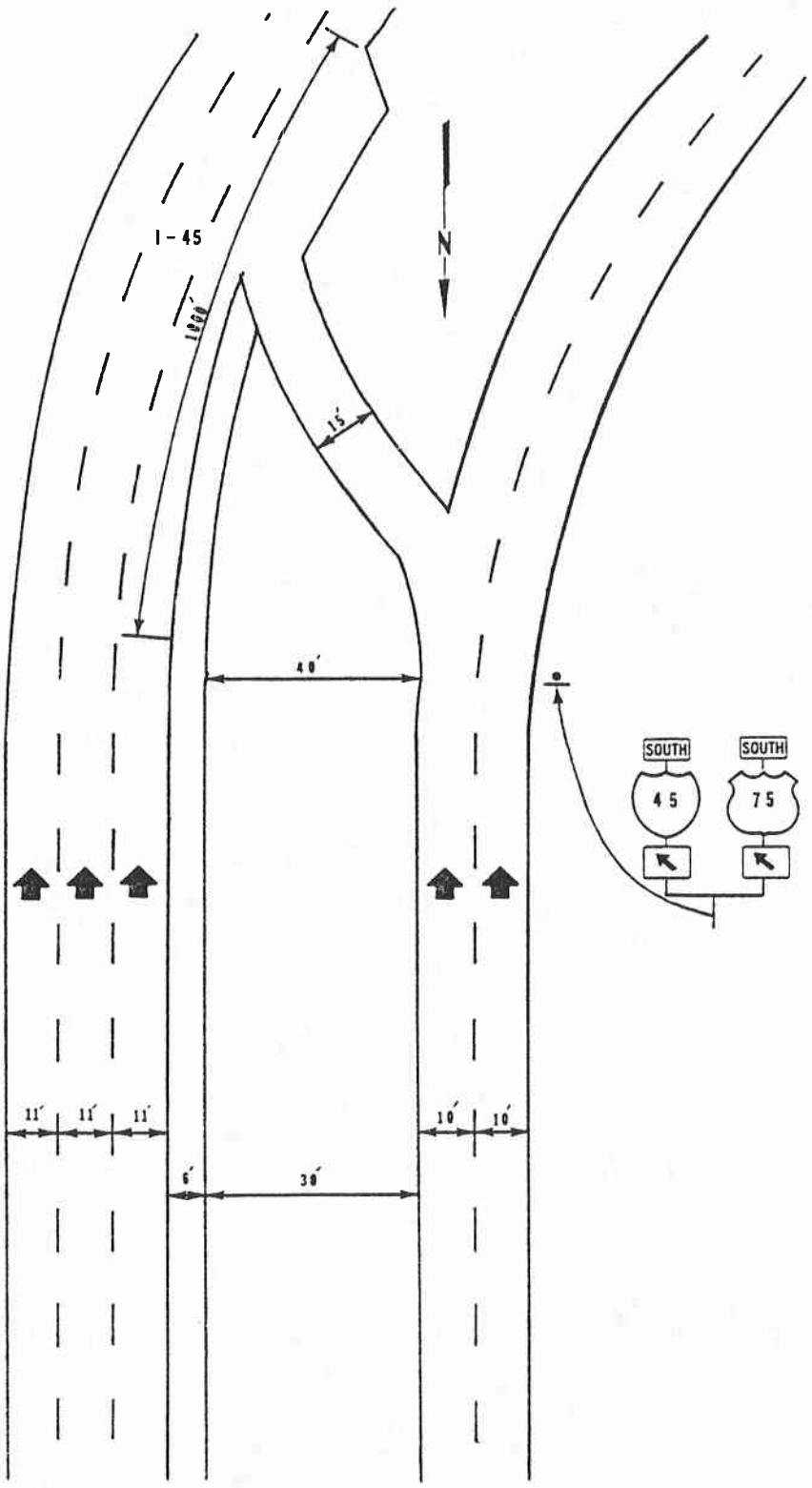
RAMP STUDY NO. 35

FRONTAGE ROAD SITE NO. 19



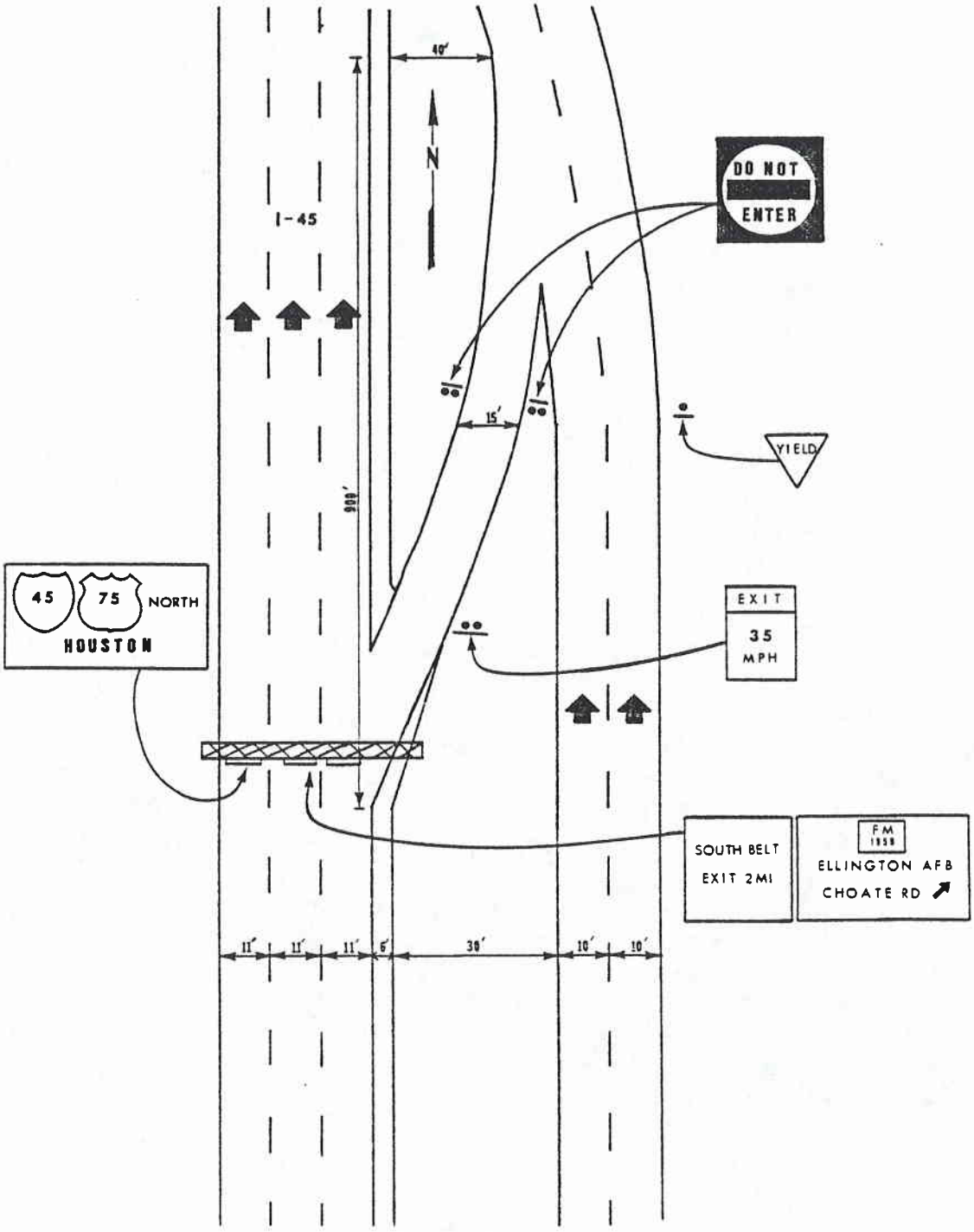
RAMP STUDY NO. 36

FRONTAGE ROAD SITE NO. 45



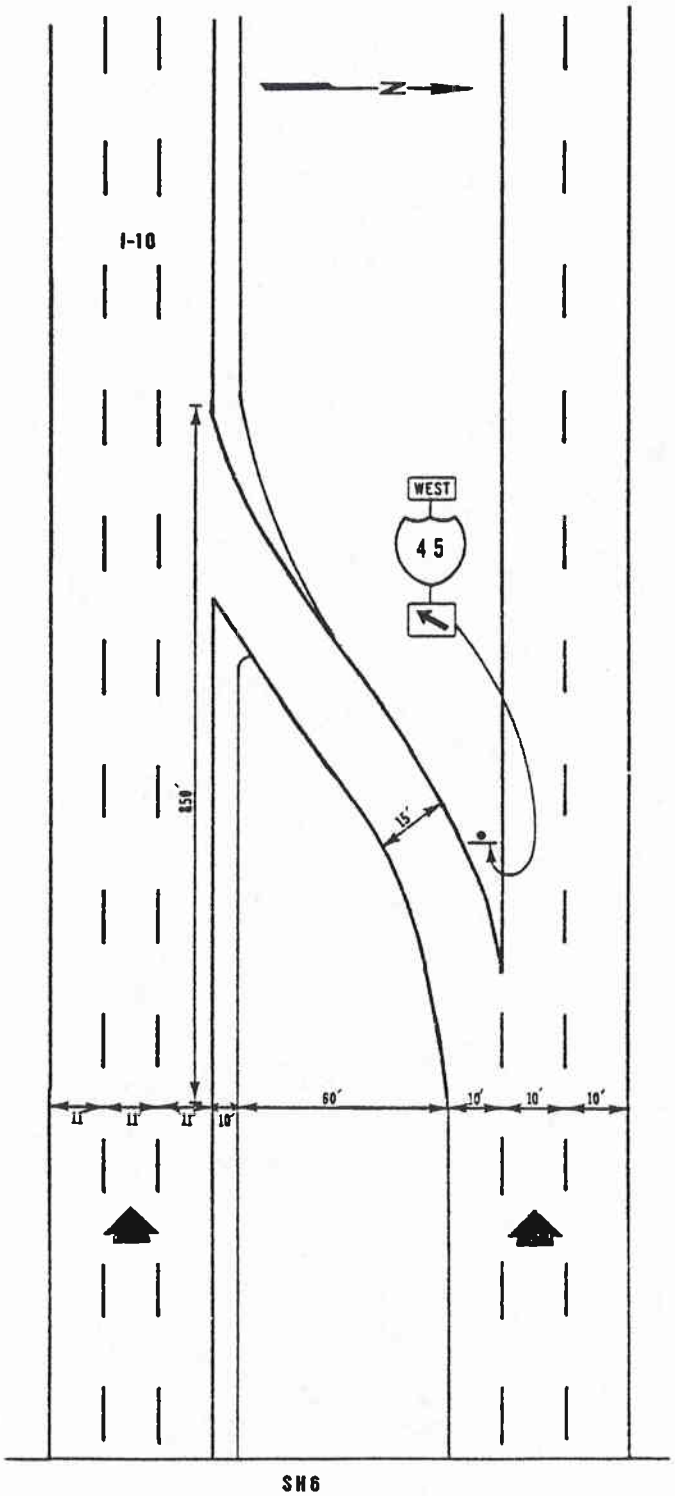
RAMP STUDY NO. 37

FRONTAGE ROAD SITE NO. 17



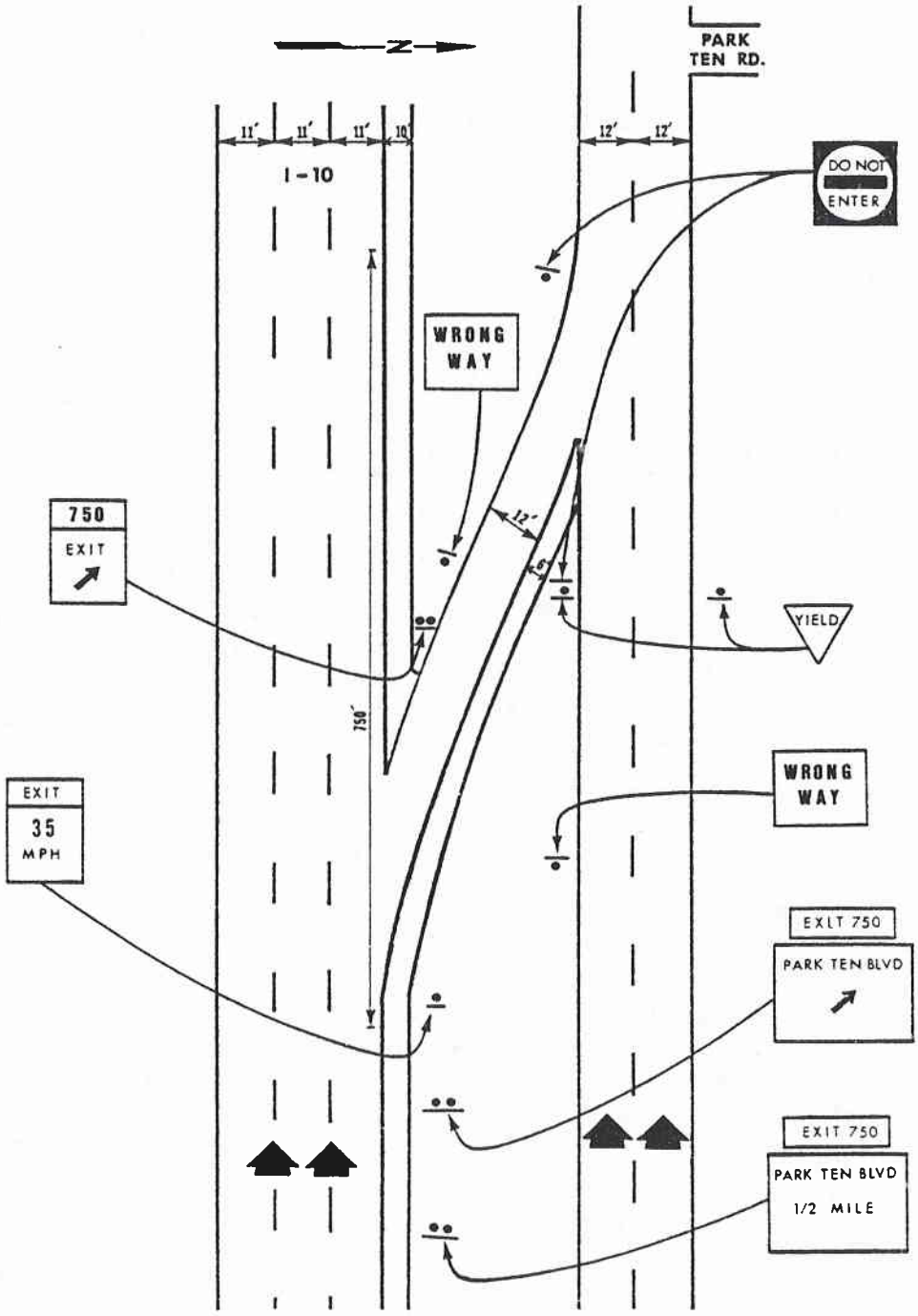
RAMP STUDY NO. 38

FRONTAGE ROAD SITE NO. 17



RAMP STUDY NO. 39

FRONTAGE ROAD SITE NO. 4



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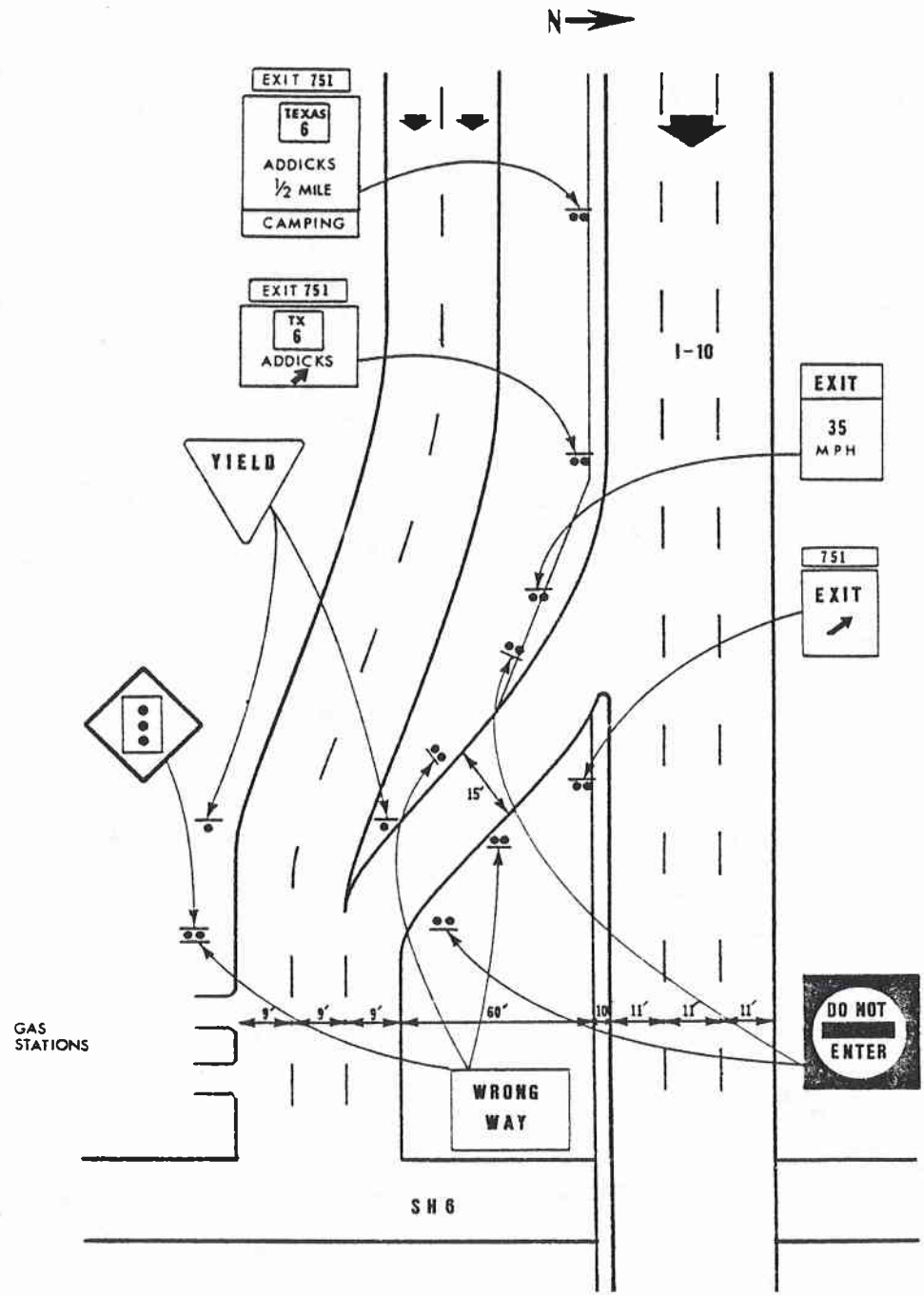

RAMP STUDY NO. 41

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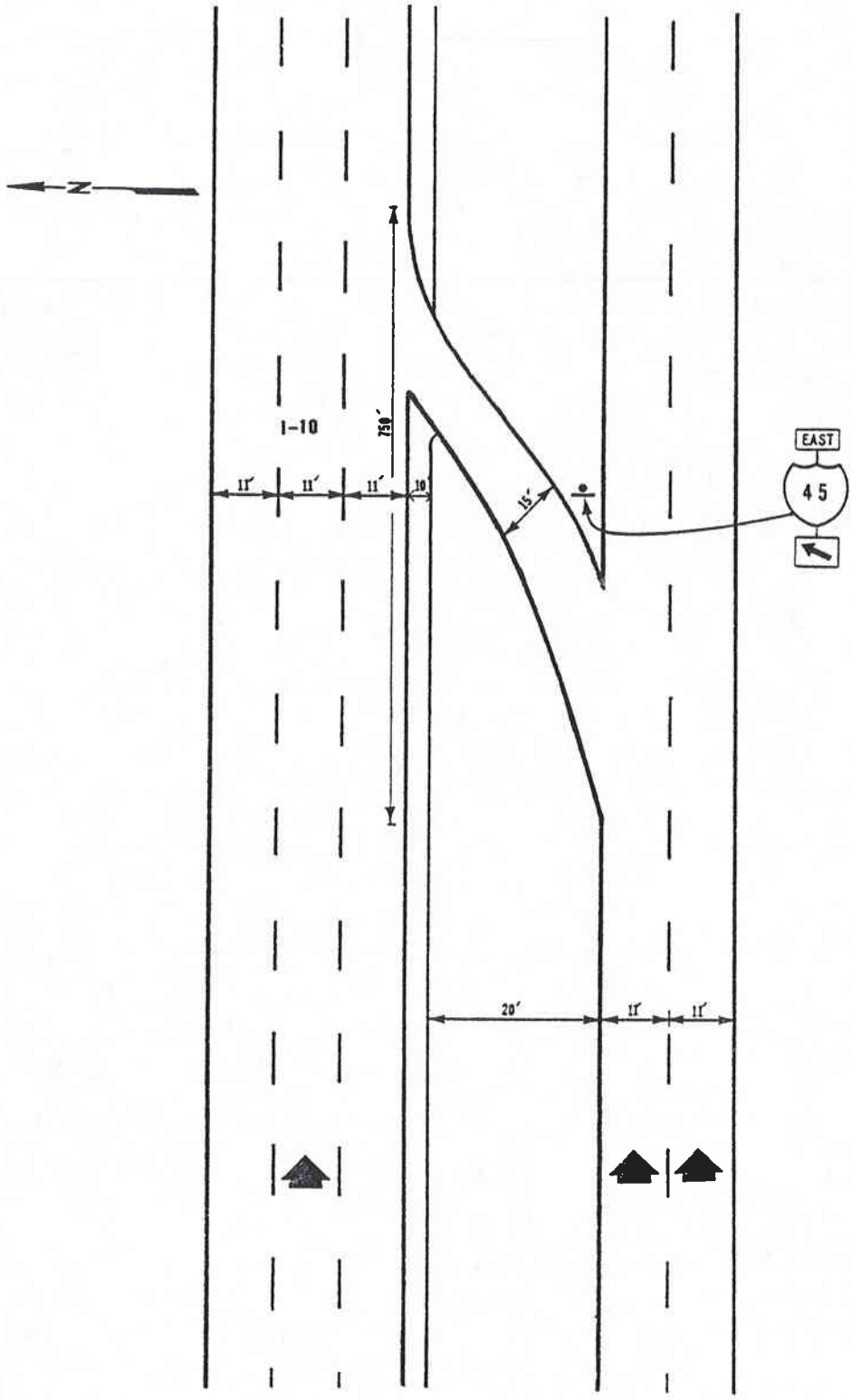
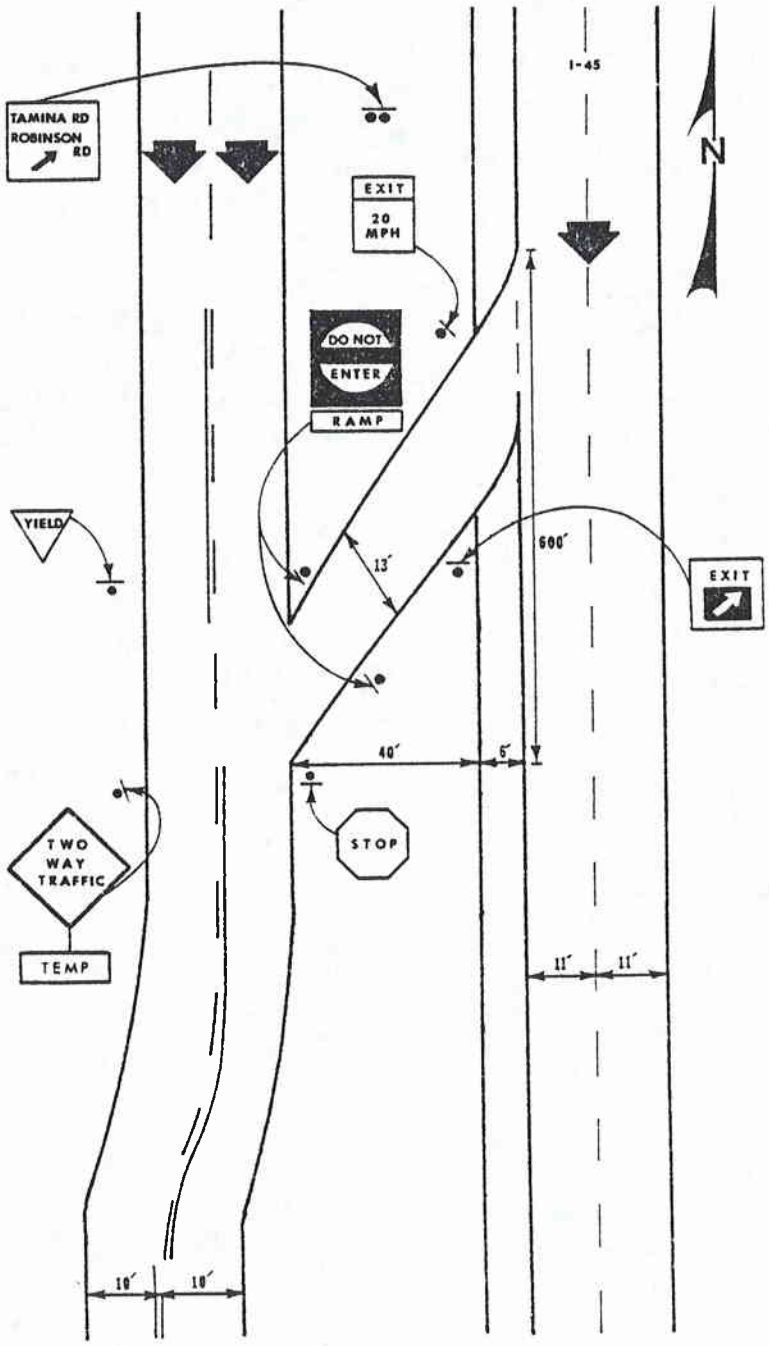


RAMP STUDY NO. 42

FRONTAGE ROAD SITE NO. 4



RAMP STUDY NO. 43

FRONTAGE ROAD SITE NO. 2