NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **175**

FREEWAY LANE DROPS

TRANSPORTATION RESEARCH BOARD
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FREEWAY LANE DROPS

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SANTA MONICA, CALIFORNIA

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST
- HIGHWAY DESIGN
- HIGHWAY SAFETY
- TRAFFIC CONTROL AND OPERATIONS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1976

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report will especially interest highway design engineers, traffic engineers, and all other highway officials concerned with improving traffic operations and safety on freeways. The report contains the findings of a survey of current design and operational practice at freeway lane drop sites in selected states across the nation. Most importantly, it contains recommendations and guidelines for lane drop design in the form of eight principles applicable to several types of lane drop conditions.

It is necessary in some circumstances to reduce the number of travel lanes on a freeway. The requirement may occur under a variety of operating and geometric conditions, and a variety of possible lane drop configurations may be applied. Thus, sound criteria are needed for the selection of appropriate lane drop designs.

The initial NCHRP research in this subject began in 1969 with the threefold objective of determining the effectiveness of existing designs, determining the effects of the significant design parameters, and recommending suitable lane drop configurations. System Development Corporation undertook this research by intensively studying traffic behavior at three sites with differing configuration. The findings from those studies were reported in *NCHRP Summary of Progress Through 1971*.

The research reported here had the same three objectives and was also conducted by System Development Corporation with an added objective of recommending remedial treatments for existing mainline lane drop situations. The eight design principles that were developed have evolved after a review of the design and operational characteristics of 65 lane drop sites. The validity of the principles has been demonstrated to a degree by their evaluation with respect to before-and-after traffic behavior at two sites where design changes were effected during the course of the study. The report suggests, however, that further validation and research would be desirable before definite design dimension can be recommended.

CONTENTS

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FREEWAY LANE DROPS

SUMMARY Research into the definition and extent of the freeway lane drop problem has yielded considerable knowledge regarding the operational characteristics of existing lane drop locations throughout the country. In general, it has been observed that existing lane drop design standards fail to provide an effective means of warning drivers of the presence and location of the impending lane drop. Very little standardization of lane drop geometric design or traffic control device treatment exists in the field, resulting in much driver confusion regarding lane drop maneuvers. In many instances lane drops are not physically well defined; they can be difficult to see because they might blend into their background or be hidden over the crest of a grade. In addition, advance warning traffic control devices are many times misleading or obscure.

A well-designed lane drop will inform an approaching driver, in a timely manner, of three very important facts: (1) that a lane drop situation is ahead; (2) how far ahead; and (3) what action the driver must take.

As a result of this research, the following eight principles have been developed to serve as guidelines for lane drop design:

1. The lane drop should be placed where the surface of the roadway remains visible continuously for a significant amount of time.
2. The lane drop should be placed away from attention-dividing conditions, such as ramps or complicated directional signing
3. The lane drop taper should provide adequate visual cues that inform a driver that his lane is ending and should allow a smooth lane change transition in the taper area.
4. The lane drop should be placed on the side of the freeway that is better with respect to given traffic and geometric conditions.
5. The lane should appear to end on the same side of the freeway as the operational lane drop.
6. When a lane drops at an exit ramp, an escape area of adequate dimensions should be provided to allow for a smooth transition into through lanes.
7. When a lane is added at an on-ramp and dropped at a nearby off-ramp, the entering drivers should be notified that the lane they are traveling in is not a continuous lane for through travel.
8. Consistent and appropriate traffic control devices (TCDs) should be used in advance of a lane drop.

Five different lane drop situations, based on design functions, have been identified:

1. Outlying situations—designed to accommodate reduced demand at the perimeter of a metropolitan area.
2. Add-drop situations—designed to accommodate temporarily increased demand at a weaving section.

3. Drop-add situations—designed to accommodate reduced demand through a major interchange.

4. Step-over situations—designed to reduce problems caused by left-hand ramps.

5. Lane split situations—designed to accomplish major route connections.

Applications of the design principles to each of the functional situations are discussed in this report.

Applications of the design principles have been also applied to lane drop design changes at two sites. Before-and-after operations analyses were performed on these two sites, and the results were compared with the conclusions obtained from application of the design principles.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

A nine-month research task was undertaken to determine the definition and extent of the freeway lane drop problem. By means of personal visits and a survey of over 20 major metropolitan areas, several hundred lane drop sites were observed and 65 were selected for more detailed evaluation. This document reports the findings of the survey along with conclusions and recommendations for lane drop design. Also included are suggestions for further research which involves the verification, amplification, and quantification of the design principles set forth in this report.

RESEARCH APPROACH

The research approach consisted of dividing the task into four major subtasks:

1. Conduct a telephone survey of traffic engineers to determine the number of lane drops and associated problems in many areas of the country.
2. Collect lane drop information by interviewing traffic engineers and observing lane drop sites. Information collected includes data on the geometrics, accident experience, and operational characteristics of selected sites; interviews with traffic engineers concerning lane drop problems; and solutions and design standards currently in use.
3. Analyze the survey findings to determine whether patterns exist in lane drop design and, if so, their operational characteristics.
4. Report these findings, lane drop design recommendations, and suggested further research.

The remainder of this report details the findings of this effort and indicates areas where additional research might be conducted. In addition, detailed descriptions of 65 lane drop sites located throughout the United States are presented in Appendix A.

CHAPTER TWO

FINDINGS

This chapter briefly describes some current lane drop design standards at the Federal and state levels, provides a classification scheme for basic lane drop situations, rates lane drop sites observed in the field according to a three-point scale standard, offers some major reasons for operational problems at lane drop sites, and presents eight design principles for lane drop situations

EXISTING LANE DROP DESIGN STANDARDS

Lane drop design standards are not comprehensively covered in existing highway engineering manuals. The survey indicates that even published standards are frequently not followed at lane drop sites

Several reports, published by the American Association of State Highway Officials (AASHO), the Federal Highway Administration (FHWA), and the Highway Research Board (HRB),* have briefly treated lane drop designs and recommended standards A summary of the reports includes

1 AASHO *Report by the Special Freeway Study and Analysis Committee* (*1*)—indicates lanes should not be dropped at exit ramps because this results in driver confusion, where through lanes are dropped downstream of ramps, a long merging lane should be provided

2 *Highway Capacity Manual* (*2*)—gives warrants for number of lanes, but does not discuss lane drop transitions

3 AASHO *A Policy on Geometric Design of Rural Highways* (*3*)—indicates lanes should be dropped beyond an exit terminal; also specifies lane and taper distances for several design speeds (by referring to acceleration lane tables)

4 *Report of the Special AASHO Traffic Safety Committee* (*4*)—indicates lanes should be dropped on the same side as and downstream of an exit ramp; taper rate should be not less than 70.1.

5. *FHWA Handbook of Highway Safety Design and Operating Practices* (*5*)—indicates taper rates should be at least 50 1 or 100:1, lanes should be dropped downstream of an off-ramp, signing and striping are important

6. *Manual on Uniform Traffic Control Devices* (*6*)—illustrates several signs for lane drops and recommends sign locations, describes and recommends use of black-on-yellow EXIT ONLY advisory signs; taper length should be lane width times design speed (or 85th percentile off-peak speed), illustrates left-side pavement drop with striping to merge two right lanes

In addition, design standards collected from many states are listed below. The Institute of Traffic Engineers has conducted a mail survey of standard practices for application of traffic control devices at freeway lane drops, which should provide information in addition to the following concerning standard practices in a number of states

California

California standards are being revised. The following comments were derived from interviews with California Department of Transportation personnel

1 Do not drop a lane at the same location as a ramp end

2. Do not present a driver with successive decisions too quickly

3 Coordinate geometry and striping, if possible.

4 Avoid drops on curves

5. Consider traffic volumes by lane and composition

6 Do not drop lanes at an off-ramp connection, unless more than 50 percent of vehicles exit.

7 Through lanes should not be dropped at a local ramp.

8 Taper should begin about 600 ft downstream from a ramp.

9. Taper length should be about 800 to 1,000 ft.

With respect to item 7, field observation indicates that through lanes in California are frequently dropped at a local ramp

Connecticut

Published standards for pavement design are presented in Figures 1 and 2 Stated signing standards are those of the MUTCD, but there is much variation in existing signing

Michigan

The following comments were derived from interviews with Michigan highway personnel.

1 Most lane drops occur at exit ramps, currently provided with an escape lane tapering from 22 ft wide

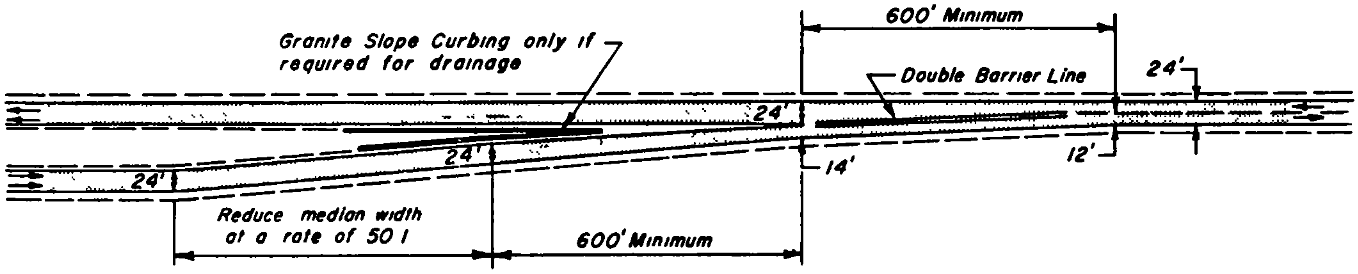
2 Future design may reduce the escape lane to 14 ft. Michigan treats add and drop lanes less than 2,600 ft long as auxiliary lanes, using different-colored pavement.

Minnesota

Minnesota standards are published in a manual and in staff memos (see Figs 3 and 4) These sources note that escape lanes should be considered

1 Following the auxiliary lane between cloverleaf loops where the loops are immediately adjacent to the mainline roadway The suggested escape lane design consists of 200 ft of tangent 12-ft lane followed by a 50:1 taper, provided that the taper would end at least 300 ft in advance of the nose for the following entrance leg

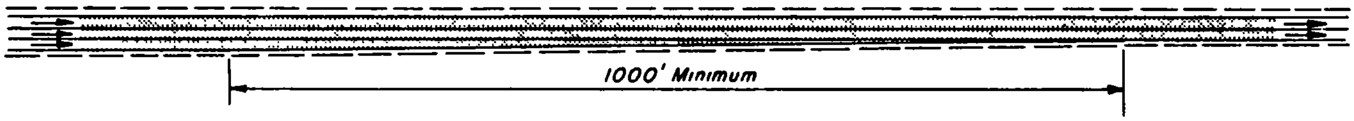
* AASHO is now the American Association of State Highway and Transportation Officials (AASHTO), and HRB is now the Transportation Research Board (TRB)



General Note

Transitions between two-lane highways and four-lane highways shall be designed to direct drivers approaching the divided section into the intended path to the right of the median without any appreciable change in direction Any significant change in direction shall be made by drivers leaving the divided section

FOUR LANES DIVIDED INTO TWO LANES UNDIVIDED

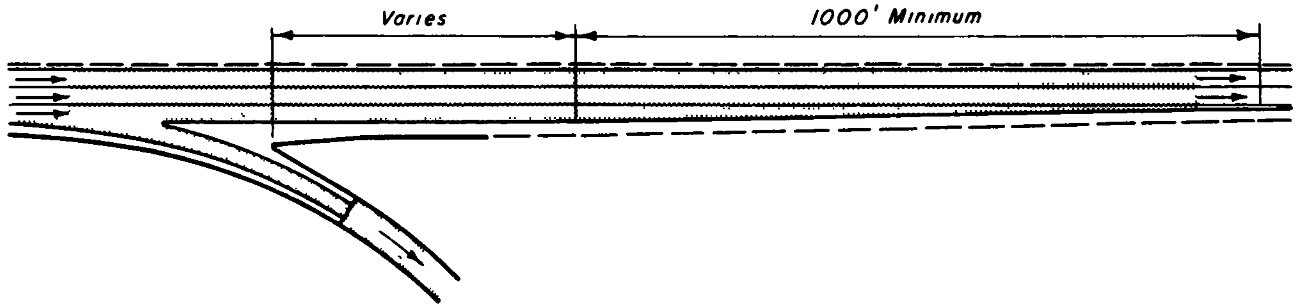


General Note

Normally, the lane drop will take place on the right in the direction of traffic Transitions shall be avoided before interchanges and at locations with horizontal and/or vertical sight distance restrictions.

ROADWAY LANE DROP

Figure 1. Connecticut design standard for a lane drop away from an interchange



General Notes

A reduction in the number of lanes at an interchange is an appropriate layout only where the traffic warrants for a considerable section of the expressway beyond the interchange do not require the greater number of lanes Because of the difficulty of predicting the daily and hourly fluctuations of traffic on low volume ramp movements, the number of lanes should not be reduced within the interchange area, such as between successive "off" and "on" ramps

Length of parallel section beyond ramp terminal varies to meet special considerations. Transition should occur on tangent section wherever possible and should avoid locations with horizontal and vertical sight distance restrictions.

Figure 2. Connecticut design standard for a lane drop at an interchange

2. Following the auxiliary lane between interchanges, where the auxiliary lane length between noses measures from 1,000 to 2,000 ft The escape lane should consist of a 50:1 taper beginning at the exit nose and having a width at the nose of 14 ft. This design may vary depending upon the projected volumes on the ramps and on the mainline lanes.

3 Following a short auxiliary lane (less than 1,000 ft between noses). Normally the escape lane should consist of 400 ft of tangent 12-ft lane followed by a 50:1 taper.

The suggested dimensions may be considered applicable in most instances; however, in all cases the projected volumes on the mainlines, ramps, loops, and weaving areas should be considered to determine the appropriate design.

For comparison, it should be noted that (Minnesota's) present standard for a major exit, which involves the dropping of a mainline lane, specifies that the escape lane shall consist of a 400-ft length of tangent 12-ft lane followed by a taper having a ratio of the design speed of fifty to one.

Missouri

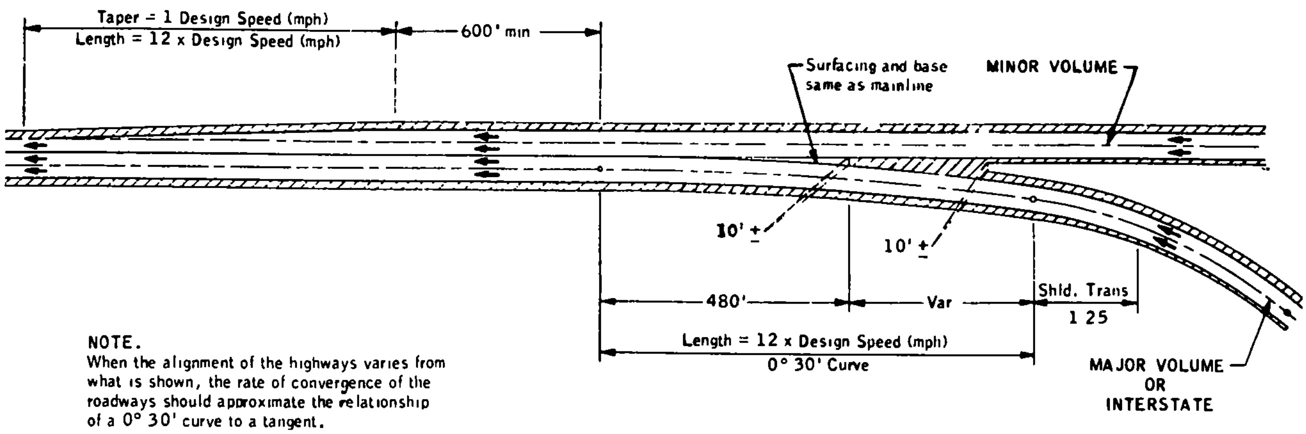
The following is abstracted from a letter from Robert N Hunter, Chief Engineer, Missouri State Highway Commission.

Missouri has no published specifications because lane drops occur infrequently. Normal practice is to drop the outside lane at a ramp exit. Missouri has experienced some problems when inside lanes were dropped; these situations have been corrected by restriping and signing to drop the right lane. Missouri favors the black-on-yellow EXIT ONLY sign, a solid stripe from 500 ft upstream of the exit gore through the gore area, and a 70:1 taper rate downstream of the gore. On those few sites away from ramps, an overhead RIGHT LANE ENDS ½ MILE is used in conjunction with a similar sign on the right, followed by RIGHT LANE ENDS 1500 FT, lane drop symbol (4-2), and LANE ENDS MERGE LEFT.

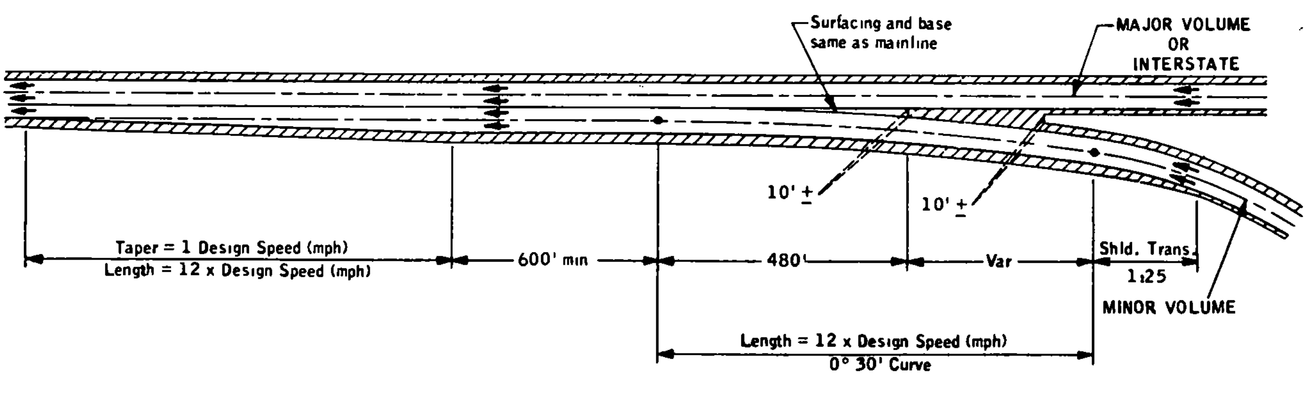
New Jersey

The following comments were derived from interviews with New Jersey personnel:

1. If a lane is dropped at an exit, a standard acceleration lane (600-ft full lane width, 600-ft taper) should be provided past the exit gore as an escape area.
2. A standard taper length of 70:1 should be used at a non-exit lane drop site.



MINOR VOLUME ON TANGENT
No scale



MAJOR VOLUME ON TANGENT
No scale

Figure 3. Minnesota design standard for a lane drop at a major highway fork.

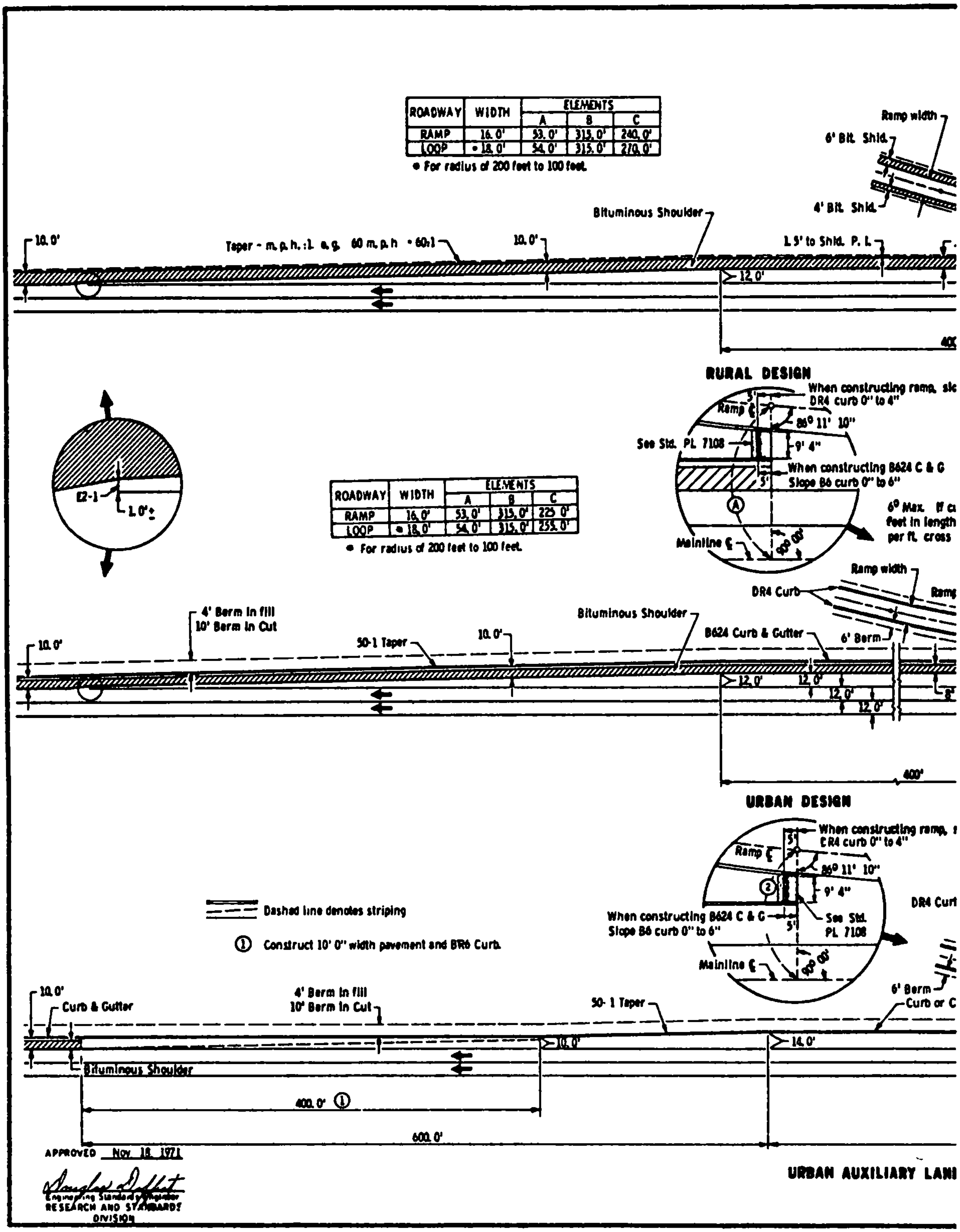


Figure 4. Minnesota design standard for a lane drop at an interchange.

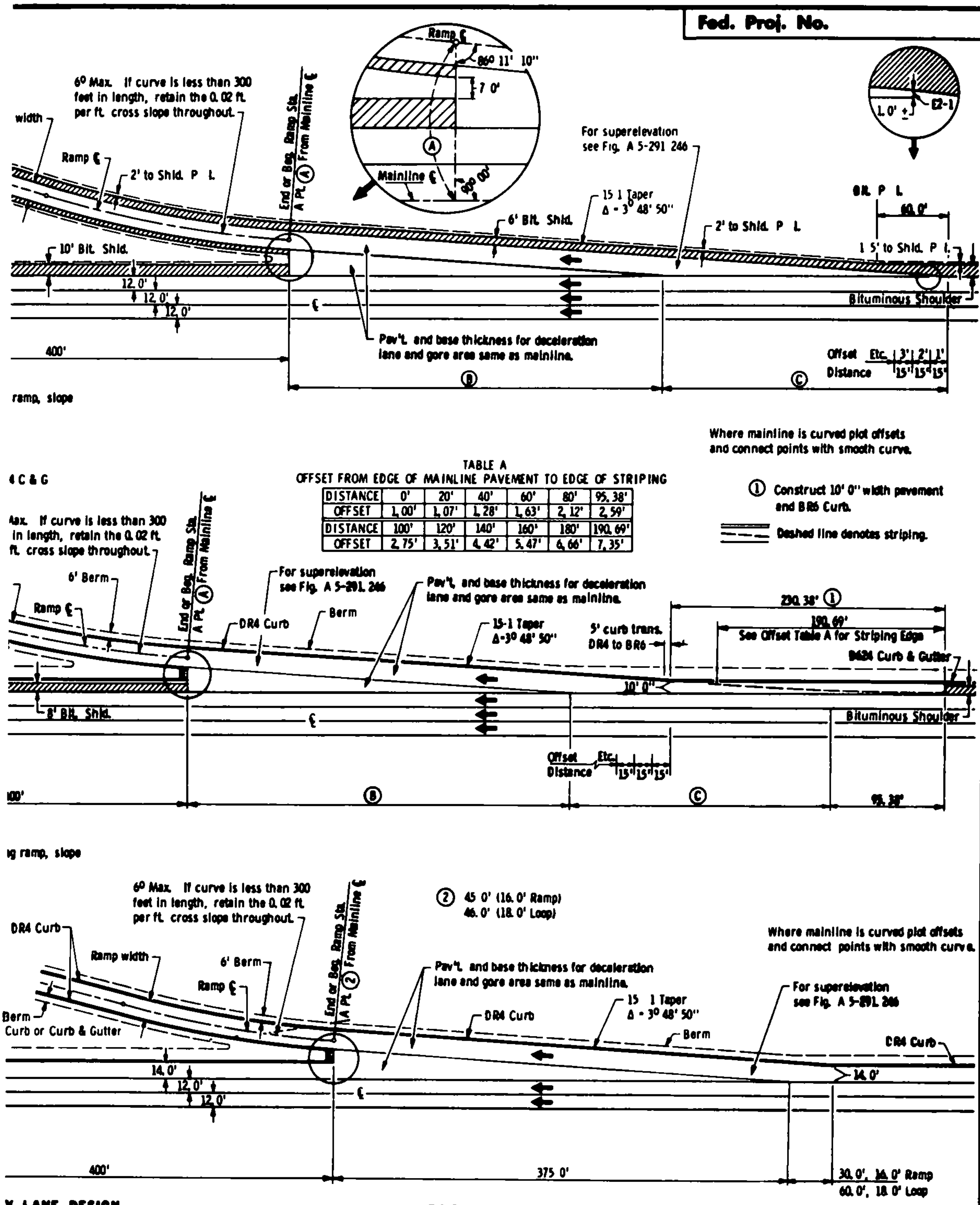


TABLE A
OFFSET FROM EDGE OF MAINLINE PAVEMENT TO EDGE OF STRIPING

DISTANCE	0'	20'	40'	60'	80'	95.38'
OFFSET	1.00'	1.07'	1.28'	1.63'	2.12'	2.59'
DISTANCE	100'	120'	140'	160'	180'	190.69'
OFFSET	2.75'	3.51'	4.42'	5.47'	6.66'	7.35'

Y LANE DESIGN

ESCAPE LANES AT MAJOR RAMP EXITS

State Proj. No. Sheet No. of Sheets

New York

According to the Deputy Chief Engineer, the following extracts from New York's published standards reflect the results of a California study of a few years ago:

> *5 05 06 Lane Drops*
>
> At diamond, cloverleaf, or other conventional types of interchanges, do not drop a lane at the exit terminal and subsequently pick it up again at the next entrance terminal Instead, carry the outside lane through the interchange area.
>
> When capacity-dictated lane drops are necessary on multi-lane divided highways, it has been found in one California study that dropping the striped and constructed lane on the median side resulted in two-thirds of the accident rate resulting from a lane drop on the right side
>
> It has also been shown that lane drop transitions on curves result in from two to ten times the accident rate as for tangent transitions.
>
> Therefore, capacity-dictated lane drops for multi-lane facilities should be made on the median side, on tangents, and away from the influence of the interchange ramps
>
> The lane drop transition should begin at least one-half mile beyond the nearest exit or entrance ramp nose. The length of taper should then be "Design Speed × Lane Width"
>
> In direct connection interchanges, where a reduction in the number of through lanes is indicated by capacity analysis, these locations should be designed as major forks, with appropriate advance and gore signing that give specific and clear lane assignments to guide the driver. .

Ohio

The following priority system is used in determining the placement of lane drops in Ohio *:

1. Continue the drop lane through an interchange and begin the taper approximately ½ mile past the final exit ramp.
2. Continue the drop lane past the final exit ramp, terminating the taper prior to the next entrance ramp.
3. Begin the lane drop taper approximately 12 ft beyond the exit ramp gore.

Right-hand lane drops are accomplished by reducing the pavement width from the left-hand side, with the pavement markings for the through lanes placed parallel to the pavement taper through the transition zone. Signing for a drop away from a ramp includes a black-on-yellow RIGHT LANE ENDS 1 MILE, and a black-on-yellow RIGHT LANE ENDS MERGE LEFT at the start of the taper, both signs are overhead. The EXIT ONLY panel is used for ramp drops, with an EXIT LEFT 1 MILE for a left-hand ramp.

Oregon

The State of Oregon has published plans for guidance in the development of lane drop standards (see Fig. 5).

* Unpublished standards based on a Deleuw, Cather and Company study, by Jack E Leisch, published in the *1965 Canadian Good Roads Association Proceedings*

Washington

The following is extracted from a State of Washington manual (Figs. 6 and 7):

> Pavements of Different Widths. When a transition is required to change the number of lanes on the open highway, the following should be used as a guide:
>
> - Locate transitions in full view of the drivers and preferably on a tangent section.
> - Supplement with traffic control devices
> - Reduce the number of lanes by only one at a time and on the right side in the direction of travel
> - The length of transition shall be determined by the formula.
>
> $$L = VT$$
>
> where L = length of transition (ft)
> V = design speed (MPH)
> T = tangential offset (ft.)
>
> Transitions occurring at turning roadways, and tapers into existing pavement widths on low speed conditions should normally have a tangential rate of change of 1.25 or flatter Nevertheless, the number of tapers should be held to a minimum. .

CLASSIFICATION OF BASIC LANE DROPS

Lane drops, as defined by highway personnel, can generally be categorized into one of five basic types. (Fig. 8 shows typical configurations of lane drop types) Appendix A is arranged by these five types of lane drops and can serve as a guide to examples of current sites.

Outlying Drop Situation

The most familiar type of lane drop site is located at the perimeter of a metropolitan area. The lane drop is produced when the basic number of lanes is no longer required to carry the traffic generated from an urban center. This lane drop type has been designated as an outlying drop situation.

A subcategory of outlying lane drops has also been identified In some cases, lanes have been dropped to accommodate a downstream physical constraint, such as a narrow bridge. Such sites have been included in this category because the problems and design of these lane drops generally reflect those of the remainder of the category.

Add-Drop Situation

A second major lane drop type is the add-drop situation. In many cases a lane is added at an on-ramp and dropped shortly thereafter at a downstream off-ramp. The observed distance between the lane addition and the lane drop has been as short as 1,500 ft or as long as more than 6,000 ft.

Drop-Add Situation

A counterpart of the add-drop situation is the drop-add situation, which has generally been observed at major freeway-to-freeway interchanges. This type of drop is installed for several reasons. First, traffic exiting from the freeway may be extremely heavy, indicating a need for two or more exiting lanes. Thus, if one full lane of traffic exits to travel to the other freeway, the additional lane is no longer needed for through traffic. Further, by dropping a

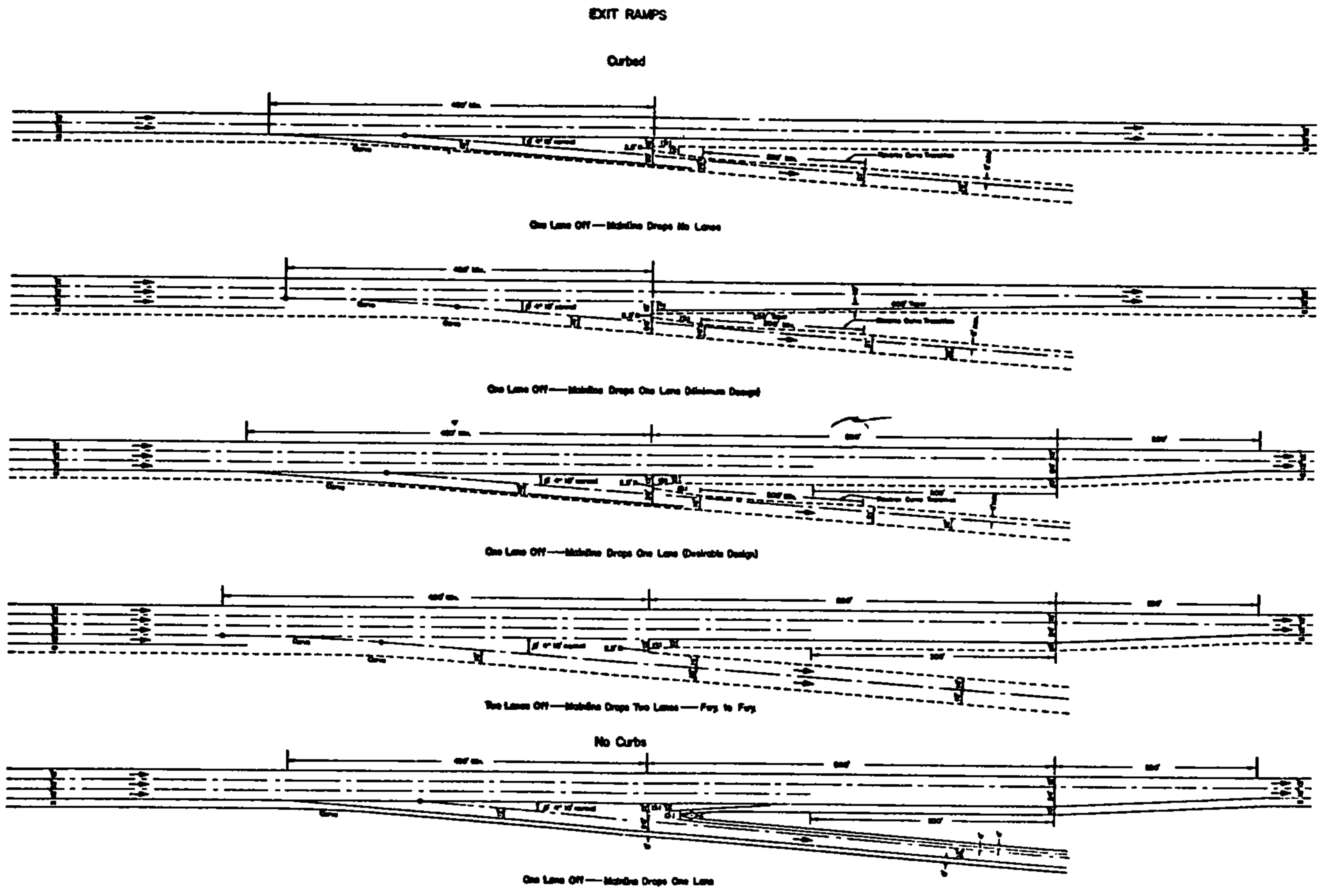


Figure 5 Oregon design recommendations for lane drops

lane through the interchange, vehicles entering on the other side of the interchange have a "free" lane in which to enter the freeway; they do not have to merge with faster-moving through traffic. It thus seems reasonable to drop a lane through a major interchange

Step-Over Situation

A fourth type of lane drop situation that results in many problems is called the step-over lane drop. In this situation, a freeway step-over is accomplished by adding and dropping, or dropping and adding, a lane on opposite sides of

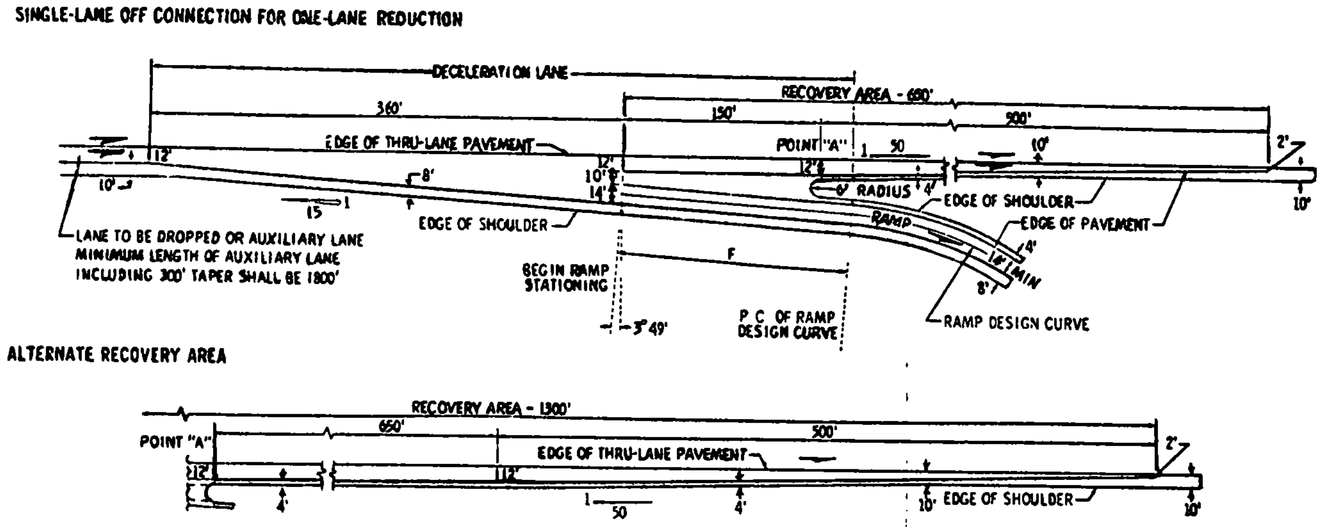


Figure 6. Washington design standards for a lane drop at an interchange (single-lane exit).

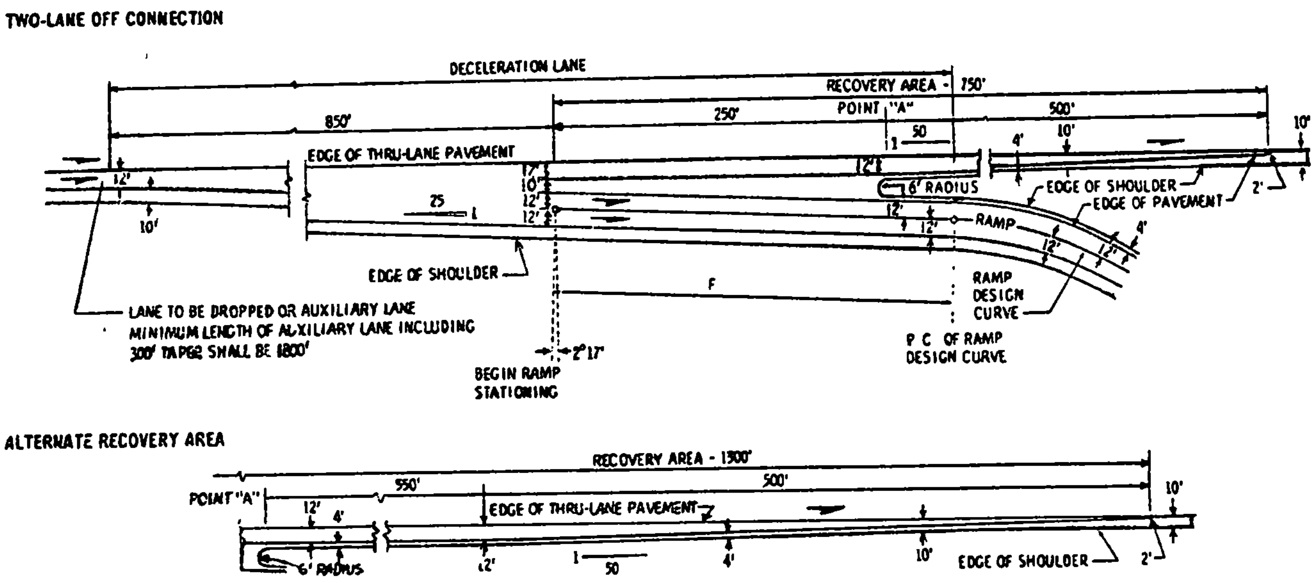


Figure 7. Washington design standards for a lane drop at an interchange (two-lane exit).

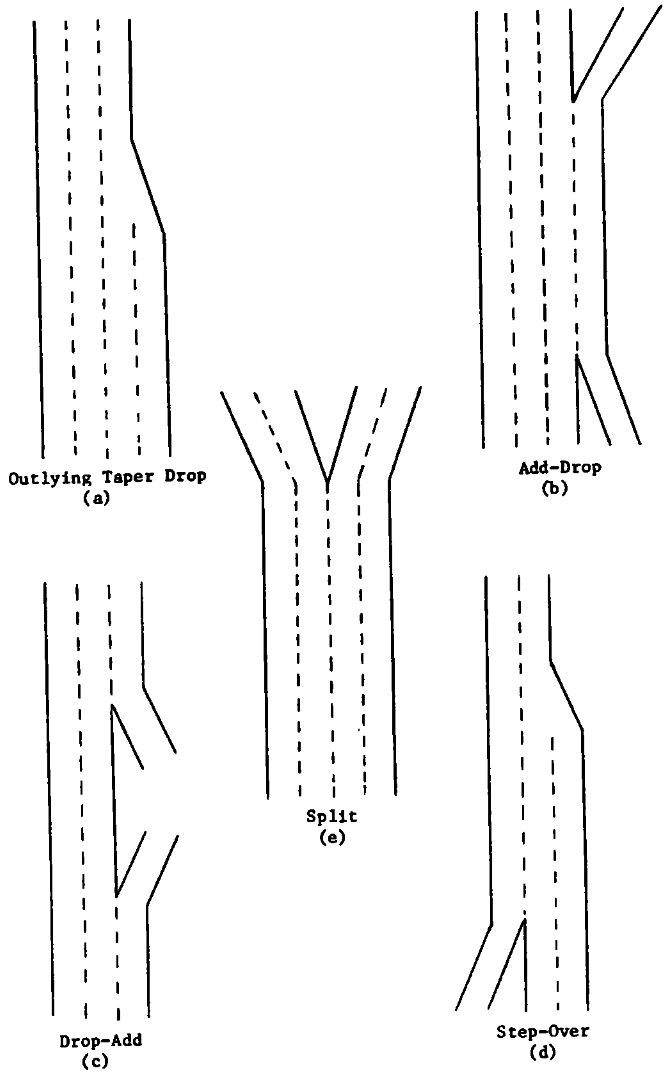


Figure 8. Lane drop classifications.

the freeway This situation is common when left-hand on-ramps are designed. A lane is added on the left at the on-ramp to avoid merging ramp vehicles with high-speed traffic and then shortly downstream, a lane is dropped on the right to avoid carrying an extra lane.

Lane Split Situation

The fifth type of lane drop, a lane split, is found on a freeway that divides into two or more legs where the design speed on each leg is generally higher than the conventional off-ramp which goes to a surface road. The point at which the division takes place is called a lane split. It is difficult to characterize a lane split because many factors must be taken into consideration. A few of these are (a) the number of lanes on the freeway prior to the split; (b) the number of lanes on each leg after the split; (c) the traffic demands on each leg downstream of the split; and (d) the hierarchy of route designations of the freeway upstream of the split or downstream of the split. In many cases, drivers are forced to change lanes to continue in their chosen direction of travel. Thus, some of the problems and some of the solutions pertinent to other categories of lane drops are found at lane splits.

CLASSIFICATION AND GRADING OF FIELD DATA OBSERVATIONS

A rough three-point scale was used to rate the relative effectiveness of the sites observed. The factors used in the grading scheme included (1) the number and severity of erratic movements, (2) lane change behavior, (3) speed change behavior, (4) opinions of state and local highway engineers, and (5) amount of citizen complaint regarding the site. A site was judged good if the number of erratic movements seemed small, if most lane changing was accomplished in advance of the taper or gore area, and if highway engineers thought that the site was currently not

a problem. A site was judged passable if no serious problems occurred, but indications of problem-producing maneuvers were frequent. A site was judged bad if many erratic movements were observed, if congestion was apparent in the lane drop area even if the general area was flowing at below capacity, or if highway engineers or citizens expressed awareness of serious problems

It must be remembered that some sites are considered problems because they are peak-hour bottlenecks If the traffic demand at peak-hour is above downstream capacity, the lane drop will become congested regardless of how it is designed. In cases where such a condition exists, the site was observed in off-peak-period operation. If it worked well under these conditions, the site was judged good regardless of the fact that during peak-hour operation breakdown occurs in the vicinity of the drop.

Each of the 65 sites observed and catalogued in Appendix A was graded by the researchers and categorized into one of the five basic lane drop types described previously. The categorization scheme is not necessarily all-inclusive or mutually exclusive. A few lane drops will defy being classified into any of the five categories; a few others will fit more than one category. However, most lane drops can be effectively classified into one category. Table 1 presents the ratings of the various sites.

OPERATIONAL PROBLEMS

The categorization scheme allows for ease in treating the situations from a design or remedial treatment standpoint. From a purely operational or driver's-eye standpoint, some of these categories can be grouped together. Thus, problems associated with exit ramp drops at a drop-add situation may be similar to those of a lane split, or the apparent conditions facing a driver entering a freeway from an on-ramp at an add-drop situation may be similar to those experienced by a driver entering the freeway on the lane-add of a drop-add situation. The problems associated with each type of basic lane drop situation are discussed, with the understanding that many problems overlap category boundaries.

Geometry-Related

Outlying Drop

Problems at outlying lane drops can be divided into two groups: those which affect drivers at a taper lane drop and those which affect drivers at an exit lane drop. The major difference between the two groups is in the effect of the choice of traffic control devices. At a taper lane drop, all traffic must be moved out of the ending lane. At an exit lane drop, only some traffic needs to change lanes; the exiting traffic is in the correct lane.

Table 2 gives the ratings for 32 sites, which are split fairly evenly between nine right-hand tapers, nine left-hand tapers, thirteen right-hand exit ramp drops and one left-hand exit ramp No distinct pattern could be observed that indicated that one of these configurations was significantly better or worse than the other; examples of both bad and good sites can be found in each configuration. Thus, it appears that factors other than simple configuration are responsible for differences in operation at lane drops.

A total of nine sites were graded in the bad category. Site 31, shown in Figure 9, is a 3-2 left-hand taper lane drop just downstream of a right-hand off-ramp/on-ramp combination. The site has many traffic control devices, but many drivers remain in the left lane until near the end of the taper. One reason could be that the lane drop occurs too close to the on-ramp, thus inviting drivers to stay out of the right-hand lanes to avoid the merging slower traffic. In addition, sight distance is rather restricted—approximately 1,100 ft from the downstream end of the taper.

Another bad lane drop situation occurs at an incompleted interchange site. Future plans, calling for a freeway to intersect at site 04 (see Fig. 10), connect the right-hand lane of the three lanes with the new freeway and drop the lane at the site in a right exit. As a temporary measure until the freeway addition is constructed, the site has operated with a right-hand taper using eight lighted barricades. The condition has existed for several years; removal of the temporary nature of the lane drop would probably improve the site.

Three bad sites (two outlying, one add-drop) seem to have the same basic problem; that is, the actual pavement was terminated on one side of the freeway and the lane was operationally dropped on the other. In all cases, the re-

TABLE 1

RATINGS OF LANE DROP SITES

LANE DROP CONFIGURATION	RATING: GOOD	PASSABLE	BAD
Outlying	02, 05, 14, 19, 23, 26, 27, 34, 38, 39, 53, 58, 59	08, 16, 28, 36, 44, 47, 48, 52, 57, 60	04, 17, 20, 25, 31, 35, 51, 61, 65
Drop-add	41	42, 55	30, 40, 49, 50, 54
Add-drop	18, 62, 63,	09, 21, 32, 33	07, 12, 13, 24, 37, 45
Split	64	43	06, 22
Step-over	15	03, 11	01, 10, 29, 46, 56

TABLE 2

RATINGS OF OUTLYING LANE DROP CONFIGURATION SITES

OUTLYING LANE DROP CONFIGURATION	RATING: GOOD	PASSABLE	BAD
Right taper	05, 19	08, 16, 52, 57	04, 17, 61
Left taper	14, 23, 38, 39, 53	28	65, 25, 31
Right ramp	02, 26, 27, 34, 58, 59	36, 44, 47, 48, 60	20, 35
Left ramp	—	—	51

sults were poor The three sites studied were all designed differently and the characteristics of sites 17, 65, and 13 are shown in Figures 11, 12, and 13, respectively. The pavement at site 17 ends on the left, and the two right lanes are merged together by moving the four left lanes towards the right lane. The pavement at site 65 ends on the right just downstream of a right-hand on-ramp, and the three right lanes are moved toward the left lane. The pavement at site 13 moves toward the right as the median widens and the pavement tapers into lane two.

The difference between sites 65 and 13 is that the site 65 lane lines do not follow the longitudinal pavement joints, whereas the site 13 lane lines are in accordance with the pavement joints. In all cases, the sites have been indicated to be confusing to the driver.

The situations highlight two main points for consideration. First, it is difficult for the driver in the median lane to understand that he must move out of his lane because of an impending lane drop when he can "see" that the pavement in front of him continues; all his cues and past experience tell him that his lane is still there. Second, even if he moves out of this lane the first time through, the commuter learns quickly enough that, had he chosen to stay in his lane, he would get where he was going just as well. That sets up a perfect stage for "freeway roulette" in which the driver in the inner lane fights to remain in his lane which, according to the lane lines, moves over slightly, while the driver in the outside lane is sure that his lane continues as well.

Though there have been numerous complaints of driver confusion over who has the right-of-way at site 13, the first lane drop study (7) concluded that site 65 experienced a much greater amount of turbulence than at the other two sites in that study.

A corollary to this difficult lane drop situation is that the sites are also difficult to sign The standard lane drop signs (W4-2) have been changed several times due to citizen complaints that the merge indicated is in the wrong direction; each time the state has made a sign change, they have received complaints A new type of sign (Fig. 14) has been installed to try to eliminate this driver confusion

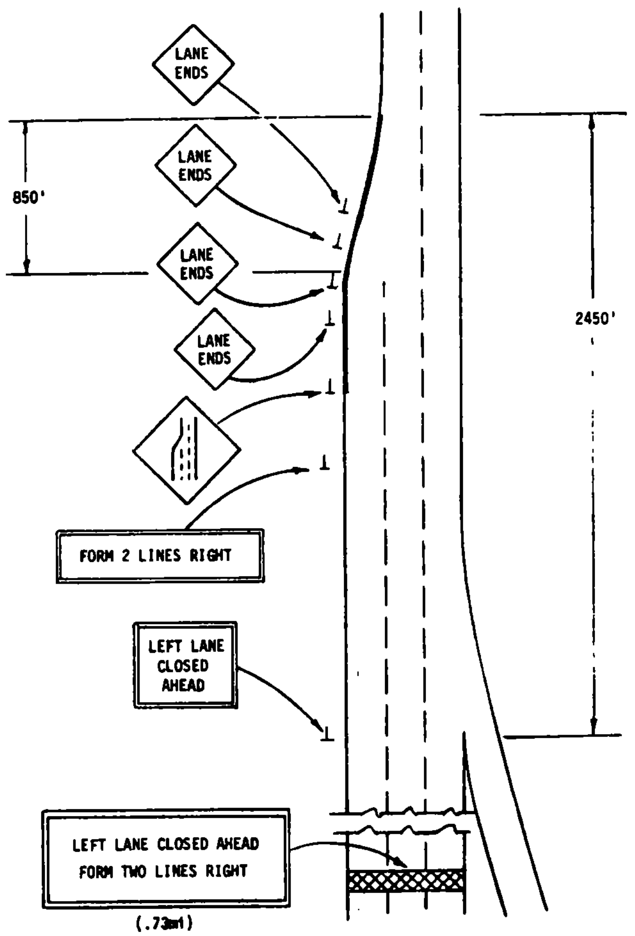


Figure 9. Site 31.

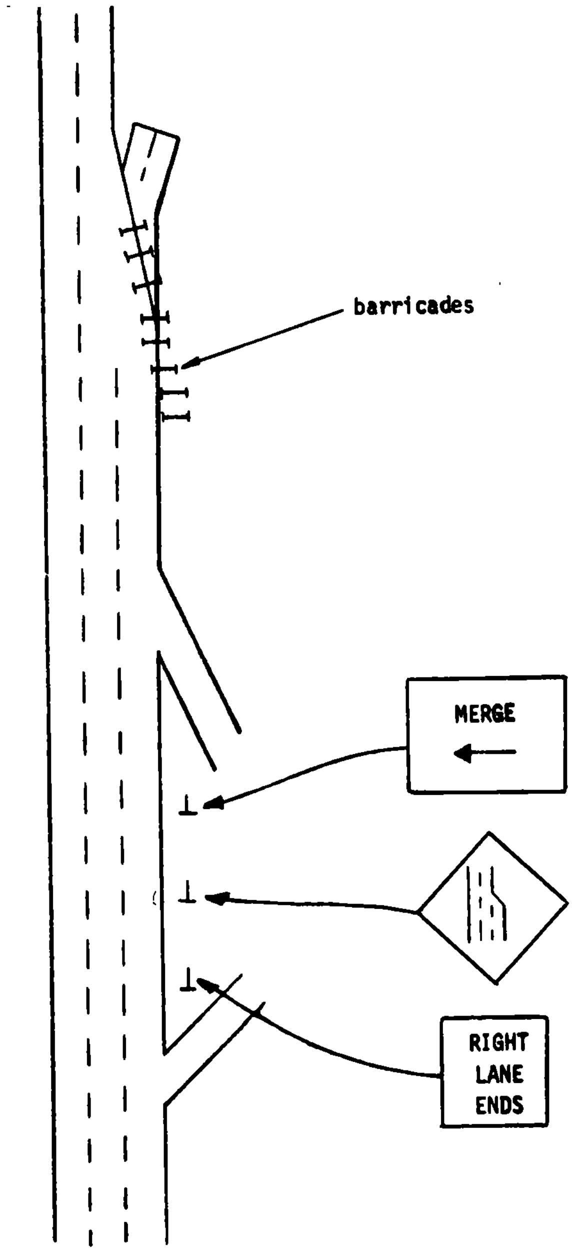


Figure 10. Site 04.

Clearly, this type of lane drop configuration is undesirable using current techniques. One state highway department has eliminated two opposite taper lane drops, one by extending the dropped lane, and the other by moving the operational lane drop upstream a few hundred feet and converting it to an exit ramp drop.

Several outlying-type sites have been designated "problem" sites by state agencies or as a result of citizens' complaints because congestion occurs during peak-hour traffic. Geometric design procedures or traffic control devices cannot eliminate a lane drop problem that is a result of insufficient downstream capacity. Site 34, shown in Figure 15, is an example of this situation. This 3-2 right-hand exit lane drop functions well during off-peak hours, but it routinely breaks down every week-day afternoon because of above-capacity demand downstream. In general, if a site suffers from this type of problem, the solution is either to continue the additional lane until there is sufficient capacity for the demand; to reduce demand by upstream control, such as on-ramp metering, or to accept the occurrence of the bottleneck

Add-Drop Situation

Almost half of the 13 add-drop sites were given bad ratings. Most of these have one common problem—poor sight distance. If drivers cannot see the lane drop in time to make a smooth transition out of the dropping lane, erratic maneuvers may result. Sites 24 and 37, respectively shown in Figures 16 and 17, both less than 1,500 ft long, are good examples Sight distance is very restricted due to the presence of vertical curves; the lane is dropped just beyond the crest of the grade. Both sites have one sign in the add-drop lane pertaining to the lane drop, an EXIT ONLY panel on a directional sign several hundred feet in front of the gore of the off-ramp. Even if a driver is looking for a directional sign at this point—which he probably isn't because he just entered the freeway—by the time he is able to read the sign he is probably close to being committed to an erratic maneuver to get out of the lane before it veers off the freeway.

The operational problems at add-drop locations generally seem to stem from the driver's confusion over whether he is in a through lane or not At most add-drop sites, normal lane lines begin just after the lane add and continue until just before the lane drop. Sometimes a solid white line replaces the lane line, yet normally it occurs too late to let the driver avoid an erratic maneuver if he wishes to remain on the freeway. One additional operational problem exists for right-lane drivers. It has been observed several times that drivers who normally travel in the right lane enter an

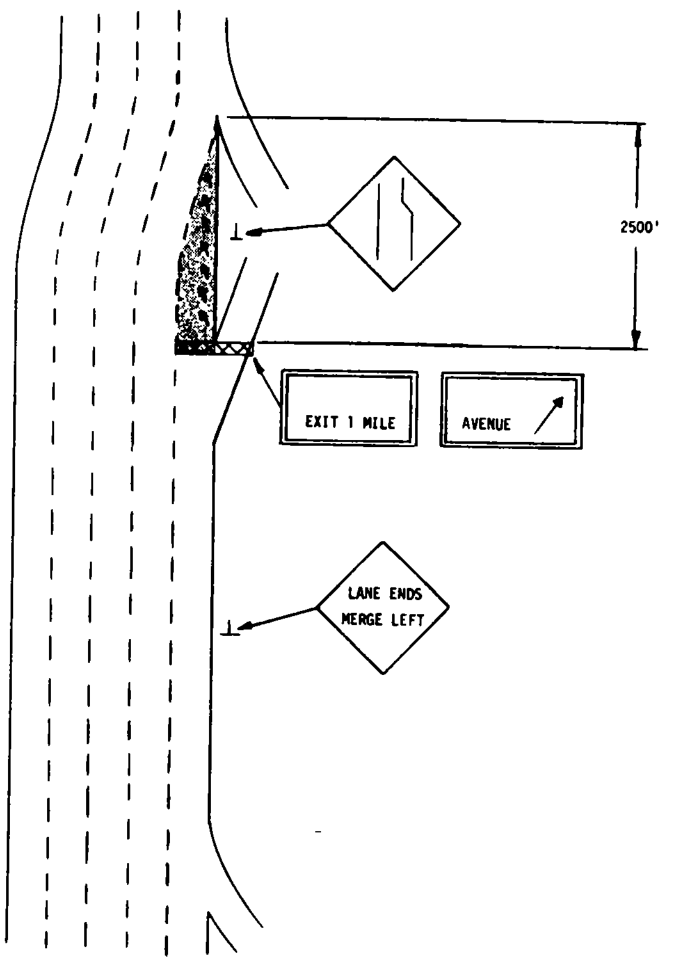


Figure 11. Site 17.

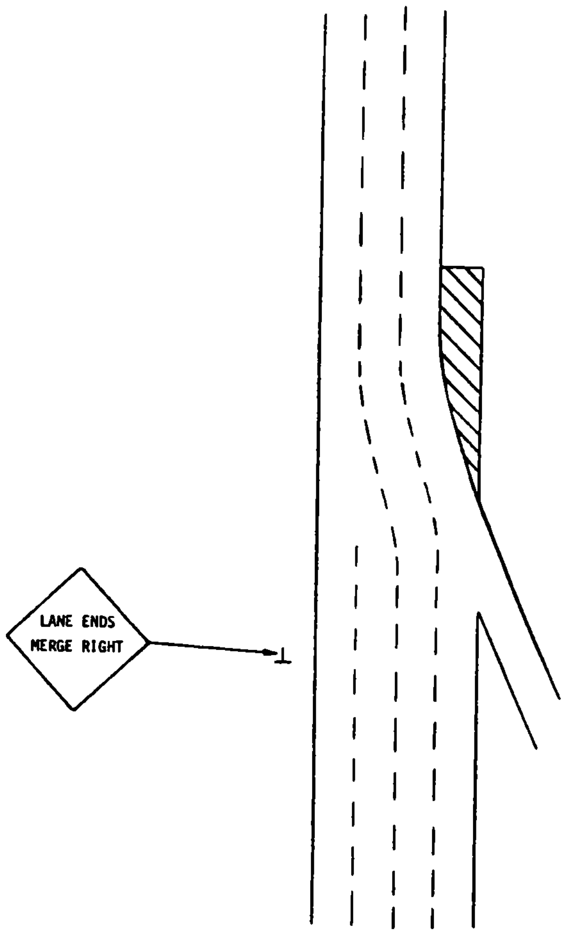


Figure 12 Site 65

add-drop lane from the through lanes only to find themselves trapped by the lane drop.

In general, add-drop lanes cause significant operational problems, possibly because drivers are unaware that the lane is a "special" one and not for through travel.

Drop-Add Situation

The drop-add situation occurs most frequently at major freeway-to-freeway interchanges As has been stated previously, the normal reason for this configuration involves the expected high volume of exiting and entering traffic at the interchange Theoretically, dropping a lane through the interchange is a good plan if the predicted volume distribution does split as intended, and if advance signing is adequate so that through drivers do not become entangled with exiting vehicles and end up on the wrong freeway. Because trucks and other slower moving vehicles are usually in the right lane, the engineer must be convinced from an operational standpoint that the benefits of dropping and adding a lane outweigh the disadvantages of moving the slower vehicles out of the right lane and back into the right lane on the other side of the interchange

Site 50, shown in Figure 18, suffers from an unfortunate volume split. A lane was dropped on the freeway northbound at the interchange to the other freeway because it was believed that a large percentage of the traffic would be exiting the northbound freeway at that point in order to use the other freeway However, for years the other freeway has remained incomplete and only a short section is operational Thus, fewer vehicles than predicted utilize that freeway, and more vehicles remain on the northbound freeway A peak-hour capacity problem has, therefore, developed on the reduced lane section through the interchange. A study at this interchange has been completed by the state highway department and construction has been approved to continue the lane through the interchange.

Enforcement of an operationally dropped lane is difficult to carry out but not impossible Two sites were judged bad because many drivers violated an operationl drop-add by remaining in the dropped lane, regardless of warning signs and pavement markings. It must be noted that, even though compliance with the lane drop restrictions at these sites was not total, general operations in the area improved However, because some operational lane drops do work well from a compliance standpoint, it appears that additional improvement in operations can be made at these sites.

Step-Over Situation

Generally, operations at step-over lane drop sites are no better, and many times worse, than the average lane drop site Step-over lane drops suffer from the same operational problems as other types of lane drops However, the situations that have required step-over lane drops to be built could probably be avoided. Two bad step-over lane drops (sites 29 and 46, respectively shown in Figs. 19 and 20), involve left-hand off-ramps. Site 46 is also at a tangent off-ramp, compounding the problem. The lane drops are placed so that it is difficult, if not impossible, to do an adequate advance signing job. This, combined with poor geometrics, allows for a very poor accident history.

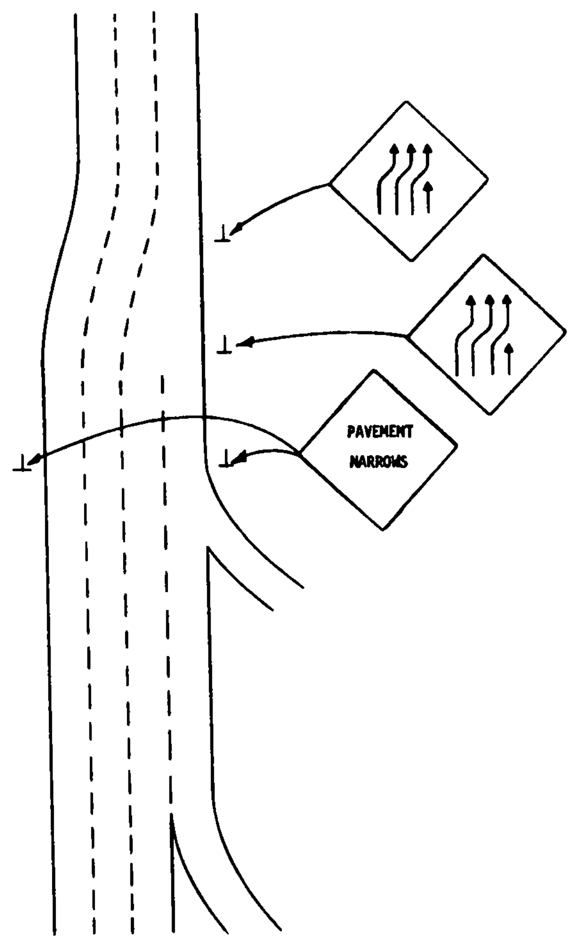


Figure 13. Site 13.

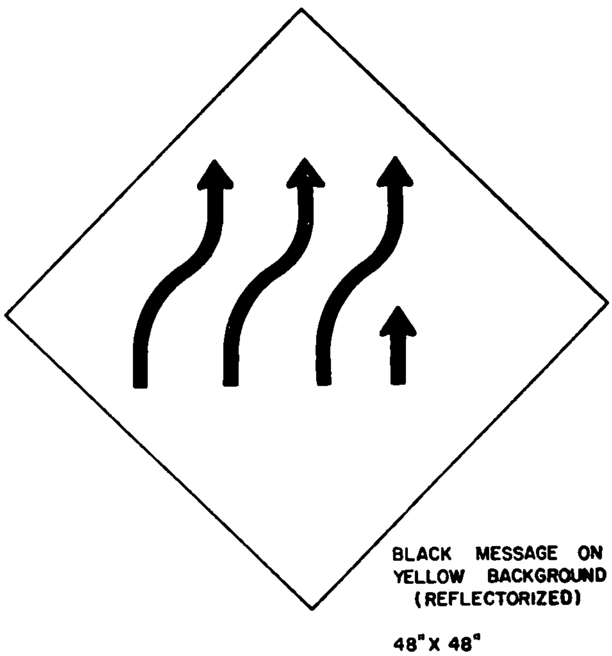


Figure 14. Newest design for lane drop signing.

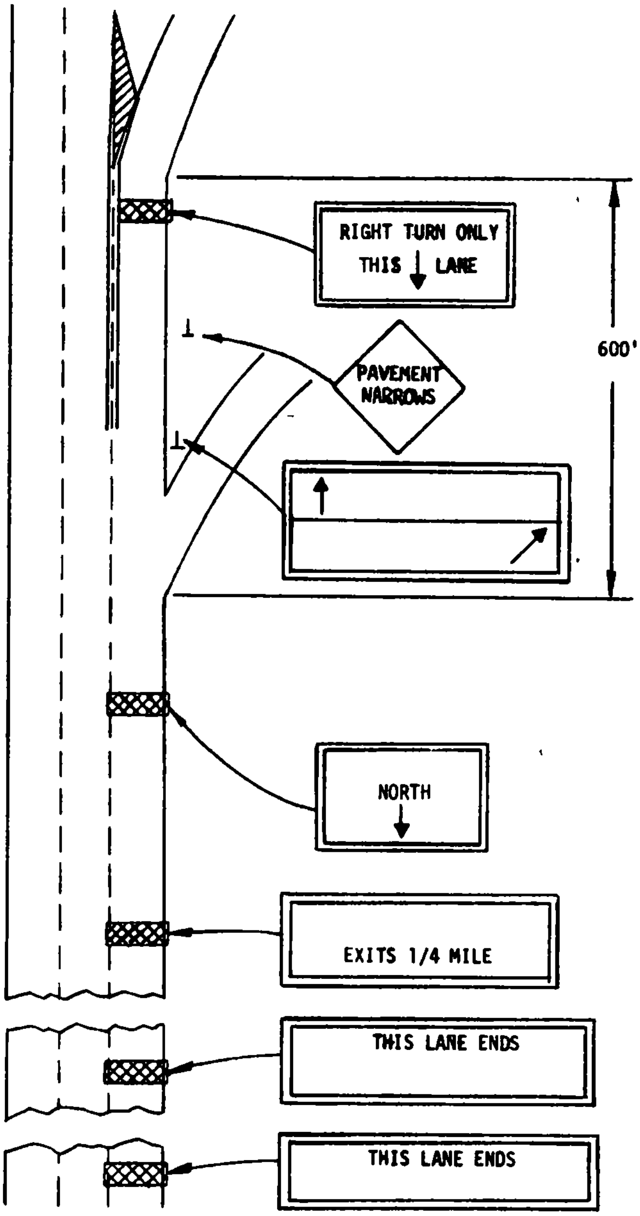


Figure 15. Site 34.

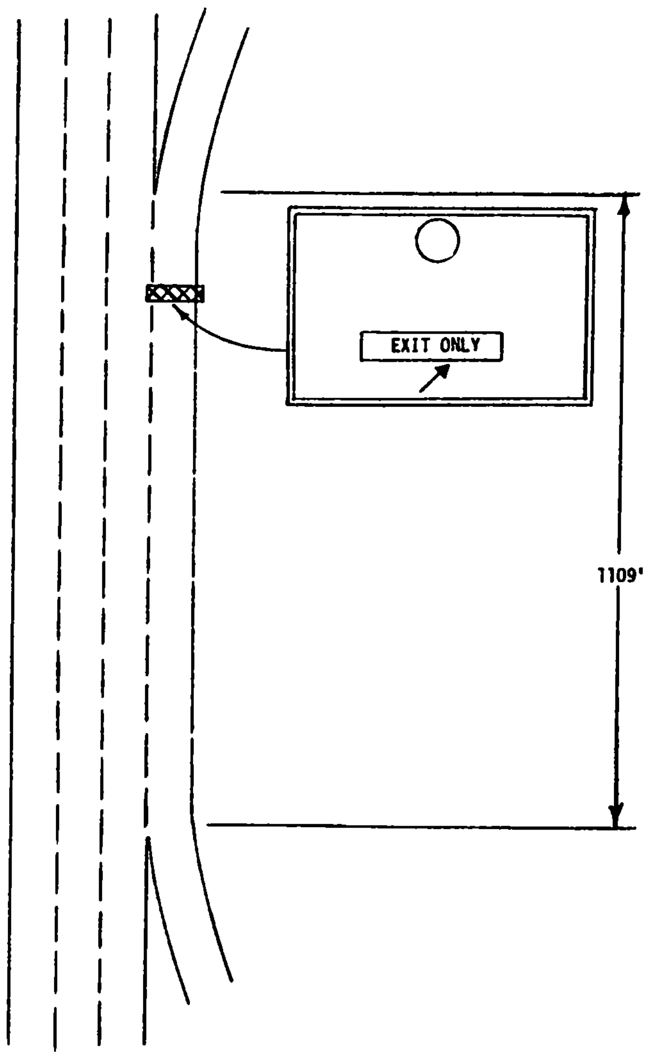


Figure 16. Site 24.

In another instance, two step-over drops were constructed to accommodate high-volume right-hand ramps. A lane was added on the left and all traffic was forced to move left one lane by means of changes in striping. The on-ramp traffic was given a "free" lane. Then shortly downstream, a high-volume off-ramp siphoned off right-lane traffic and the added left lane was dropped, which forced the two left lanes of traffic to merge. The sites were reconstructed in this manner because of geometric restrictions on the right; a weaving lane could have been added on the right. On one of the sites, a downstream restriction (a narrow two-lane bridge) prevented the added left lane from continuing. This section of freeway has a severe problem basically because of the high-volume ramps and insufficient weaving area. The forced lane drops do not work well because they are too close to the weaving section and not enough distance is available for adequate warning and smooth transition.

Lane-Split Situations

Operational problems at the few lane splits observed by the researchers indicate driver confusion over which route to travel and, in some cases, poor sight distance. Site 06, shown in Figure 21, has relatively adequate sight distance, but is a very complex interchange. Traveling eastbound on the freeway, the driver finds that the three left lanes exit onto a surface street just downstream of the interchange while the two right lanes split into an east-west directionally signed freeway that physically runs north-south at the interchange. Thus, a driver must be in one of the two right lanes in order to make an effective left-turn to travel north. Many last-minute maneuvers were observed by the researchers, including one in which a driver stopped his vehicle in the gore area and consulted a road map. This indicates that many operational problems at lane splits are not due to simple inattention to road signs.

The more complex problem at lane splits seems to be directional guidance. However, this is a problem which

needs an entire study to itself. In the present research effort, lane splits are treated briefly and in a manner comparable to other lane drops. Thus, lane splits are considered from a geometric design viewpoint with regard to sight distance, construction, and the like

Traffic Congestion-Related

When traffic demand exceeds the capacity of the freeway lane drop downstream, congestion and eventual breakdown occurs. From the observation of lane drop operations that approach freeway breakdown near lane drop locations, it appears that the most likely point of breakdown will be downstream of the lane drop rather than at the lane drop itself. Flow levels exceeding 2,000 vehicles per lane per hour for the lanes in the downstream section have been observed at lane drop sites. At those flow levels, some vehicles had difficulty finding acceptable gaps in order to move out of the dropped lane, but total breakdown did not result from such maneuvers. If freeway breakdown did occur at a lane drop site, the breakdown point was downstream of the actual lane drop, usually at the first ramp.

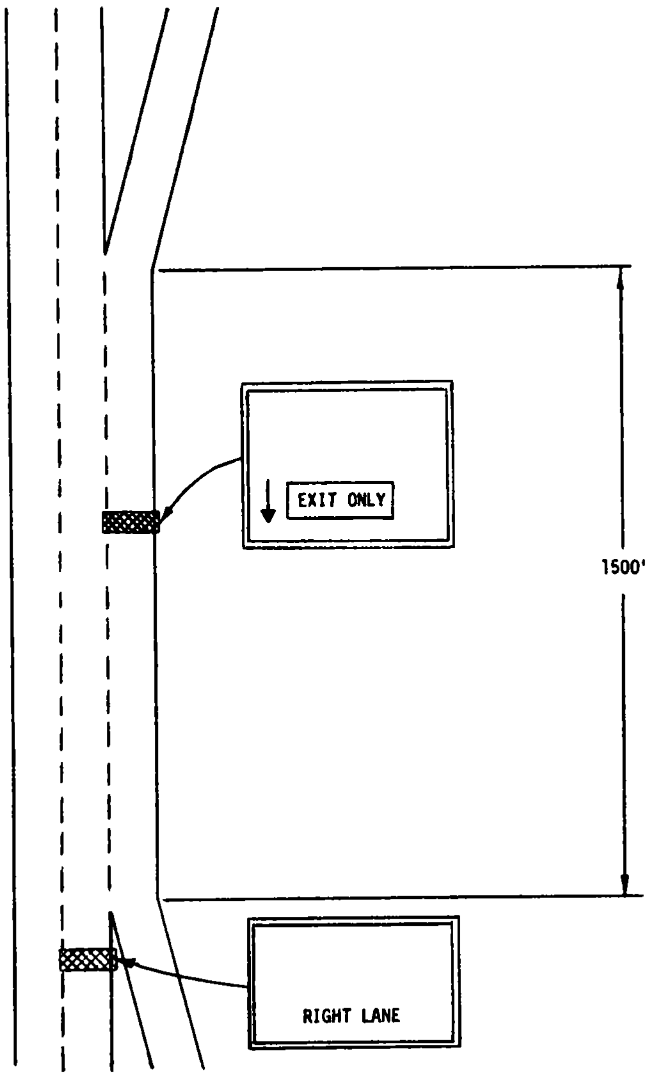


Figure 17. Site 37.

Driver Behavior-Related

A lane drop site may be a problem even though demand remains below downstream capacity. In general, an operational problem exists if a significant number of drivers make erratic maneuvers in the area of the lane drop. Erratic maneuvers include sudden speed changes; abrupt lane changes; and lane changes that require driving through a ramp gore area, an escape lane, or a lane drop taper. Some of these erratic maneuvers can result in unsafe conditions or even accidents, many may result in increased driver anxiety.

Although some of these maneuvers may involve a deliberate attempt by a driver to gain some advantage in traffic position, most maneuvers probably result from the driver's failure to recognize the requirements to negotiate the lane drop area until it is too late for him to reach his desired lane without making the erratic movement.

The requirements for negotiating a lane drop are (a) an awareness of an impending lane drop, (b) a knowledge of the location of the lane drop, and (c) an ability to decide upon an appropriate maneuver and the ability to execute the maneuver. When a driver is in the vicinity of a lane drop, the longer that information regarding these three requirements is withheld from him, the fewer the options he

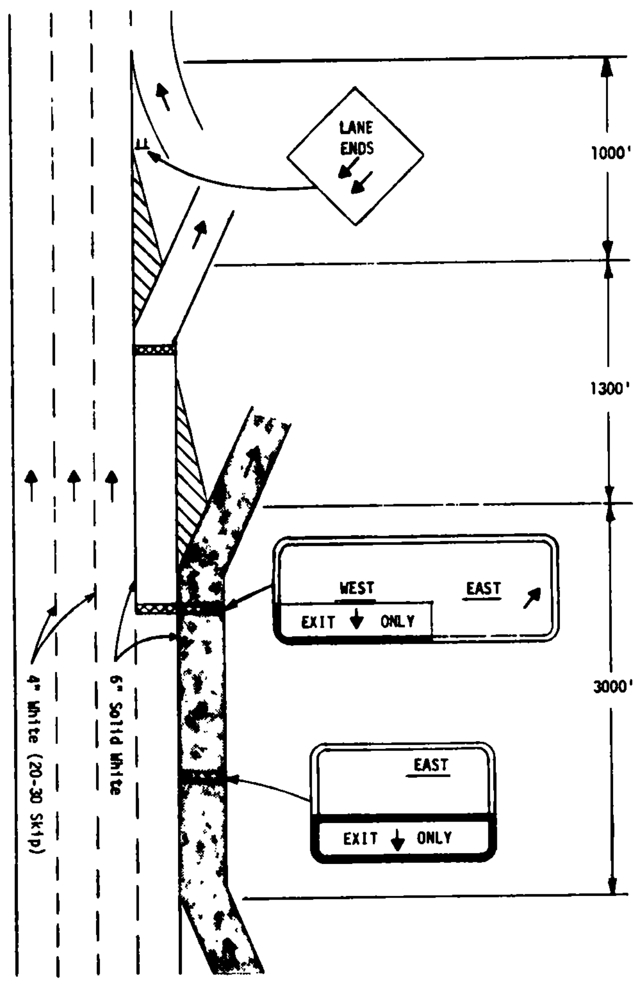


Figure 18. Site 40.

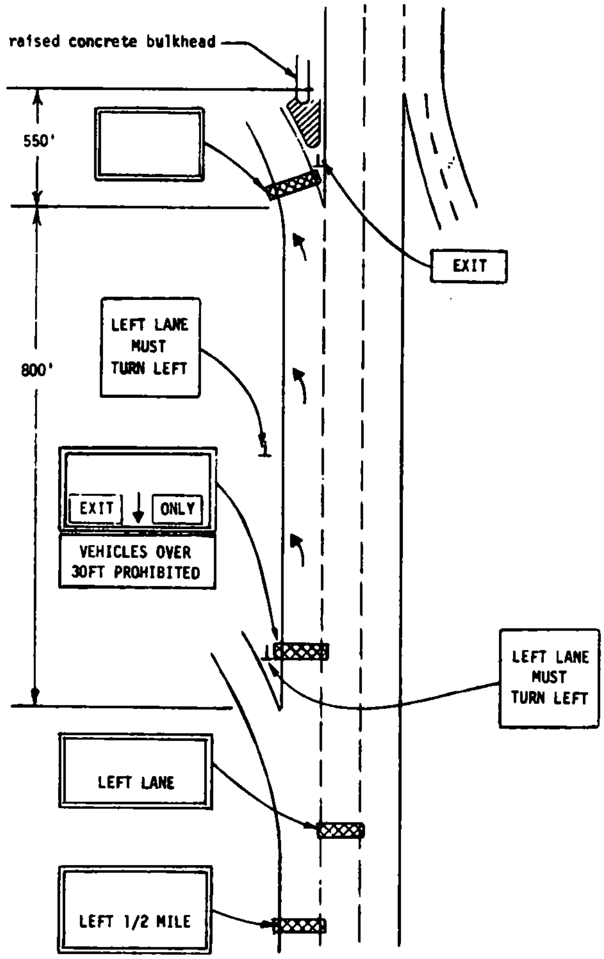


Figure 19. Site 29.

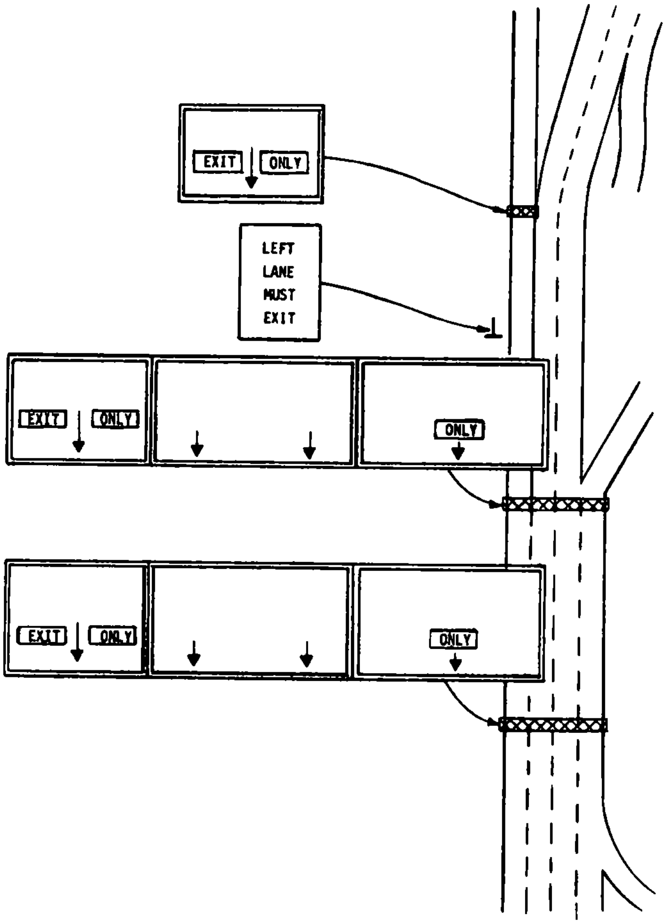


Figure 20. Site 46.

has for making a smooth transition through the area. Therefore, lack of important information necessary for negotiating the lane drop may be seen as the source of driver behavior-related operational problems at lane drop locations.

Solutions

Two solutions to congestion-related operational problems caused by demand exceeding downstream capacity are fairly straightforward, although not easy to accomplish. They are (a) to extend the lane until demand is reduced to a level below lane reduction capacity, and (b) to reduce upstream demand. The 1965 AASHO manual (*3*) indicates a design capacity of 1,200 vehicles per hour (vph) on suburban freeways and 1,500 vph on urban freeways. If the demand predictions hold true, then a lane can be dropped without creating a geometric bottleneck when demand reaches the design capacity volume of the downstream section of the lane drop location.

Solving operational problems caused by erratic driver behavior is not straightforward. Three requirements for negotiating a lane dop (i.e., indication of presence, indication of location, and indication of appropriate action) form the basis for design policy in the construction of the lane drop Once a decision has been made that the level of demand or geometric design constraints indicate a lane drop is desirable or necessary, then work can begin on the physical design of the lane drop, such as deciding where to place it, how to construct it, how to inform drivers of it. Solutions to the design of an effective, safe lane drop involve all of those aspects. The goal of lane drop design policy is to develop a lane drop that gives a driver the appropriate timely information necessary to allow him to make a smooth transition through the lane drop area.

Probably the most important factor in the geometrics of a lane drop is in designing its location such that it can be seen by drivers approaching the area The most direct visual cue a driver can receive is that of the roadway geometry itself, which shows him that the lane in which he is traveling either ends or leads him in a direction contrary to his intended direction of travel. Geometric conditions continuously provide the driver with cues that he uses to negotiate his chosen path of travel. Traffic control devices, on the other hand, can provide advance warning of the impending lane drop, enhancement of the visibility of the actual lane drop area, and directional information when a choice of traveled way must be made.

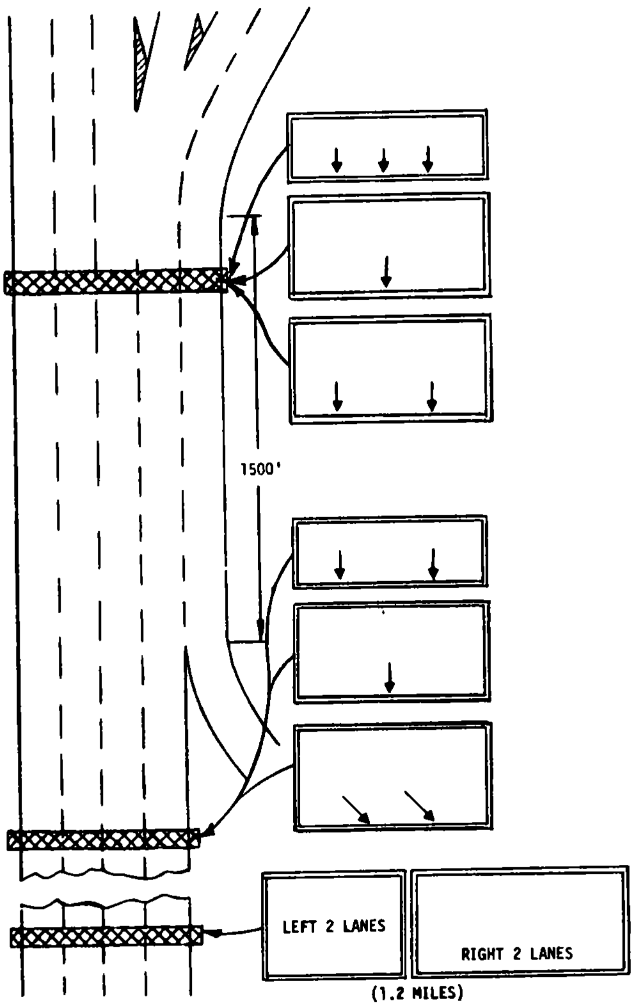


Figure 21 Site 06.

DESIGN PRINCIPLES

Eight principles of lane drop design have been identified. Discussion of the principles and their applications emphasizes the clarity with which geometric cues must be presented.

1. Provide continuous visibility—*The lane drop should be placed where the surface of the roadway remains continuously visible for a significant amount of time.* The first design principle indicates that roadway surface continuity is important because it provides the most reliable visual cue to the driver. Surface continuity stipulates that the entire roadway surface must be visible from the beginning of the lane drop to the end of the lane drop and must remain in continuous view as the driver traverses the section. In rolling terrain, a lane drop located just over the crest of a grade or just beyond a horizontal curve is not desirable because the visual cue is lost to the driver. On the other hand, a lane drop located at the end of a sag vertical curve or on an upgrade can be seen by the driver in time for him to take proper action even in the absence of appropriate advance signing

The distance required for a driver to (a) perceive that a lane is ending, (b) evaluate alternative courses of action, and (c) maneuver to an adjacent lane, if desirable, is the minimum distance that should be "in-view" to a driver approaching a lane drop. Perception-reaction times as reported in the *Transportation and Traffic Engineering Handbook* (*7*) can be as much as 3 to 4 sec for complicated situations. The AASHO standards (*3*) assume the perception time value to be 1.5 sec and the total of perception and brake reaction to be 2.5 sec. At a lane drop, brake reaction time is probably not appropriate because that is not a desirable reaction. AASHO also indicates that a normal lane change is accomplished at a rate of ⅓ sec per foot of lateral movement, or 4 sec for 12-ft lanes. An unforced freeway lane change has been observed to average 2 to 3 sec. However, it has been observed that lane changes associated with moving out of a lane drop situation average 7 sec Additional data are required before average maneuver time for leaving a lane drop is determined. If one assumes that under nonrestrictive conditions it is desirable to move all vehicles out of the lane before the beginning of the taper, or before the operational gore, the minimum surface continuity distance is:

$$\text{"in-view" distance} = \text{maneuver time} \times \text{design speed} \quad (1)$$

where in-view distance is the distance of surface continuity to the beginning of the lane drop taper or operational gore.

Some questions arise: Is in-view distance a practical parameter? Can a driver on a straight and level section of freeway see a lane drop nearly one-quarter mile distant? Can roadways be designed to accommodate a lane drop subject to such restraints? The answers to these questions should be explored in future research

2. Minimize attention-dividing conditions—*The lane drop should be placed away from attention-dividing conditions, such as ramps or complicated directional signing* This principle states that conditions that divide the attention of the driver should be minimized in a lane drop area. This improves the likelihood that the driver will concentrate on the roadway in front of him and that he will be required to make only one decision at a time.

Ideally, no extraneous attention-dividing conditions exist in a lane drop area; practically, this is nearly impossible to achieve in urban areas. Some common distractions include (a) additional ramps other than those directly involved with the lane drop, (b) directional signs requiring imminent decisions to be made downstream of the lane drop, (c) service information, and (d) warning signs pertaining to other geometric conditions. Site 07, shown in Figure 22, illustrates such distractions in the nature of a left-hand curve and several on-ramps, which interfere with the lane drop.

To achieve the objective of minimizing distractions from a construction standpoint, a lane drop should be built where the complete sequence of lane drop information can be given to the driver without interruption. Thus, if lane drop design standards indicate that advance signing for the lane drop should begin one-half mile upstream of the lane drop, no additional ramps or other distractions should be constructed within that distance.

3 Provide adequate transition cues—*The lane drop taper*

should allow for a smooth transition for drivers to make a lane change in the taper area and should provide adequate visual cues that inform the driver that his lane is ending. The third principle indicates that the taper should be long enough to allow for "fail-safe" maneuvers for drivers who enter the taper area with no prior knowledge of the lane drop, this may occur even at lane drops with well-designed visibility. A visually observable taper is probably the most reliable cue available for informing drivers of an impending lane drop

Stub-end lane drops and too-short tapers should be avoided Where a stub-end is desirable from a construction standpoint, it should be disguised by forming an artificial taper. This can be accomplished by covering upstream pavement with dirt and adding a removable-type curbing to form an appropriate taper A too-short taper is shown in Figure 23 Although the visual lane-ending cues are dramatic, the situation forces drivers to make undesirable panic lane changes or speed changes.

On the other hand, a too-long lane drop taper may cause a driver to miss important visual cues that tell him the lane is ending. At some unspecified point, called the closure threshold, a driver is unable to visually perceive that the lane is narrowing The threshold has not been established

Further research should be conducted to define the numerical range of the "happy medium" for a standard-length lane drop taper. Lane drops with a taper should be designed to provide a "fail-safe" factor in terms of the lateral rate at which a full-speed motorist is forced over by the pavement edge line. If a motorist has failed to understand the advance signs and special pavement markings, he should be led to merge gradually enough so that he and motorists in the adjacent lanes can safely adjust. In other words, the motorist who for any reason is unresponsive to all else may be guided by the edge line (right or left). It may also be desirable to create a buffer zone beyond the edge line before the errant driver reaches the actual edge of the pavement and/or shoulder.

4. Create lane drops on better freeway side—*The lane drop should be placed on the better side of the freeway for given traffic and geometric conditions.* This principle addresses whether to build a lane drop taper on the left or the right. There seems to be no definitive answer to this question. One argument states that the left-hand drop is advantageous because (a) the left two lanes usually carry less traffic, (b) it is away from the influence of ramp turbulence on the right, and (c) vehicles generally flow at a more uniform speed in the left lanes because there are few slower commercial vehicles The opposing argument states that

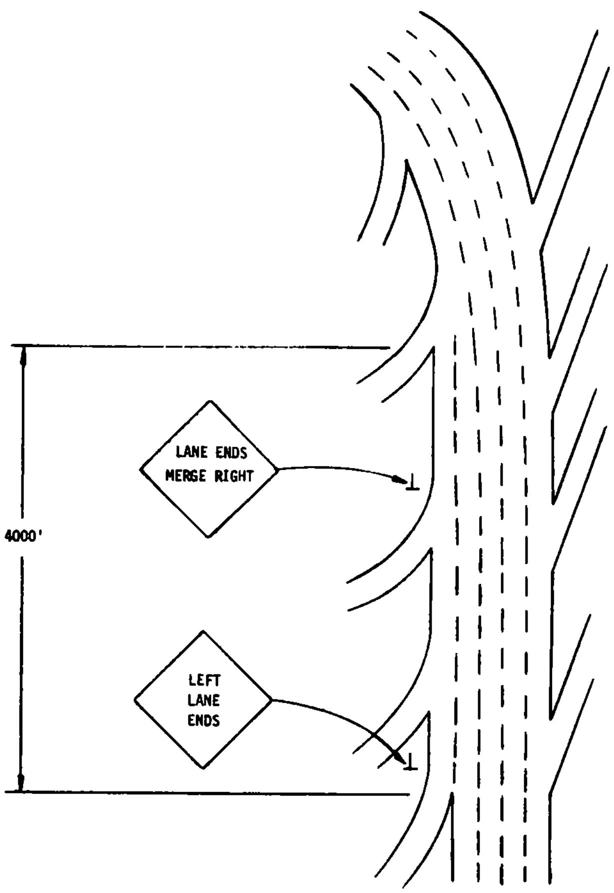


Figure 22. Site 07.

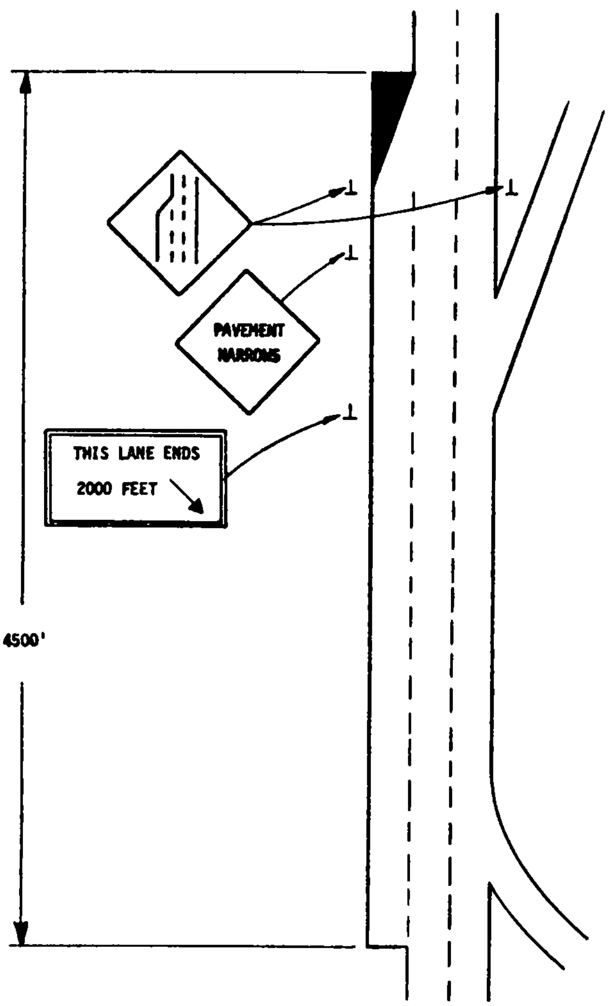


Figure 23. Site 11.

the right-hand drop is advantageous because (a) drivers are accustomed to having lanes (i.e., acceleration lanes) end on the right and they can merge better from right to left than left to right, (b) traffic is generally slower in the right lanes and would make the merge at slower speeds, and (c) the right lanes usually carry less traffic.*

* Driver lane preference seems to be a regional phenomenon Several states have laws that make it mandatory to remain in the right lane except to pass, others do not Thus, some areas experience different lane distributions than others

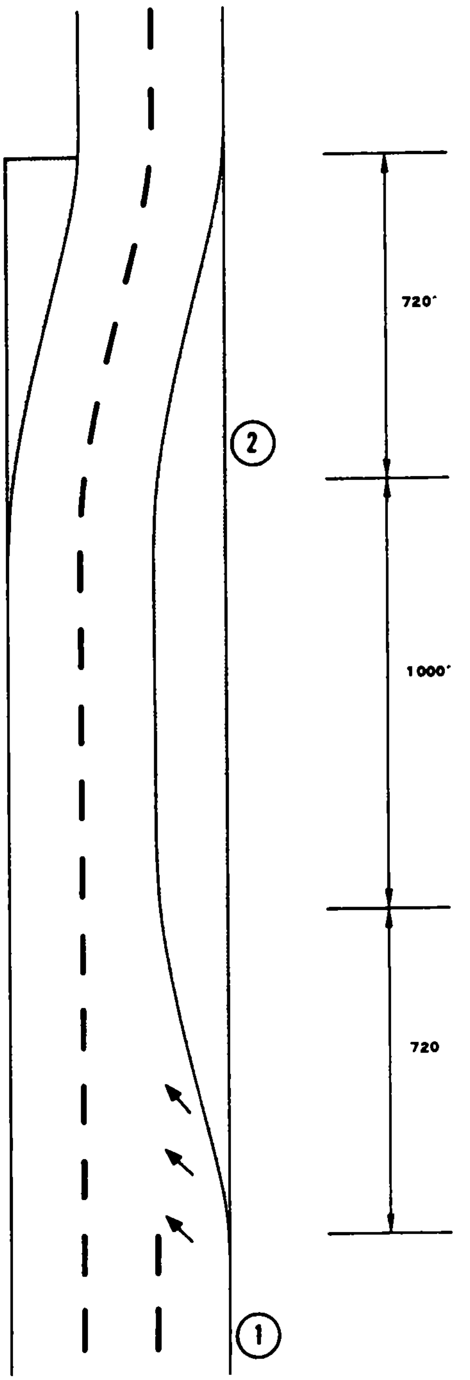


Figure 24. Disguised continuing pavement at an operational lane drop.

To help determine which lane to drop from a freeway, the following factors should be considered:

1. What type of lane distribution is expected? It is preferable to merge the two most lightly traveled lanes.
2 What type of traffic composition is expected? If a large percentage of heavy trucks or recreational vehicles is expected, consideration should be given to merging the two left lanes.
3. What other geometric features, such as ramps, are nearby? Lane drops generally work better away from the influence of ramp turbulence.
4. Will the sight distance be significantly better on one side than the other? Sight distance is always critical.
5. Will it be more difficult to sign a lane drop on one side than the other? Appropriate signing can significantly improve a bad situation.

By examining these factors, an engineer can then make a reasonable judgment concerning which side of the freeway should have the lane drop.

5. Coordinate visual and operational drop—*The lane should appear to end on the same side of the freeway as the operational lane drop.* In some cases it is physically advantageous, yet not operationally desirable, to drop a lane on a particular side of the freeway A case of this sort can occur when the dropped lane has a high probability of future continuation, as in site 17 (see Fig. 11) From a construction viewpoint, it is desirable to drop the left lane by stubbing off the pavement However, from an operations view, this handling of a lane drop is far from optimum. To correct the situation, merging the right two lanes is accomplished through striping and signing. (Appendix C describes the results of such a change in markings.) Theoretically, this solves the problem; practically, the results of such situations are less than optimum For example, such treatment sets up a right-of-way problem for two drivers

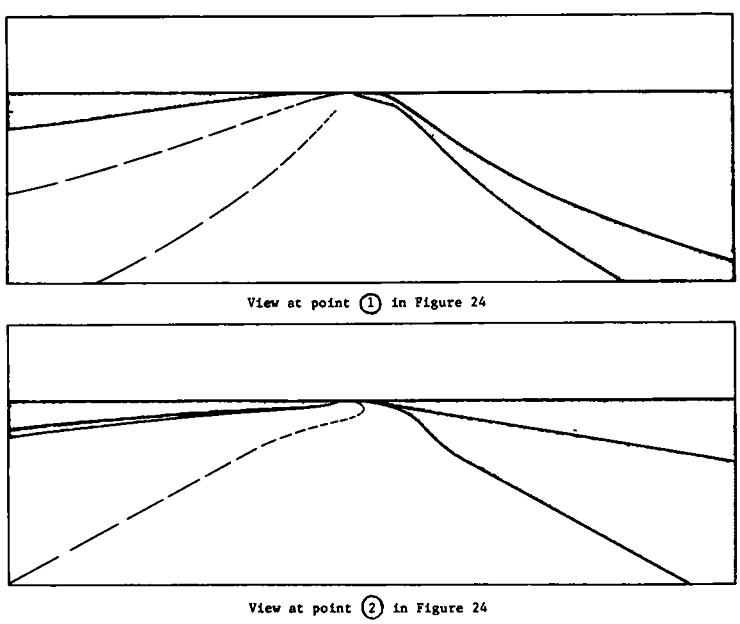


Figure 25. Perspective views of the lane drop situation shown in Figure 24.

who arrive simultaneously at the lane drop and also results in the loss of valuable information cues. A practical solution to this problem should be sought.

A design solution to the problem has been proposed by the California Division of Highways and is shown in Figure 24. To a driver approaching this lane drop, the visual cues from the shoulder of the freeway indicating an impending lane drop are seen at point 1 on the illustration. At point 2 the driver only sees a slight curving of the roadway alignment. Ideally, point 2 and point 1 should not be in view simultaneously. Figure 25 shows perspective views from points 1 and 2 shown on Figure 24.

The main requirement for placement of the operational lane drop is the undetectability of the physical lane drop Even repeat users should not be readily aware of the occurrence of the physical lane drop; this is the one lane drop that should be hidden. The operational lane drop should be constructed so that the lane looks as if it is ending. This may be accomplished through the use of a temporary curbing, filling in the unused pavement with dirt, or making the surface similar to the shoulder treatment The downstream drop can be stubbed-off and treated in the same manner. This technique obviously requires the laying of pavement and then not using it, but the increase in operational efficiency more than offsets the cost of the unused pavement. The "after" configuration described in Appendix D is a good example of how a bad situation can be improved by disguising the physical drop from the operational drop.

6. Provide adequate escape area—*When a lane drops at an exit ramp, an escape area of adequate dimensions should be provided to allow for a smooth transition into through lanes.* The sixth design principle defines the nature of the escape area as just that—an area for merging into the through lane once the driver is too close to the exit gore to make a normal lane change

Figure 26 shows a plan view and a perspective view of a suggested exit ramp lane drop configuration. There is a definite indication that the lane is not continuing past the interchange, but the configuration does allow a driver to safely change to a through lane even if he does not begin his lane change until entering the operational gore area, which should be plainly visible to the driver. The shoulder has been eliminated at the physical gore, to be picked up again as the pavement tapers

A full acceleration lane is not needed because the driver is probably traveling at or near freeway speed. A full lane width plus shoulder width can confuse the driver by providing too wide an area. From a construction standpoint, it may be desirable to stub off the pavement at the gore and allow traffic to use the shoulder as the escape area This is reasonable if pavement markings resembling a taper can be made permanently as visible as a pavement taper. The ideal taper length has not yet been determined for this situation, but it is reasonable to hypothesize that the taper should begin at the physical gore and should resemble a standard taper.

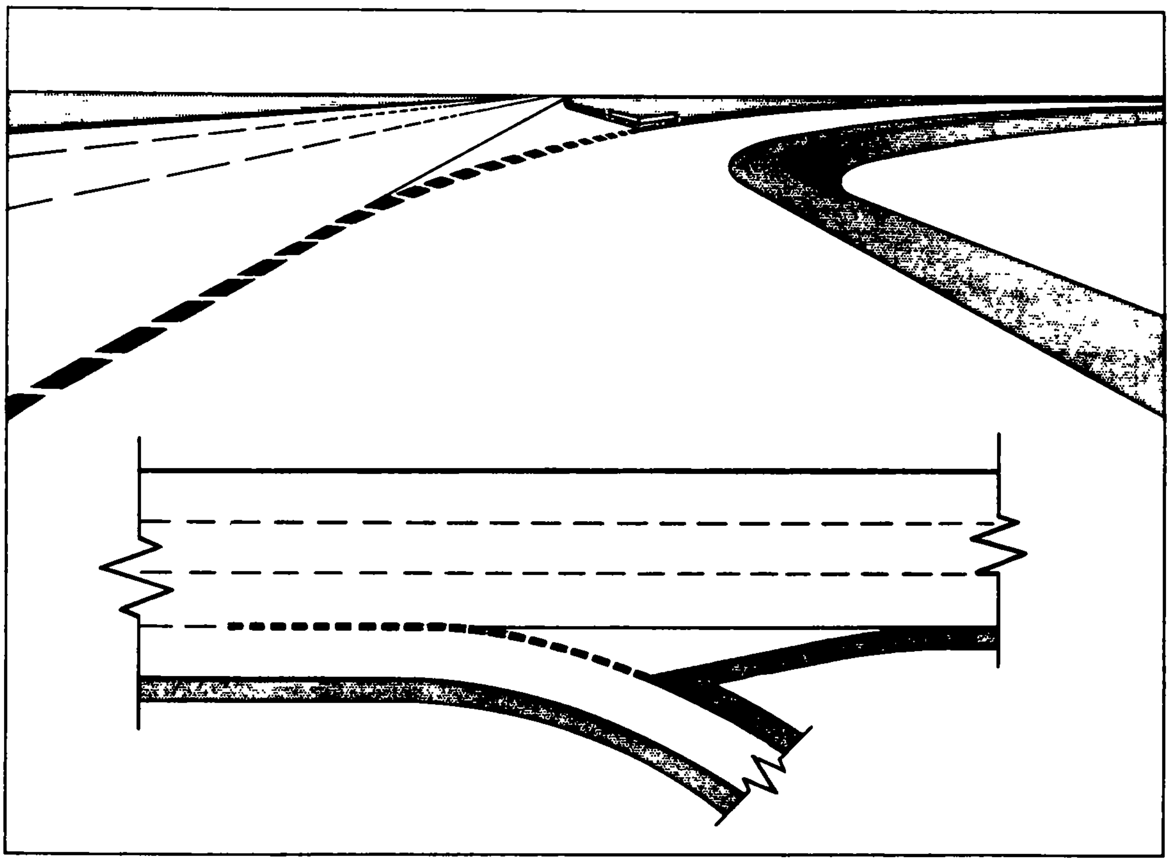


Figure 26. Perspective and plan views of an exit ramp lane drop

7. Notify driver that lane is not continuous—*When a lane is added at an on-ramp and dropped at a nearby off-ramp, the entering drivers should be notified that the lane they are traveling in is not a continuous lane for through travel* The seventh principle pertains to add-drop lanes used when an on-ramp/off-ramp pairing warrants an additional lane for weaving and capacity through the section. However, steps should be taken to inform drivers entering the freeway at this point, as well as informing the through traffic, that the lane is only a temporary addition to the freeway. Traffic control devices (TCDs) must perform the information function when sight distance restrictions prevent drivers from observing the lane drop from the lane add point. These conditions are shown in site 62, Figure 27

Normal lane lines should not be used to delineate the two adjacent lanes because they would reinforce the concept that a through lane has been permanently added Instead, the special lane should be as different as possible from the through lane. Three methods accomplish this: (a) contrasting pavement, (b) special-purpose lane delineations, and (c) signing. Ideally, some combination of these methods would be used. Figure 28 shows several warning methods that can be employed at an add-drop location. Views B, C, and D give the message that this is

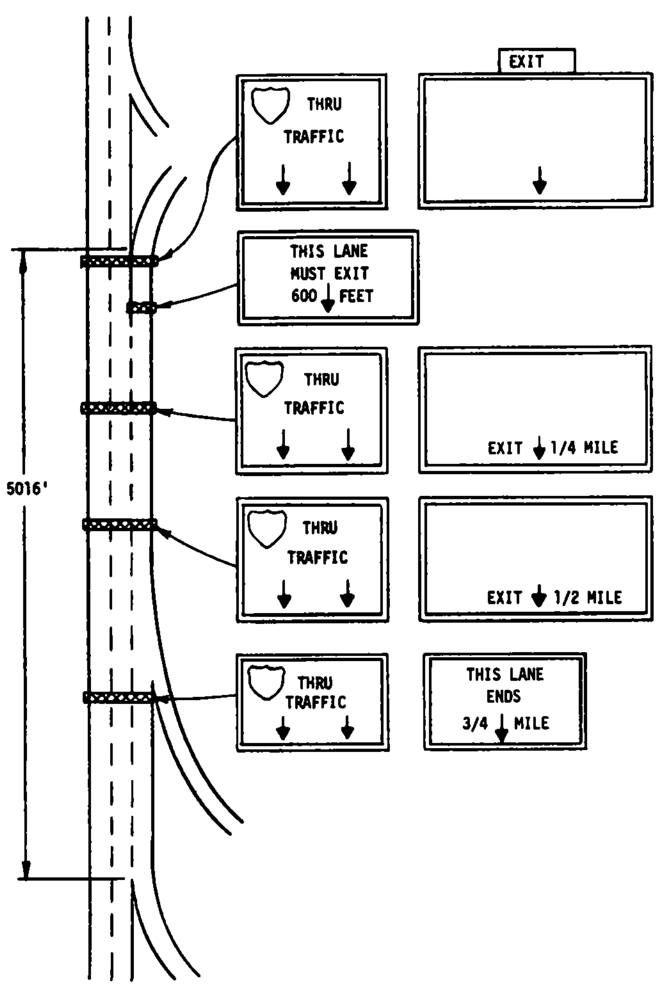
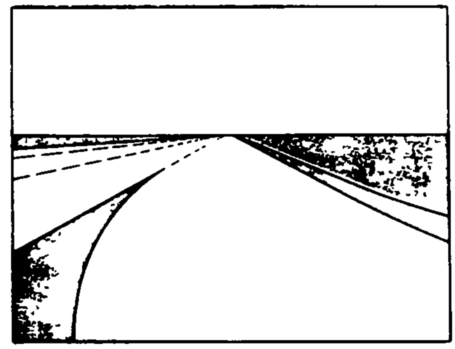
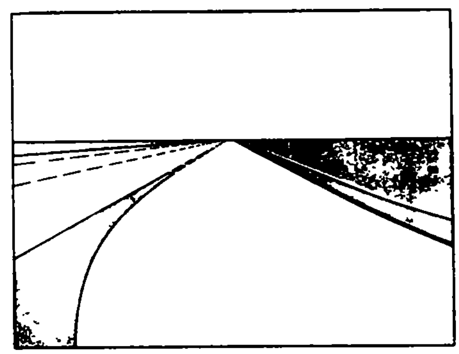


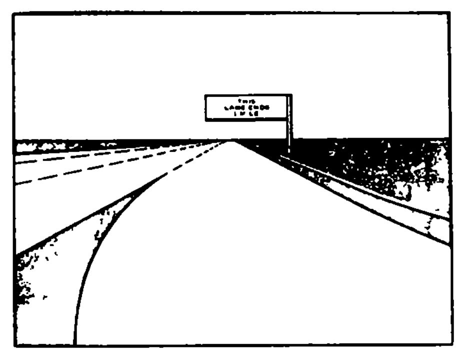
Figure 27. Site 62.



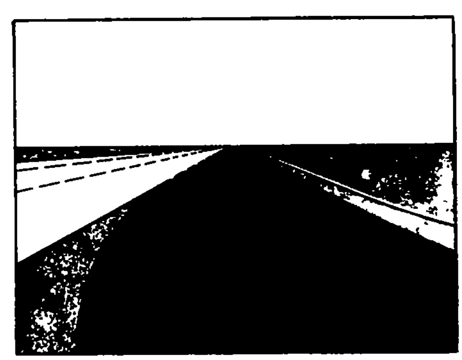
A. No warning device: Normal lane lines



B. Warning device: Special lane lines



C. Warning device: Black-on-yellow over-head sign



D. Warning device: Contrasting pavement

Figure 28. Warning information systems at lane add-drop locations.

a special lane Additionally, an add-drop lane should have normal minimum sight distance to the lane drop gore and an escape area, as previously described.

8 Use adequate traffic control devices—*Consistent and appropriate traffic control devices (TCDs) should be used in advance of a lane drop.* The last design principle indicates that consistent and appropriate traffic control devices should be used in advance of a lane drop. The package of traffic control devices used at a lane drop should inform the driver (a) what is going to happen, (b) where it is going to happen, and (c) what he should do about it.

At the present time, many sites have incomplete or misleading information The driver may be told to merge left but, in actuality, the other lanes may move into his lane, such as in the situation where a lane is operationally dropped on the opposite side of the freeway from the physical drop. At some sites where a right-hand lane drop occurs, messages such as SLOWER TRAFFIC KEEP RIGHT appear just prior to the lane drop. Occasionally missing information is detrimental to lane drop performance. For example, a simple ROAD NARROWS sign does not inform the driver of two very important facts: (a) it does not tell him how far before the road narrows, and (b) it does not tell him whether he is supposed to change lanes. Devices should not confuse the driver with additional information unrelated to the task of traversing the lane drop section.

Obviously, different TCD packages are necessary for different lane drop situations. The manual (*6*) designates four lane drop signs; however, over 50 significantly different lane drop signs have been observed in twenty metropolitan areas visited during the conduct of this project, and that does not even begin to consider the combinations and placement variations put into practice.

CHAPTER THREE

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Safe driving consists of managing a vehicle in its committed zone to avoid obstacles. A vehicle's committed zone is the area in which the driver is committed to travel based on current velocity and deceleration characteristics and geometric constraints. This task can become quite complex when there is impairment of the driver's ability to predict, or to anticipate, what lies ahead Driver expectation can be impaired by loss of vision due to fog, snow, rain, dust, or by missing or misleading visual cues. Highways must be designed to provide visual cues sufficient to make up for these losses, often through the use of traffic control devices. The driver has learned to expect certain visual cues far enough in advance of hazards, or potential hazards, to enable him to safely manage his committed zone and avoid contact with obstacles.

There are only two things drivers can do to alter their committed zone: change direction or change speed. A safe trajectory is considered to be one that reveals that the driver has seen the available visual cues, has correctly interpreted them, and has adjusted his path smoothly and well in advance of the obstacle. The driver's trajectory should be such that there is evidence he was not taken by surprise and that he was able to allow a comfortable margin for error without having to adjust his speed.

Field observations at over 60 lane drop sites have led to the conclusion that lane drops that operate successfully have resulted in safe motoring trajectories, while lane drops that do not operate successfully reveal the opposite types of motoring trajectories—namely, abrupt path changes as well as changes that occur closer to the obstacles, often accompanied by speed changes.

It is not unexpected that many drivers appear to be surprised or confused at lane drops. Although lane drops have been classified in five basic design categories, over 50 different signs have been observed as well as so many different combinations of TCDs that almost no two sites have the same treatment.

From the analysis of site observations, discussions with engineers in many state agencies, and at meetings of AASHTO, ITE, and TRB, a set of principles for the design of lane drops have been developed. The design principles have been translated into tentative application procedures, but further experiments are needed to test these procedures.

SUGGESTED RESEARCH

Further research will be required to translate design procedures into practical procedures for implementation. For example, several different values of taper length and ratio have been proposed; experiments to determine the minimum and maximum taper values would be desirable. Also, many different traffic control device treatments are in use for each lane drop category; properly designed experiments should be conducted to select the best treatments for each category. Other items that need testing include the length and width of escape areas at exit ramp drops, the best locations for warning signs, and the best location for the operational taper if it is to be on the opposite side of the roadway

from the physical lane end In addition to developing criteria for ideal lane drops and new construction, methods for improving existing conditions are needed.

Additional basic research is needed into driver reaction and the time needed for lane changing at freeway lane drops, sight distance requirements for advance warning signs and for pavement markings, and enhancement of taper and gore marking visibility.

The ideal method for conducting lane drop research would be to collect detailed field observations on existing lane drop sites at which conditions can be controlled, and to continue an iterative process of making small changes in the sites and measuring the resulting changes in traffic operations. However, this approach is impractical both from a cost standpoint and the risk involved for highway users. Additionally, it is impossible to control essential conditions such as weather, seasonal shifts in driver population, and nearby distracting geometric conditions, such as ramps.

A more practical approach involves collecting field data to support the development of some of the basic hypotheses and, concurrently, conducting a series of laboratory experiments to test these hypotheses The laboratory experiments can also be used to compare a large range of solutions to specific problems and to select that alternative which appears most promising for field application

An objective procedure is needed for evaluating traffic operations at lane drops so that the engineer can measure the effect of any changes he may implement and determine how a site compares with others of its type In this regard, variations in lane change behavior and in the rate of erratic maneuvers are the most important differences in traffic operations among lane drops.

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3. American Association of State Highway Officials, *A Policy on Geometric Design of Rural Highways* (1966).
4. American Association of State Highway Officials, *Highway Design and Operational Practices Related to Highway Safety.*
5. Federal Highway Administration, *Handbook of Highway Safety Design and Operating Practices* (1968)
6. Federal Highway Admin , *Manual on Uniform Traffic Control Devices* (1971).
7. Institute of Traffic Engineers, *Transportation and Traffic Engineering Handbook* (1965).

A-1

APPENDIX A - A SAMPLE OF LANE DROP SITES ACROSS THE COUNTRY

Sixty-five freeway lane drop sites were selected for inclusion in this study The purpose of this appendix is to document the study sites visited and to provide a compendium of existing lane drop configurations The schematic drawings are not to scale The Appendix is organized by lane drop category.

CLASSIFICATION AND GRADING OF FIELD DATA OBSERVATIONS

A rough three-grade scale was developed to rate the relative effectiveness of the sites observed. The factors used in the grading scheme included (1) the number and severity of erratic movements, (2) lane change behavior, (3) speed change behavior, (4) opinions of state and local highway engineers, and (5) amount of citizen complaint regarding the site. A site was judged good if the number of erratic movements seemed small, most lane-changing was accomplished in advance of the taper or gore area, and highway engineers thought that the site was not presently a problem. A site was judged passable if no serious problems occurred, but indications of problem-producing maneuvers were frequent A site was judged bad if many erratic movements were observed, if congestion was apparent in the lane drop area even if the general area was flowing at below capacity, or if highway engineers or citizens expressed opinions of serious problems.

A-2

It must be remembered that some sites are considered problems because they are peak-hour bottlenecks If the traffic demand at peak-hour is above downstream capacity, the lane drop will become congested regardless of how it is designed In cases where such a condition exists, the site was observed in off-peak-hour operation If it worked well under these conditions, the site was judged good regardless of the fact that during peak-hour operation breakdown occurs in the vicinity of the drop

Each of the 65 sites observed and catalogued in this appendix was given a grade and categorized into one of the five basic lane drop types described in the previous report body The categorization scheme is not necessarily all-inclusive or mutually exclusive A few lane drops will defy being classified into any of the five categories, a few lane drops will fit more than one category However, most lane drops can be effectively classified into one category The sight distance at a site is taken from the point where the actual (operational and/or physical) lane drop is visible to an approaching driver

A-3

TYPE A -- OUTLYING DROP SITUATIONS

Site 38

, Type 3 - 2 left

Sight Distance 5 mile

Vertical Curvature Level

Horizontal Curvature Tangent

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3 No Counts Available

Lane 4

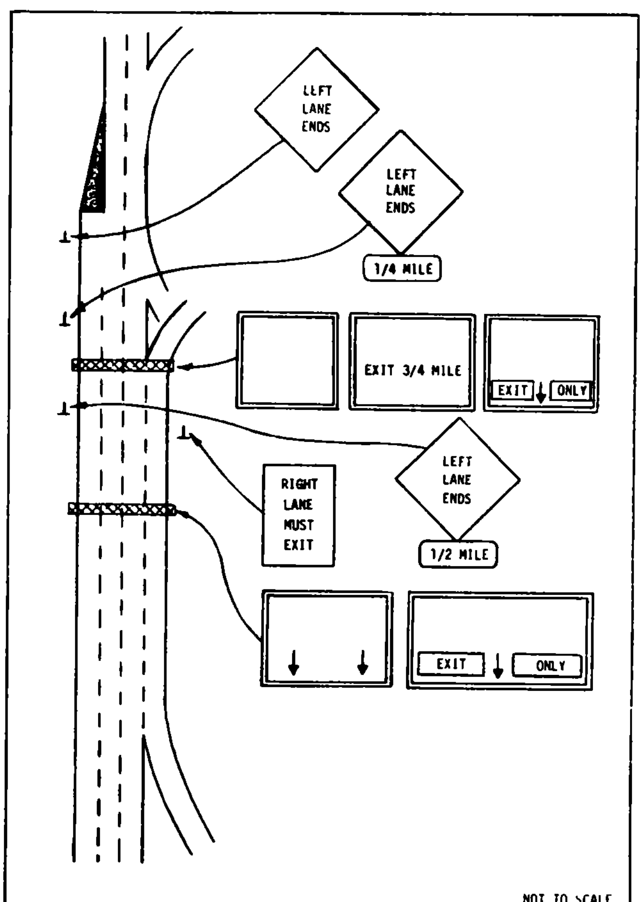
Lane 5

Accident Experience Light

Operational Characteristics A few vehicles use the taper area to make their lane change Taper area is rather short Traffic volumes are fairly light Lane drop works well under present traffic volumes

Figure A-1

A-4



A-5

Site 39

, Type 3 - 2 left

Sight Distance 28 mile

Vertical Curvature Level

Horizontal Curvature Tangent

Pavement Type Concrete

ADT

One-Way

Two-Way 29,878 (1972)

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3 No Counts Available

Lane 4

Lane 5

Accident Experience Light

Operational Characteristics Traffic volumes were fairly light Most traffic was out of the lane well before the taper area Lane drop works well under present traffic volumes

Figure A-2

A-7

Site 19

, Type 4 - 3 Type C - Right

Sight Distance Over 1 mile

Vertical Curvature 7 miles upstream beginning of long downgrade

Horizontal Curvature 2 degrees left

Pavement Type Concrete--upstream / asphalt--downstream

ADT

One-Way 58,000

Two-Way

5-Minute Count Time - 4 45 P M

Total 357

Trucks 13 , Percentage 3 %

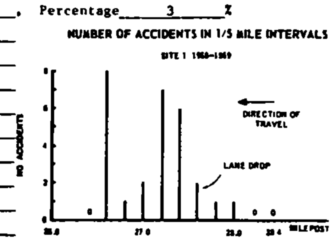
Lane 1 36

Lane 2 89

Lane 3 103

Lane 4 129

Lane 5

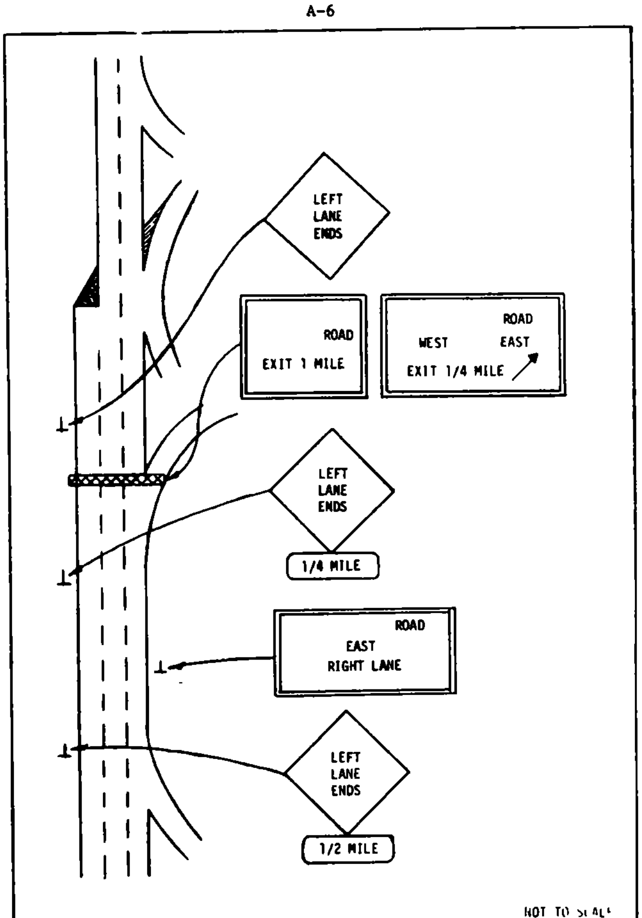


Accident Experience

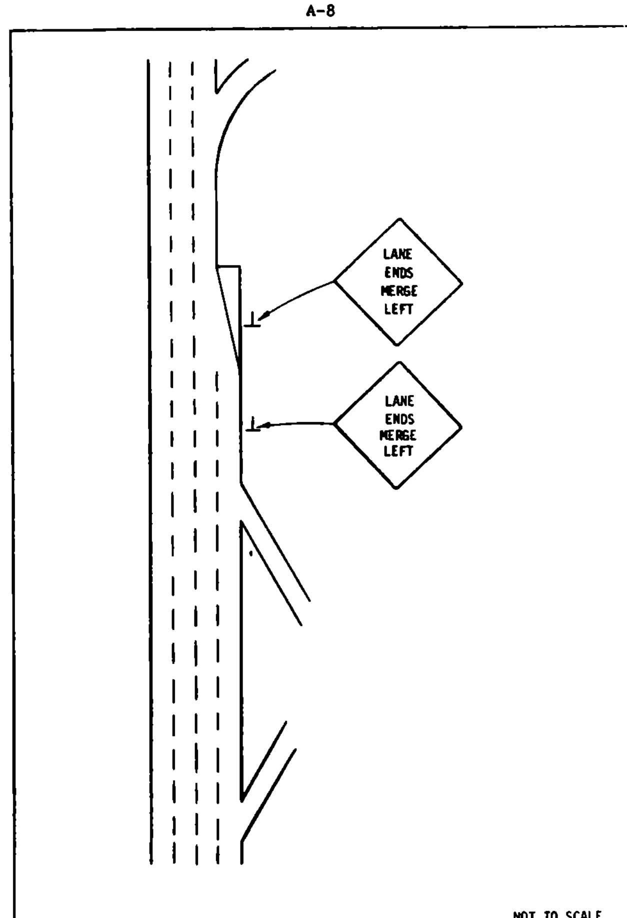
Operational Characteristics The speeds in each lane remain approximately constant until two-thirds of the way through the lane drop taper where a gradual line decrease in speeds is observed. This uniformity in speed decrease in all lanes suggests that the cause of decrease is not the lane drop itself but rather a geometric feature (the leveling out of a long downgrade) The movement of vehicles out of the drop lane can be seen to be smooth and gradual with almost no cars in lane 1 near the end of the taper

Figure A-3

A-6



A-8



A-9

Site 17

, Type 5 - 4 Right

Sight Distance 700'

Vertical Curvature Slight upgrade - beginning 3,300' upstream and cresting 700' upstream

Horizontal Curvature Straight

Pavement Type Concrete

ADT

One-Way 160,000

Two-Way

5-Minute Count Time - 3 30 P M

Total 771

Trucks 18, Percentage 2 %

Lane 1 66

Lane 2 162

Lane 3 149

Lane 4 138

Lane 5 159

Ramp 97

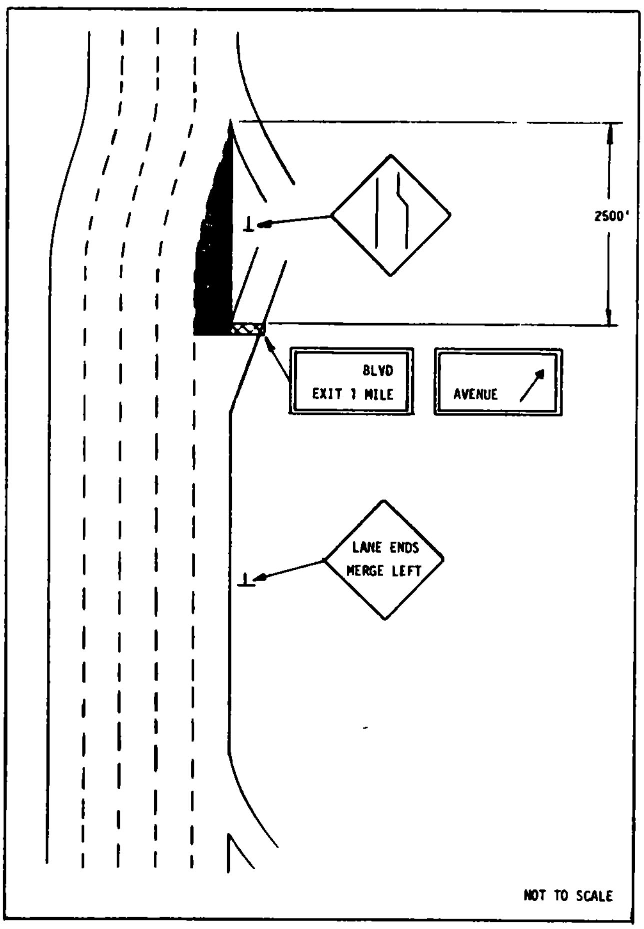
Accident Experience Lane drop was installed June of 1972 No information available yet

Operational Characteristics Site does not work very well Many vehicles do not respond until lane drop is visible, some 700' before the end of the taper Some drivers never move out of right lane since they know the pavement continues

Site was changed to an exit lane drop in late January 1973 It is reevaluated with this configuration in Appendix C of this report.

Figure A-4

A-10



A-11

Site 65

, Type 4 - 3 left taper

Sight Distance

Vertical Curvature level

Horizontal Curvature right - hand curve beginning 3 miles upstream of right lane end

Pavement Type Concrete

ADT

One-Way

Two-Way 53,000

5-Minute Count

Total

Trucks, Percentage %

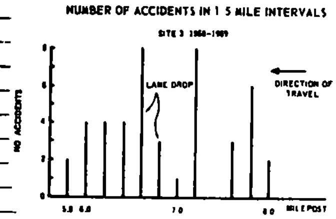
Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

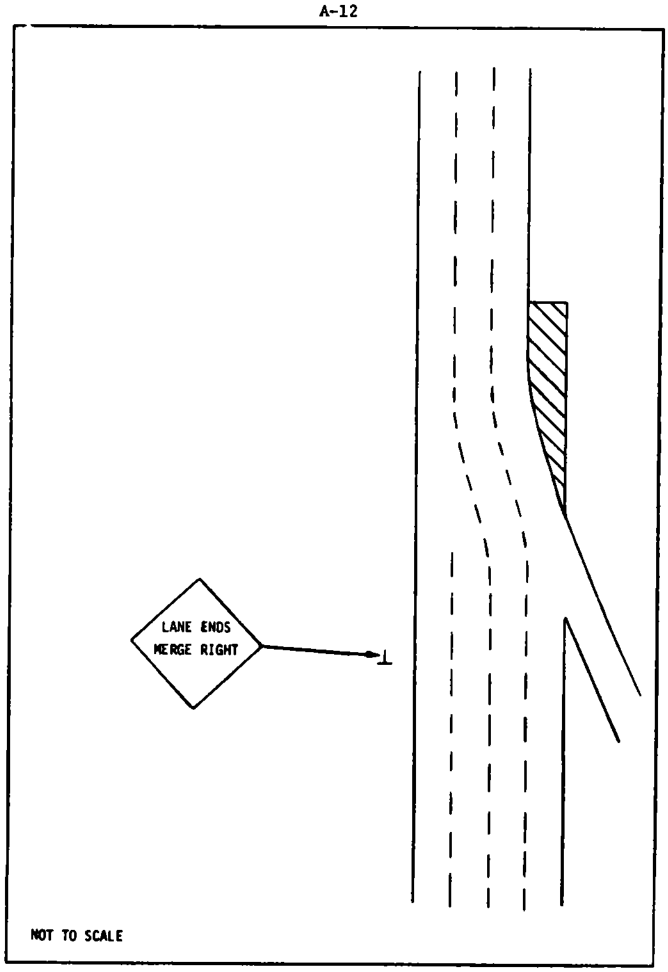


Accident Experience

Operational Characteristics The results for Site 65 , in which lane 3 is merged into lane 4, show a uniformity of behavior at all flow levels. The two lanes that merge at the lane drop show a severe decrease in speeds, however, lane 1 has virtually no speed drop and lane 2 drops only slightly The disturbances in speed in all lanes increases as the flow increases The traffic flow rate curves indicate that vehicles in lane 4 follow the signing and start to merge right upstream of the lane drop, then are forced back to the left by the pavement markings in the lane drop taper area Flows in lanes 1 and 2 remain relatively undisturbed, except for the influx of a very few vehicles from the on-ramp upstream of the lane drop The slight speed increase in lanes 1 and 2 at the upstream end of the lane drop taper was observed during all three periods, but no explanation of its cause has been found

Figure A-5

A-12



A-13

Site 14

, Type 3 - 2 Left - Taper

Sight Distance 5 mile

Vertical Curvature Slight downgrade beginning .5, upgrade prior to .5 mile.

Horizontal Curvature Slight

Pavement Type Concrete

ADT

One-Way

Two-Way 41,500 (1968) Peak Hour 2-way - 4350 (at beginning of first rumble strip)

5-Minute Count Time 11 30 A M

Total 175

Trucks 16 , Percentage 9 %

Lane 1 70

Lane 2 91

Lane 3 14

Lane 4

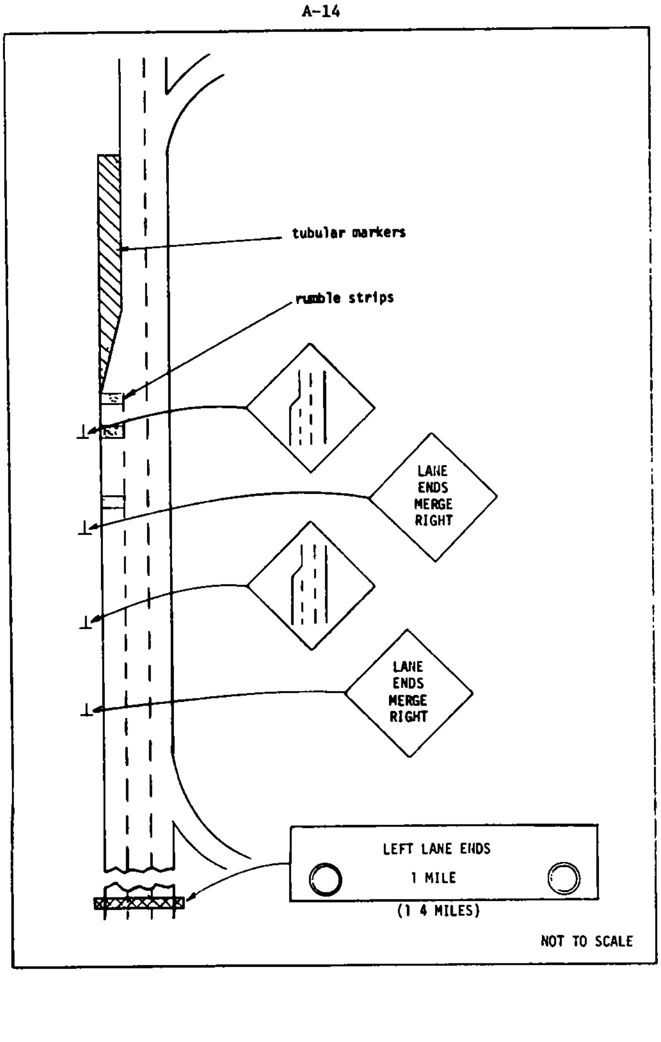
Lane 5

Accident Experience

Operational Characteristics Site works ok in off peak hours. Very uneven lane distribution at peak hours, two left lanes are by far the most heavily traveled Site is scheduled to be restriped into a right taper lane drop. This site is reevaluated in Appendix C of this report

Figure A-6

A-14



A-15

Site 16

, Type 4 - 3 Taper-Right

Sight Distance 1 mile

Vertical Curvature Slight upgrade cresting 1 mile upstream

Horizontal Curvature Straight

Pavement Type Concrete

ADT

One-Way

Two-Way 67,000 (1968) Peak Hour 5,300

5-Minute Count Time - 4 00 P M

Total 259

Trucks , Percentage %

Lane 1 62

Lane 2 62

Lane 3 68

Lane 4 67

Lane 5

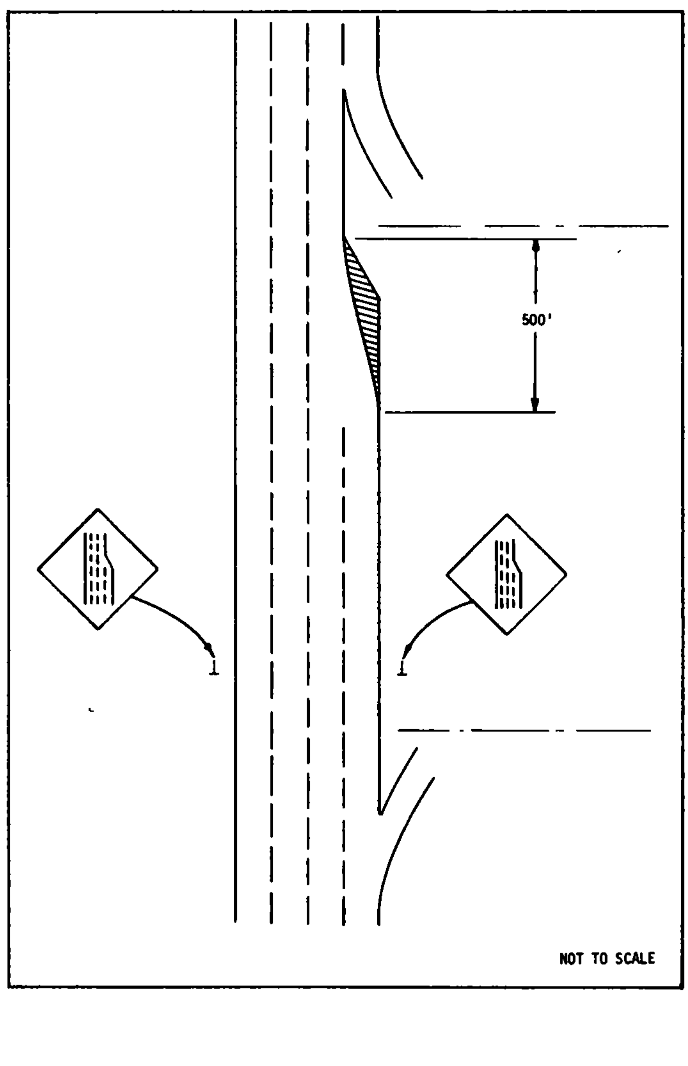
1 - 2 126

3 - 4 135

Accident Experience

Operational Characteristics Seems to operate fairly well, however, traffic is relatively light There are some last minute merge maneuvers. This may be due to the fact that there is only one sign which is 0.1 miles upstream of the taper start Similiar in design and signing to site 05.

Figure A-7



A-17

Site 25

, Type 4 - 3 left

Sight Distance .1 mile

Vertical Curvature Crest of upgrade 500' upstream Taper on slight downgrade

Horizontal Curvature Slight reverse curve

Pavement Type Asphalt

ADT

One-Way. 45,000

Two-Way:

5-Minute Count Time - 8:00 a m

Total 339

Trucks 35 ; Percentage 10 %

Lane 1 68

Lane 2 105

Lane 3 132

Lane 4 34

Lane 5

Accident Experience Per correspondence with the State Department of Highways, there were no lane drop related accidents from November 12, 1971 to May 1, 1972 (period of time current lane drop signing was in effect).

Operational Characteristics Works well during off-peak hours Downstream congestion causes breakdown during peak a m. hour Commuters in left lane take advantage of unloaded lane drop area and cause merging problem Several near-miss incidents were observed

Figure A-8

A-19

Site 26

, Type 5 - 4 Trap - Right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way 38,000

Two-Way

5-Minute Count Time - 11 40 A M

Total 369

Trucks 42 , Percentage 11 %

Lane 1 75

Lane 2 60

Lane 3 70

Lane 4 61

Lane 5

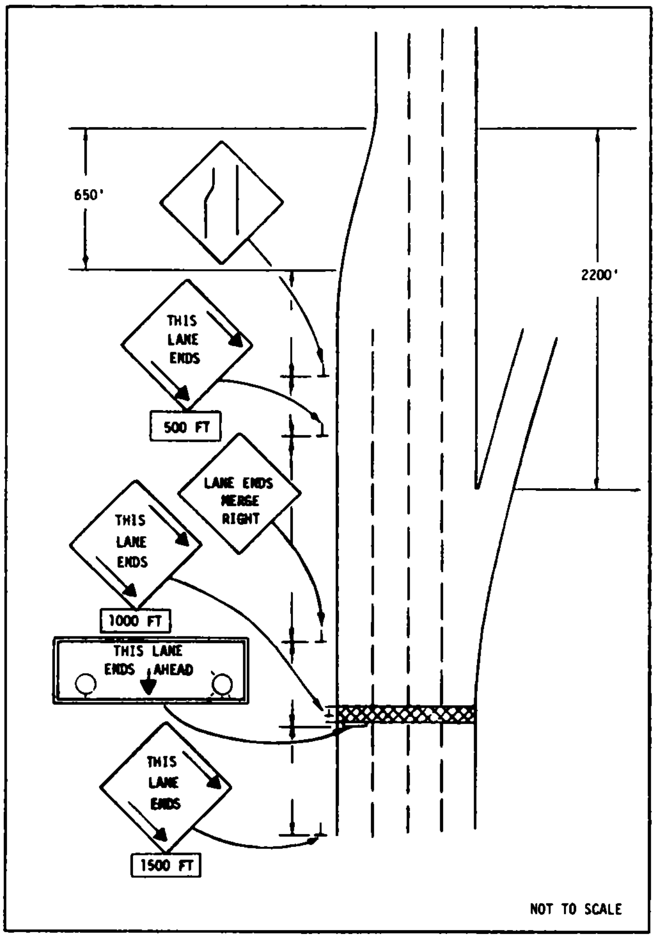
Ramp 61

Accident Experience

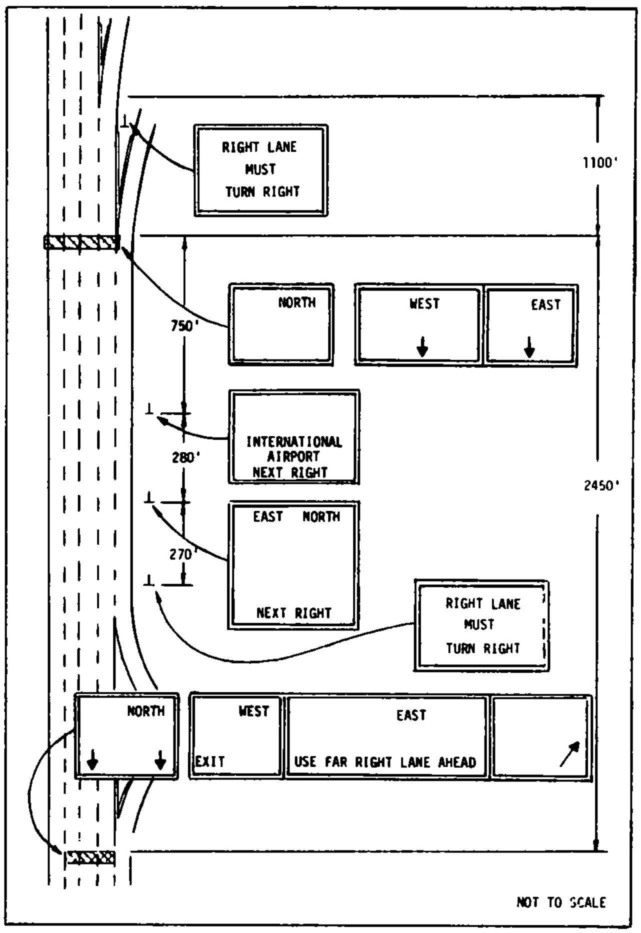
Operational Characteristics A significant amount of last minute maneuvering occurs at lane drop

Figure A-9

A-18



A-20



A-21

Site 28

, Type 3 - 2 left

Sight Distance 06 miles

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way

Two-Way 20,150

5-Minute Count Time 4 35 P M

Total 263

Trucks 7 , Percentage 2 %

Lane 1 81

Lane 2 132

Lane 3 50

Lane 4

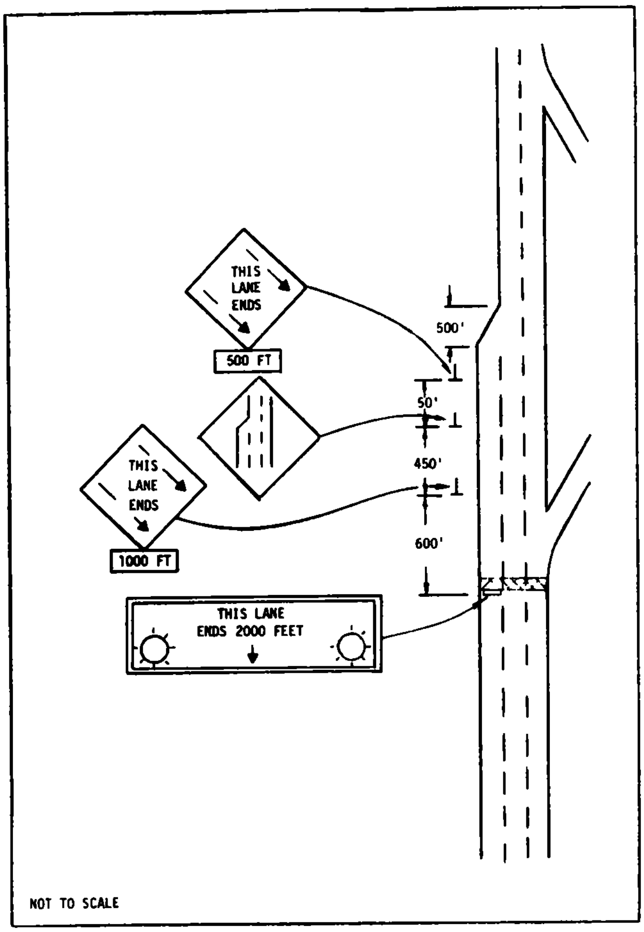
Lane 5

Accident Experience Accident experience is light.

Operational Characteristics A few last drivers use all the taper before merging in through lanes Operates fairly well at below capacity volumes.

Figure A-10

A-22



A-23

Site 57

, Type 3 - 2 Trap-Right

Sight Distance 25 mile

Vertical Curvature level

Horizontal Curvature Straight

Pavement Type Asphalt

ADT

One-Way

Two-Way

5-Minute Count Time - 11 10 A M

Total 108

Trucks 1 , Percentage 1 %

Lane 1 22

Lane 2 53

Lane 3 17

Lane 4

Lane 5

Ramp 16

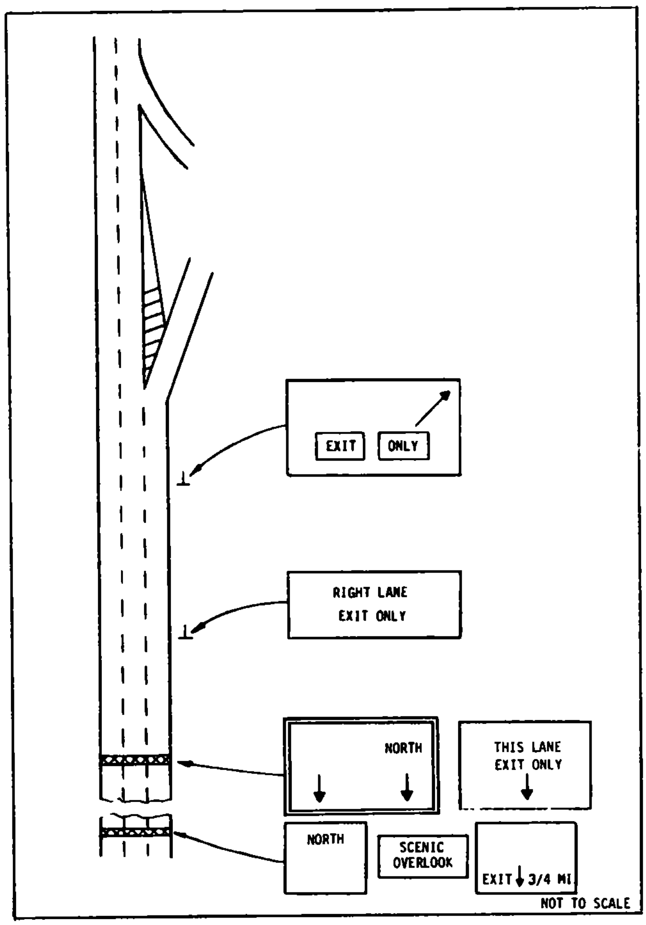
ERR 0

Accident Experience

Operational Characteristics Many vehicles crossed the solid white line at the gore and continued in the long escape area for some distance Some vehicles did not seem disturbed about traveling in this lane for some time Traffic volumes are fairly light

Figure A-11

A-24



A-25

Site 51

, Type: 4 - 3 Right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics Site very confusing. Poor delineation of geometrics.

Figure A-12

A-27

Site 05

, Type 4 - 3 Right taper

Sight Distance

Vertical Curvature Level except over interchange
1% up and 3% down (1/2 mile east to 1/4 mile west of interchange)

Horizontal Curvature Slight left-right reverse curve between on-ramp and left-hand exit

Pavement Type Concrete

ADT

One-Way

Two-Way 163,500

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

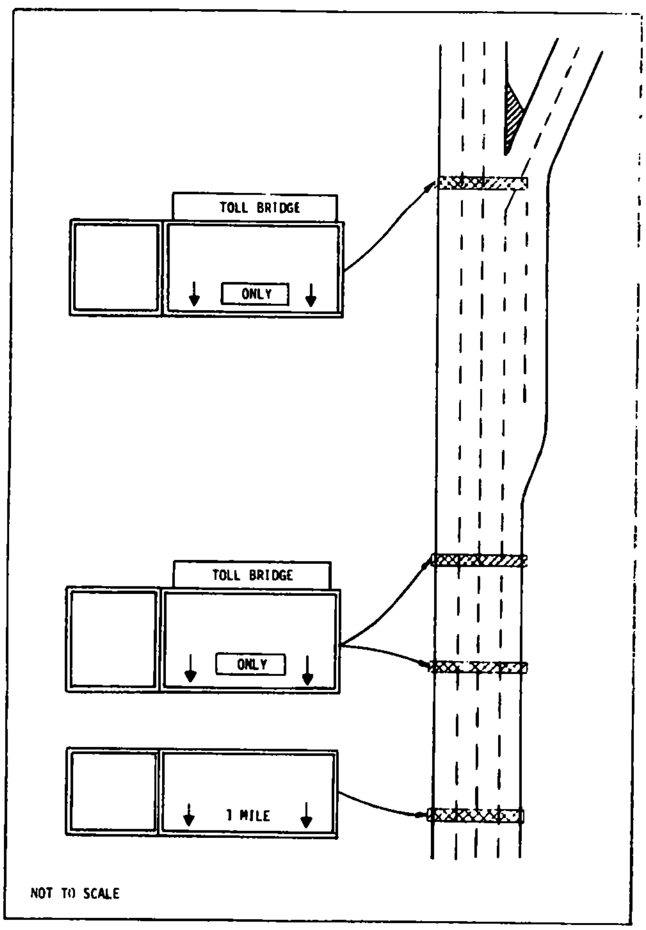
Lane 5

Accident Experience Accidents/Million Vehicle Miles 1964 = 86 1965 = 47
Number of Fatalities: 1964 = 6 1965 = 7
Fatality Rate: 1964 = 0.79 1965 = 0 92

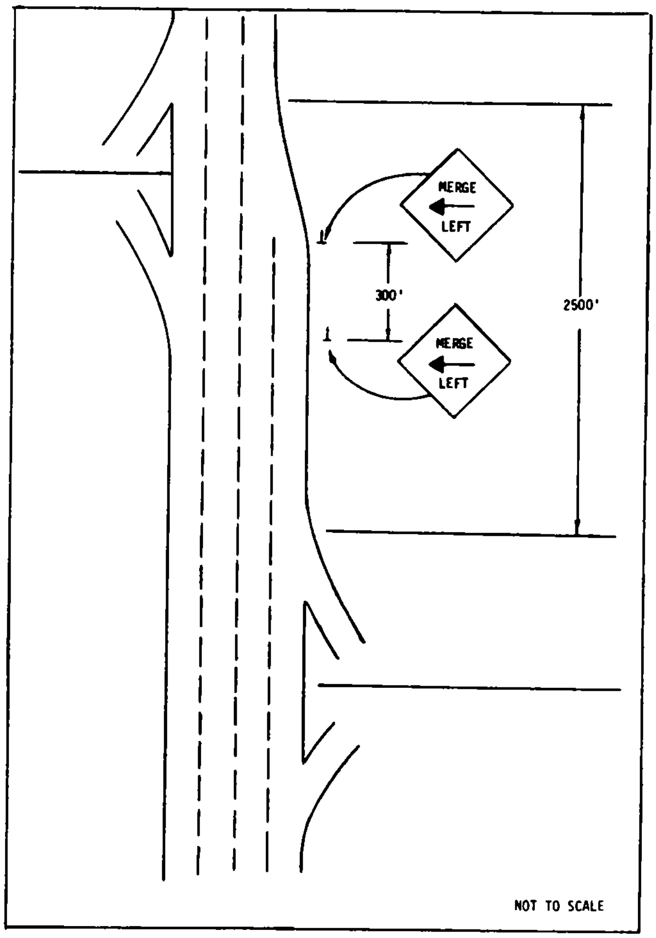
Operational Characteristics It works quite well in off-peak hours but has downstream capacity problems which cause freeway breakdown during the evening rush hour Signing is minimal but the sight distance is comparitively good

Figure A-13

A-26



A-28



A-29

Site 08

Type 3 - 2 right taper (to become trap) (under construction)
3rd lane add-on, right

Sight Distance 1100'

Vertical Curvature Slight downgrade 1/4 mile before drop

Horizontal Curvature Right-hand curve downstream of lane drop

Pavement Type Concrete

ADT

One-Way

Two-Way 84,900

5-Minute Count Time - 11 00 a m

Total	161
Trucks	47, Percentage 29 %
Lane 1	1
Lane 2	80
Lane 3	80
Lane 4	
Lane 5	

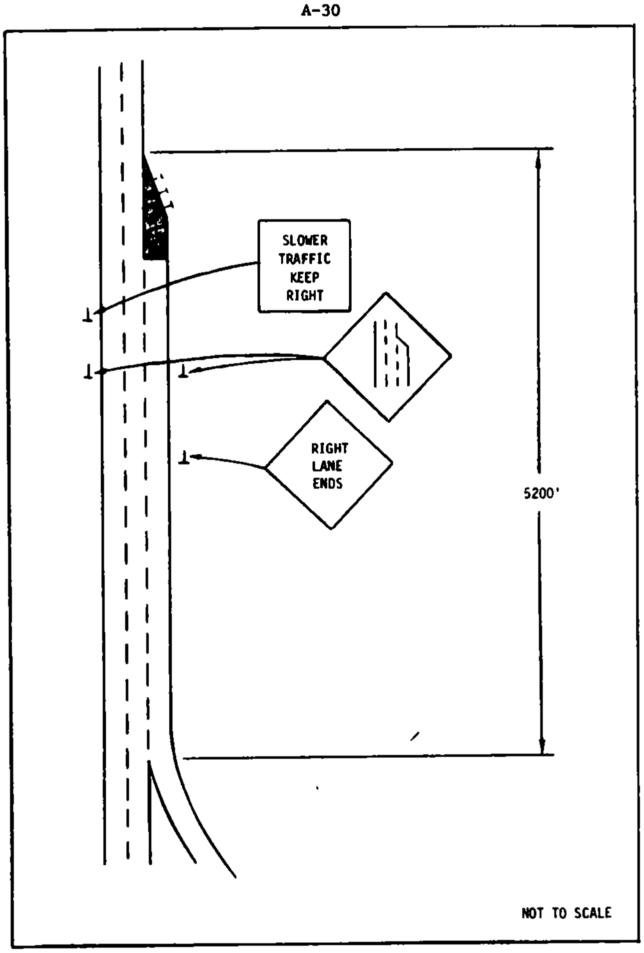
Accident Experience Serious accidents at the lane drop have been reported *

Operational Characteristics A lot of last-minute lane changes are made in the red pavement (shaded area) The site is currently under construction and is being changed from a taper lane drop to an exit ramp lane drop

* Accidents/Million Vehicle Miles 1964 = 0 41 1965 = 0 69
Number of Fatalities 1964 = 6 1965 = 10
Fatality Rate 1964 = 0 89 1965 = 1 62

Figure A-14

A-30



A-31

Site 47

Type 3 - 2 Ramp

Sight Distance

Vertical Curvature 0 3 miles upstream = -2 40%, 0 0 = 2 00%

Horizontal Curvature 0 3 miles upstream, D=3°00', R=1910'
0 0 D=0°45', R=7639

Pavement Type Concrete

ADT

One-Way 41,578 (1971)

Two-Way

~~5-Minute Count~~ Average hourly volumes

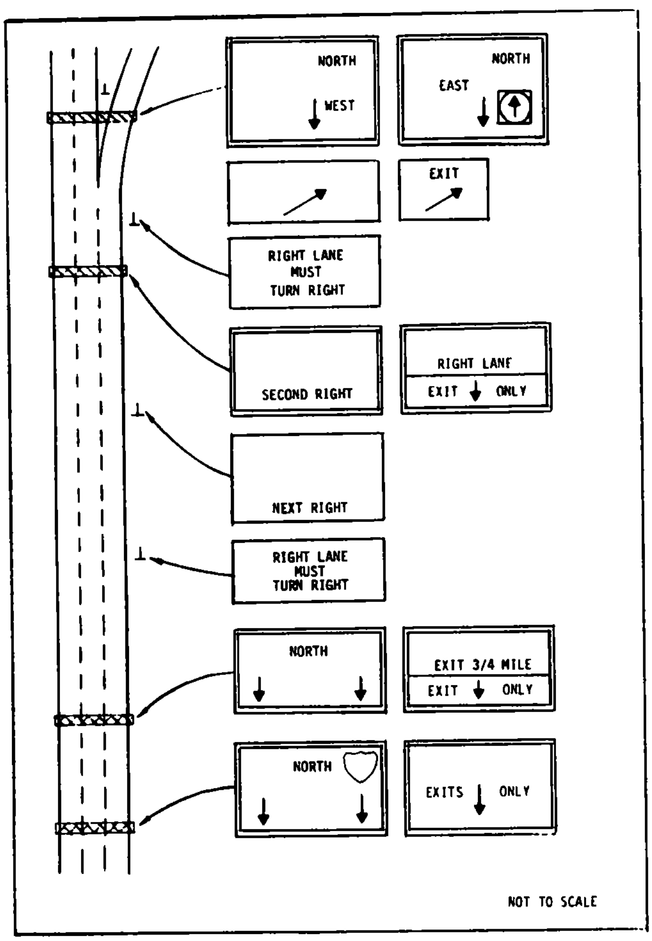
Total	2066
Trucks	, Percentage %
Lane 1	346
Lane 2	920
Lane 3	800
Lane 4	
Lane 5	

Accident Experience Accident rate = 1 12 accidents per million vehicles

Operational Characteristics Mean speeds ranged from 48-53 mph during study Overall erratic movement rate = 6,100/million vehicles, overall brakelight rate = 57,800/million vehicles

Figure A-15.

A-32



A-33

Site 48

_______________, Type: 3 - 2 Ramp

Sight Distance

Vertical Curvature 1.3% grade upstream of lane drop/-2.18% grade just downstream of lane drop.

Horizontal Curvature Straight Section

Pavement Type Concrete

ADT

One-Way 17,718 (1971)

Two-Way

~~5-Minute Count~~ Average hourly volumes

Total 830

Trucks _______________, Percentage ____ %

Lane 1 260

Lane 2 370

Lane 3 200

Lane 4

Lane 5

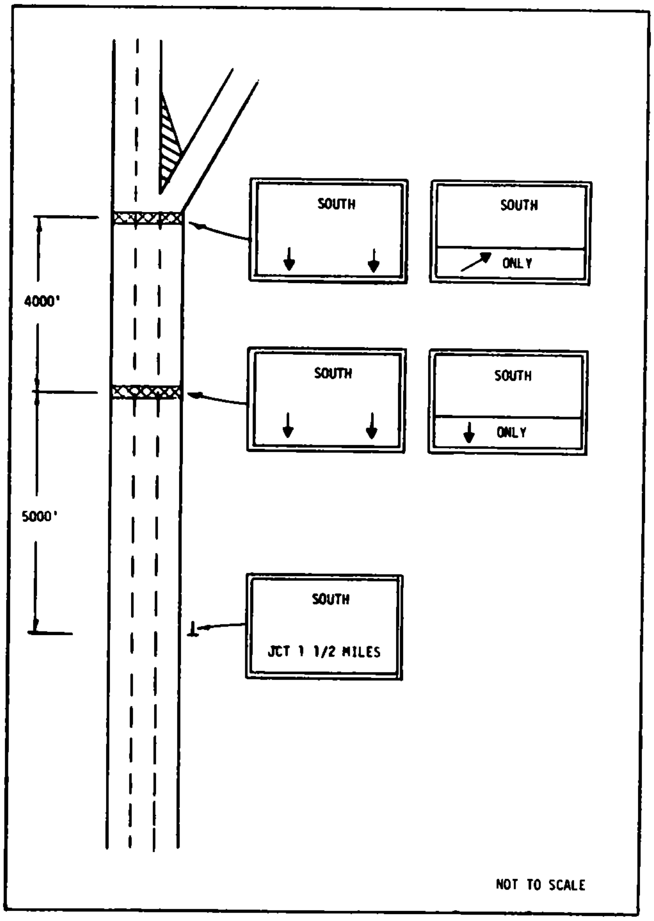
Accident Experience Accident Rate 0 77 accidents per million vehicles (1971)

See Attached

Operational Characteristics See attached - Erratic maneuver counts and spot speeds

Figure A-16

A-34



A-35

ACCIDENT SUMMARY

STUDY PERIOD - January 1, 1971 - December 31, 1971

ACCIDENT RATE - 0 77 accidents per million vehicles

INJURY RATE - 0 46 injury accidents per million vehicles

	TOTAL	PERCENT
NUMBER OF ACCIDENTS	5	100
ACCIDENT TYPES		
Rear-End	2	40
Multiple Rear-End	1	20
Lost Control	1	20
Sideswipe	1	20
ACCIDENTS INVOLVING INJURY	3	60
TOTAL NUMBER INJURED	6	
TOTAL FATALITIES	0	0
LIGHT CONDITION		
Daylight	3	60
Dark	1	20
Dawn or Dusk	1	20
PAVEMENT CONDITION		
Wet	0	0
Dry	5	100

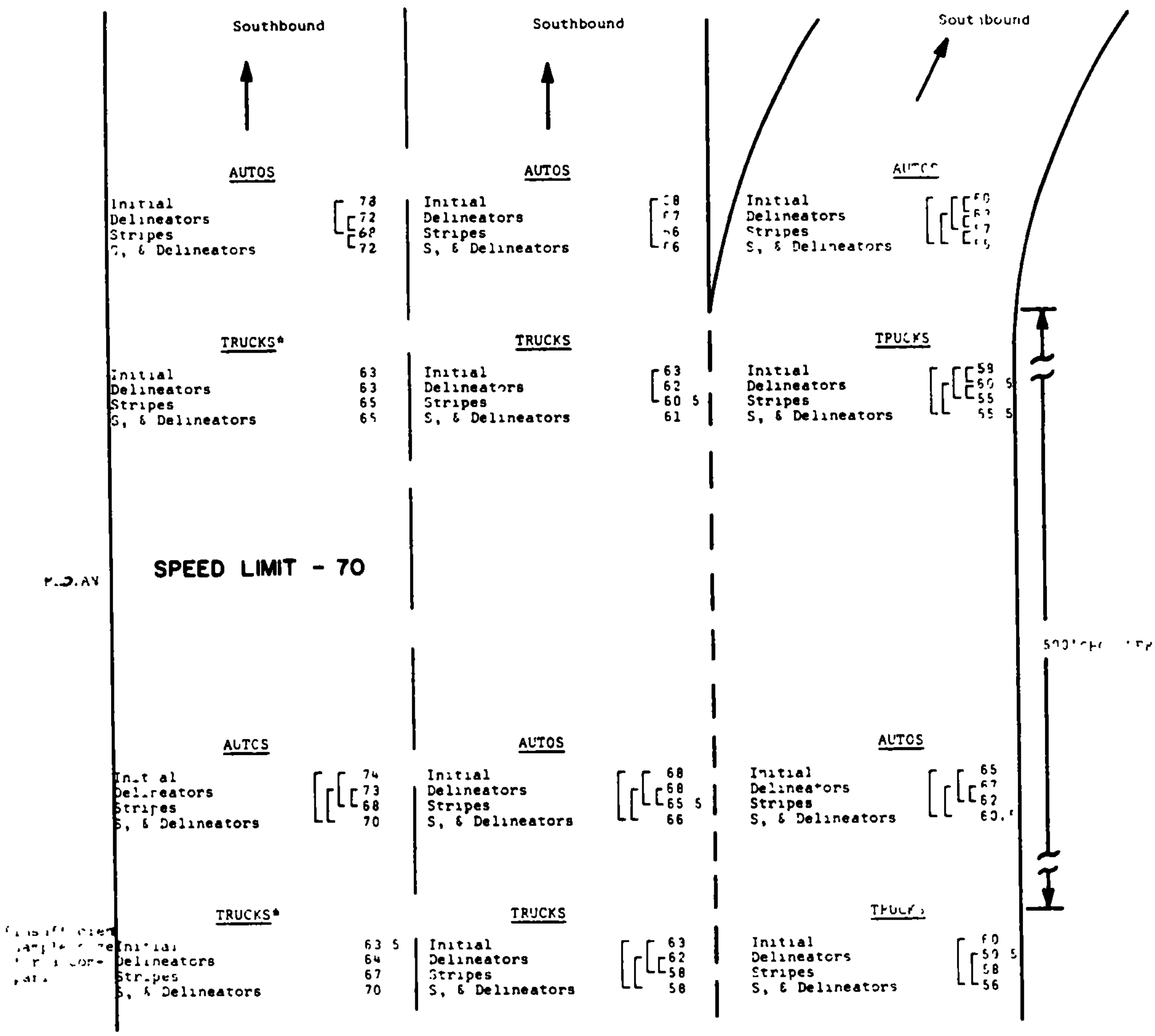
Figure A-16.

A-36

THE FINAL STUDY
ERRATIC MOVEMENT AND BRAKELIGHT RATES AND AVERAGE HOURLY VOLUMES
DAYTIME CONDITIONS

LOCATION	STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED	ERRATIC MOVEMENT RATES: CUT ACROSS GORE	CROWDED WEAVE	SWERVE	SLOWED DRASTICALLY	STOPPED	STOPPED AND BRAKED	MULTIPLE ERRORS	TOTAL
1 75 SB AT 1 71 SB	1	ORIGINAL	1.11	.26	.13	.18	.04	0	.23	2.06
	2	AMBER DELINEATORS	.88	.05	.13	.17	.02	0	.29	1.53
	3	YELLOW STRIPING	1.00	.15	.05	04	0	.05	.31	1.56
	4	AMBER DELINEATORS & YELLOW STRIPING	.02	.02	.28	.06	.02	0	.09	.48

LOCATION	STUDY NUMBER	TRAFFIC CONTROL DEVICE(S) EMPLOYED	BRAKELIGHT RATES: MEDIAN LANE	MIDDLE LANE	SHOULDER LANE	SINGLE LANE	TOTAL	AVERAGE HOURLY VOLUMES: MEDIAN LANE	MIDDLE LANE	SHOULDER LANE	TOTAL
1 75 SB AT 1 71 SB	1	ORIGINAL	78	1.46	23.91		8.42	178	356	239	772
	2	AMBER DELINEATORS	1.06	1.84	20.42		7.67	223	394	289	905
	3	YELLOW STRIPING	.57	2.06	24.80		9.63	219	392	316	927
	4	AMBER DELINEATORS & YELLOW STRIPING	.27	.61	15.37		5.15	197	366	256	819



BRACKETS DENOTE STATISTICALLY SIGNIFICANT MEAN SPEED DEVIATIONS

Mean Speeds at the – – – – – – – Single Lane Exit with Taper

Figure A-16.

A-38

Site 59

, Type: 3 - 2 Trap, right

Sight Distance 3 miles

Vertical Curvature

Horizontal Curvature

Pavement Type Asphalt

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics Traffic very light, no problems.

Figure A-17

A-40

Site 58

, Type 3 - 2 Trap Right

Sight Distance 2 miles

Vertical Curvature

Horizontal Curvature

Pavement Type Asphalt

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

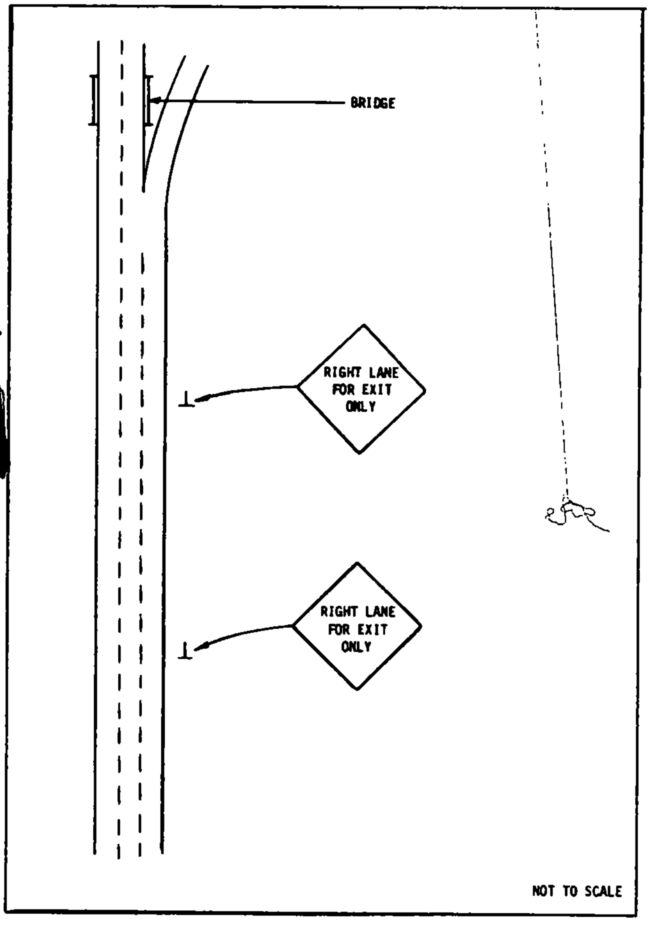
Lane 5

Accident Experience

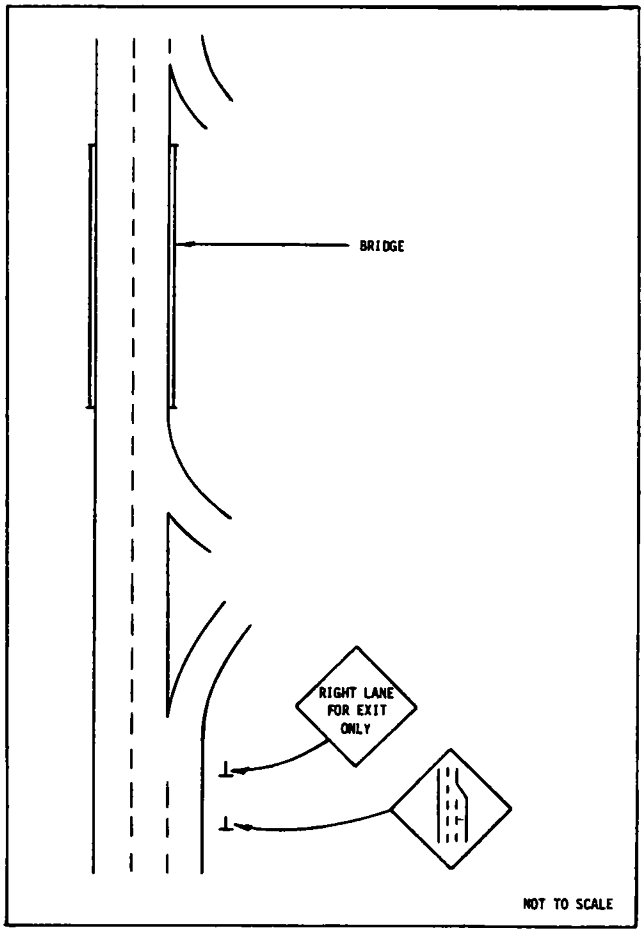
Operational Characteristics Traffic very light; 3 - 2 lane drop caused by two lane bridge, lane is added again beyond bridge

Figure A-18

A-39



A-41



A-42

Site 60

Type. 4 - 3 Trap, right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type Asphalt

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics Heavy afternoon traffic. A few on-ramp vehicles have trouble merging into through traffic before lane ends due to heavy traffic and short weaving area

Figure A-19

A-44

Site 61

Type: 3 - 2 Taper, right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way

Two-Way

5-Minute Count Time - 11:30 a m

Total 104

Trucks 16, Percentage 15 %

Lane 1 23

Lane 2 49

Lane 3 18

Lane 4

Lane 5

ERR 6

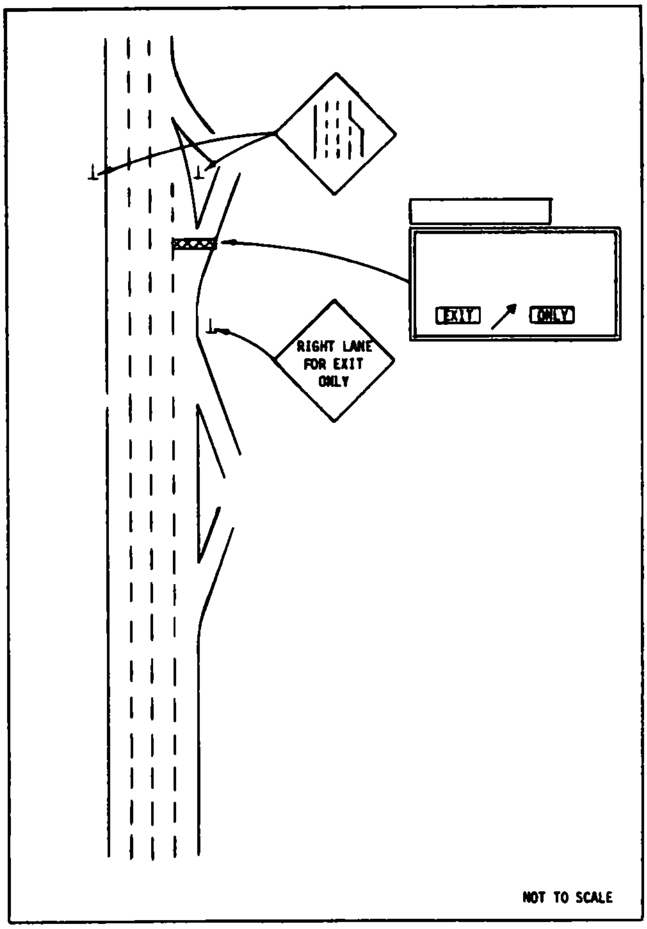
R 14

Accident Experience

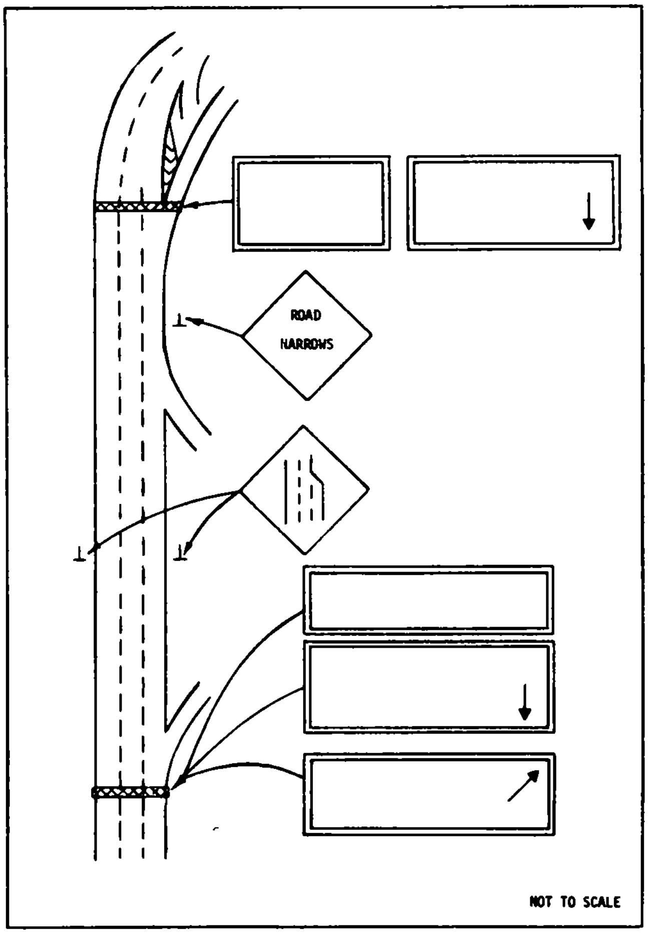
Operational Characteristics Many vehicles cross pavement striping near gore area Some vehicles entering freeway just upstream of lane drop have difficulties merging into a through lane before the lane drop area

Figure A-20

A-43



A-45



A-46

Site 04

; Type 3 - 2 Right Taper

Sight Distance 1/4 mile or more

Vertical Curvature level

Horizontal Curvature Slight left-hand curve in taper area

Pavement Type Concrete

ADT

One-Way. 41,800 (1970)

Two-Way:

5-Minute Count Time - 7:30 A.M.

Total 267

Trucks 6 ; Percentage 2 %

Lane 1 133

Lane 2 115

Lane 3 19

Lane 4

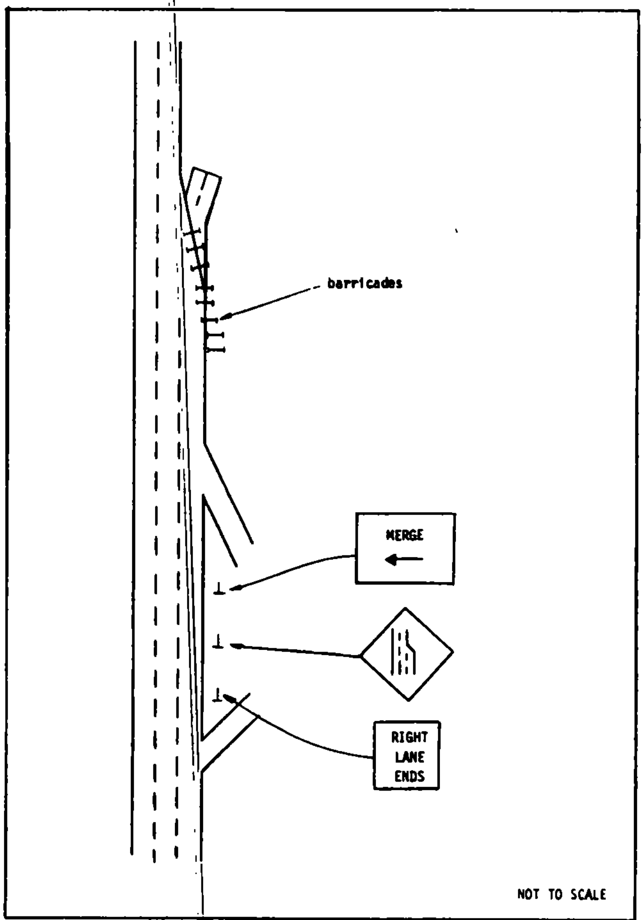
Lane 5

Accident Experience Light

Operational Characteristics AM peak hour carries the most traffic during a typical day Speeds steady through entire area. 55-60 mph. Some vehicles use trapped lane to gain an advantage because it is empty well in advance. 3000-4000 feet. Those vehicles usually traveling quite fast, have no trouble squeezing in because volume is below capacity. No visible pavement markings other than skip white.

Figure A-21.

A-47



A-48

Site 02

, Type 4 - 3 Trap Right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way 52,700 (1970) Peak Hour - 6,126

Two-Way

5-Minute Count Time - 5 10 P.M

Total 379

Trucks 12 , Percentage 3 %

Lane 1 153

Lane 2 125

Lane 3 101

Lane 4

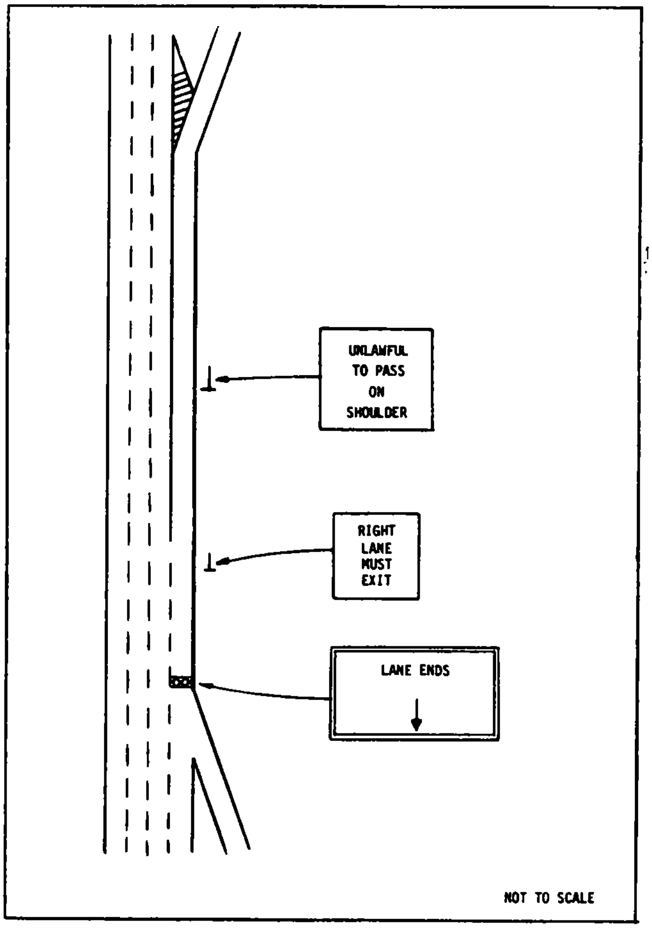
Lane 5

Accident Experience Low

Operational Characteristics Downstream congestion backing up into area caused slowdowns Stoppages noted after counts were made. During peak 5-minute period speeds varied from 45 to 25. Some vehicles using escape lane get honked at, but generally merges were smooth Shock waves in right-hand lane take longer to dissipate Generally, operation must be considered quite acceptable. Metered freeway demo will have effect when implemented in 1973. Signing for this lane drop is entirely temporary, as state engineers overlooked that aspect in original contract Solid white line virtually gone already for this winter.

Figure A-22

A-49



A-50

Site 52

, Type 3 - 2 Taper, right

Sight Distance 3 miles

Vertical Curvature .3 Slight up-grade

Horizontal Curvature Sharp left 7

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

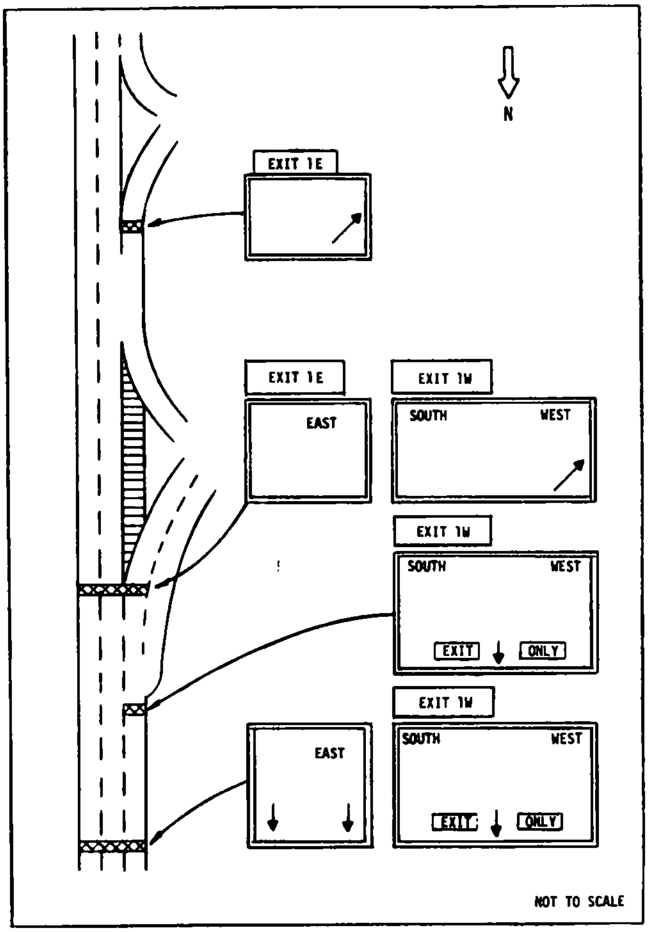
Accident Experience Large number of accidents in area, yearly accidents near operational lanedrop as follows 1968=4, 1969=5, 1970=21, 1971=13, 1972=8.*

Operational Characteristics Operates poorly, a capacity problem during peak hours When freeway was originally designed, the right lane was continued to the second exit causing problems between through drivers, exit traffic and traffic entering from the loop connection Hence, the right lane was striped closed creating a lane drop at the first exit. Some vehicles ignore the operational drop causing downstream conflicts

* Dramatic increase between 1969 and 1970 has not yet been explained

Figure A-23.

A-51



A-52

Site 53

, Type 3 - 2 Taper left

Sight Distance .2 miles

Vertical Curvature 12 Slight up-grade

Horizontal Curvature None

Pavement Type

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

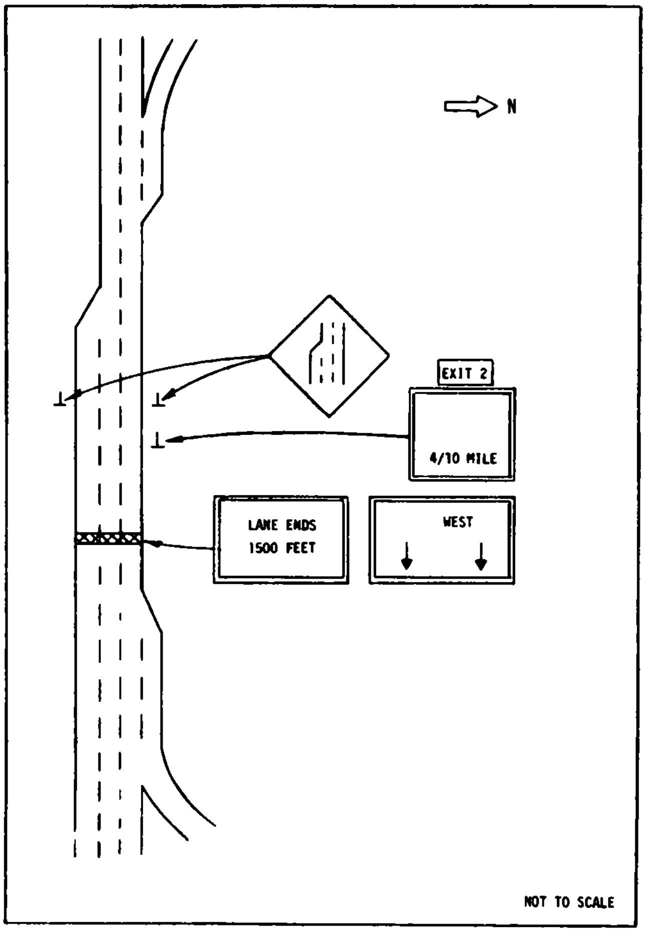
Lane 5

Accident Experience Light, slight increase in number of accidents over the years, probably due to increased volumes

Operational Characteristics At 4 20 P M the site had capacity problems Operates poorly during peak hours, capacity problem

Figure A-24

A-53



A-54

Site 44

, Type 4 - 3 Exit Right

Sight Distance 1 mile

Vertical Curvature Slight upgrade

Horizontal Curvature Slight right-hand curve - .65, Slight left - .1

Pavement Type Concrete

ADT

One-Way 36,625 (1970)

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3 No Counts Available

Lane 4

Lane 5

Accident Experience 1970 accident rate = 2.07 accidents/million vehicle miles

Operational Characteristics Site works OK at light volumes

Figure A-25.

A-56

Site 34

, Type: 3 - 2 Trap, right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type Asphalt

ADT

One-Way 42,750 approaching 4,750 exiting

Two-Way.

5-Minute Count Time - 3:45 p m

Total 268

Trucks 12 , Percentage 4 %

Lane 1 122

Lane 2 111

Lane 3

Lane 4

Lane 5

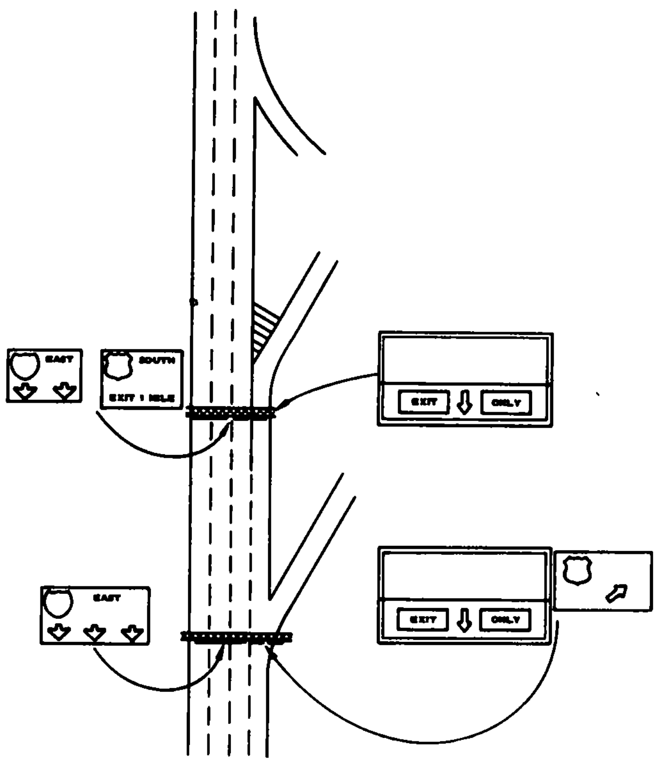
Ramp 35

Accident Experience See attached

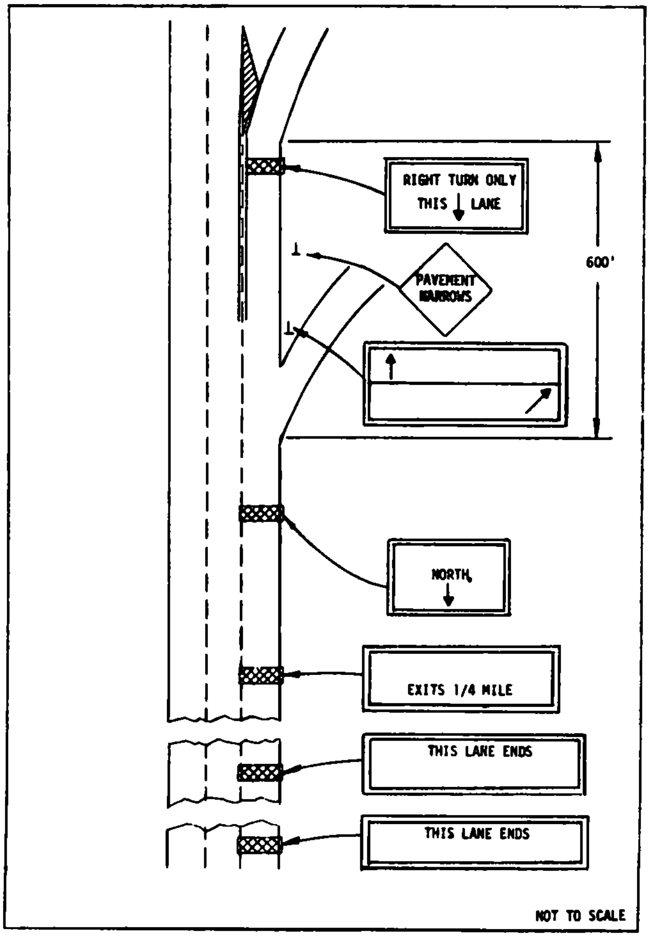
Operational Characteristics Site works well during off-peak hours. Breakdown occurs during peak hour due to a downstream capacity restriction

Figure A-26

A-55



A-57



A-58

Site 35

, Type 4 - 3 Right at Ramp

Sight Distance .2 miles

Vertical Curvature

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way 28,200 approaching 6,300 exiting

Two-Way

5-Minute Count Time - 11 35 A.M

Total 132

Trucks 9 , Percentage 3 %

Lane 1

Lane 2 71

Lane 3 21

Lane 4 14

Lane 5

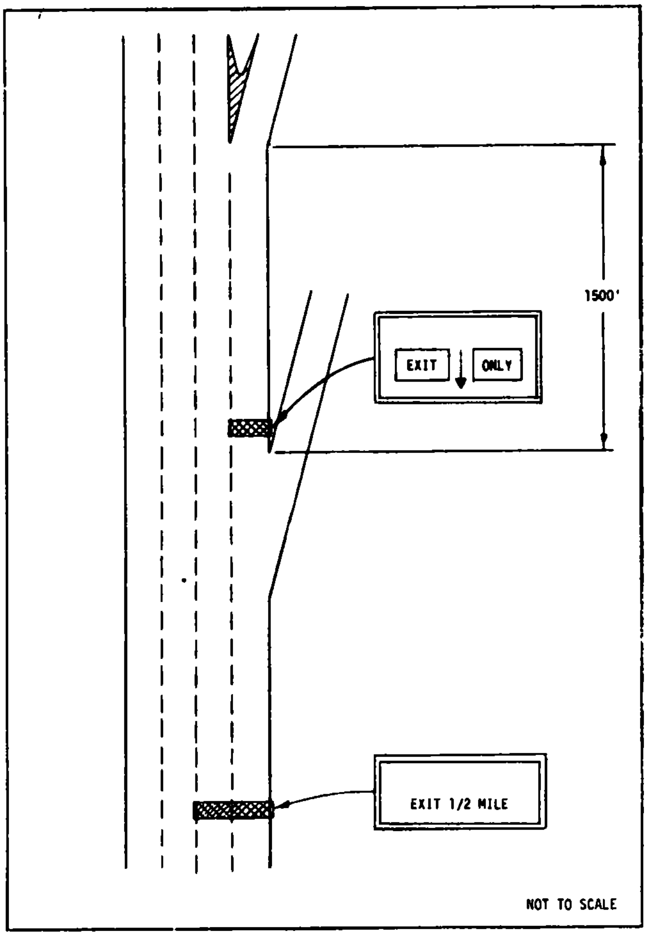
Ramp 26

Accident Experience Light accident experience

Operational Characteristics Many erratic maneuvers observed in escape area after gore.

Figure A-27

A-59



A-60

Site 36

, Type 3 - 2 Right to ramp

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type Asphalt

ADT

One-Way 39,100 approaching 6,100 exiting

Two-Way

5-Minute Count Time - 4 45 P m

Total 292

Trucks 22 , Percentage 7 %

Lane 1

Lane 2 114

Lane 3 139

Lane 4

Lane 5

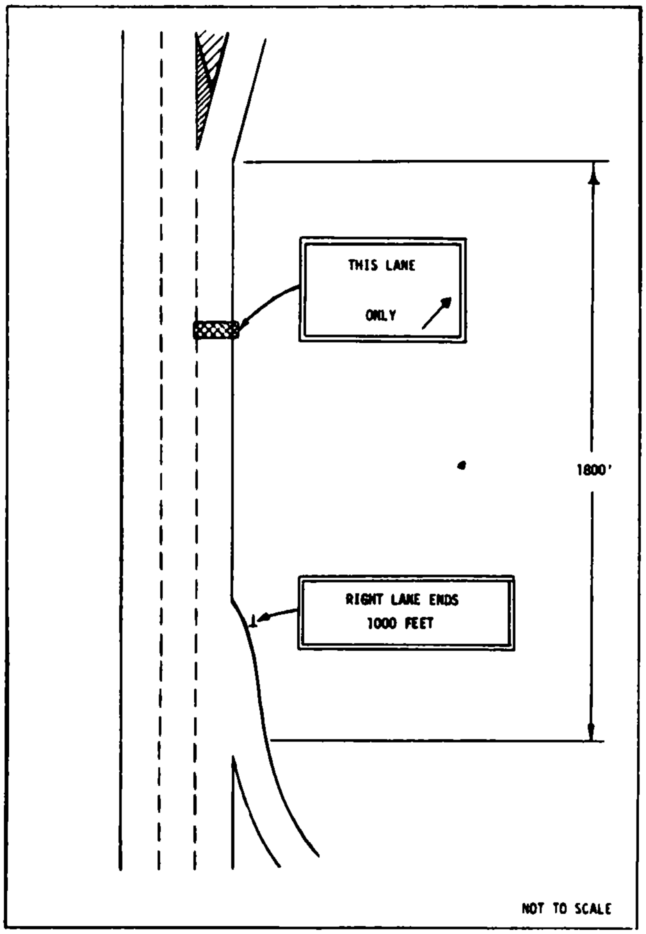
Ramp 39

Accident Experience Most accidents seem to be congestion related, only a few near lane drop

Operational Characteristics This site operates with a minimum of disturbance A few vehicles were observed making last-minute maneuvers

Figure A-28

A-61



A-62

Site 20

; Type 4 - 3 Trap Right

Sight Distance 1 mile

Vertical Curvature -0 30% grade

Horizontal Curvature No curve

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count Time - 4.50 P.M

Total 191

Trucks 8, Percentage 4 %

Lane 1 47

Lane 2 47

Lane 3 49

Lane 4 48

Lane 5

Accident Experience Light - 9 accidents over last 3 years at first off ramp, 3 accidents at lane drop off-ramp

Operational Characteristics Traffic moves fairly well through section, some last minute manuevers

Figure A-29.

A-64

Site 23

, Type: 4 - 3 Taper, left

Sight Distance .5 mile

Vertical Curvature -1 06% to +1 496% (400' vertical curve)

Horizontal Curvature No curve

Pavement Type Concrete

ADT

One-Way:

Two-Way: 26,842

5-Minute Count

Total 115

Trucks ; Percentage %

Lane 1 25

Lane 2 45

Lane 3 40

Lane 4 5

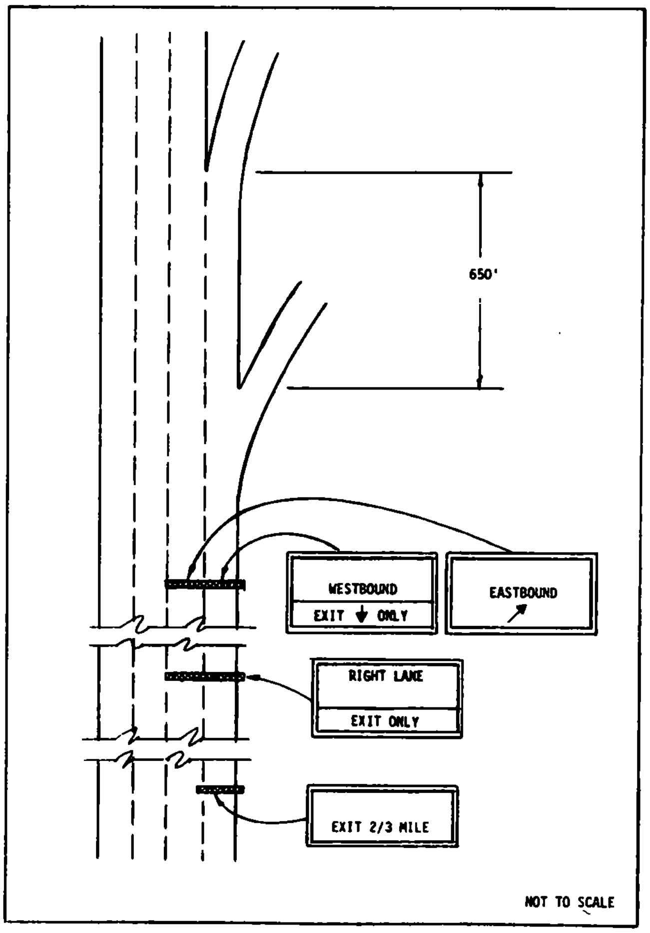
Lane 5

Accident Experience Only a few accidents indicated

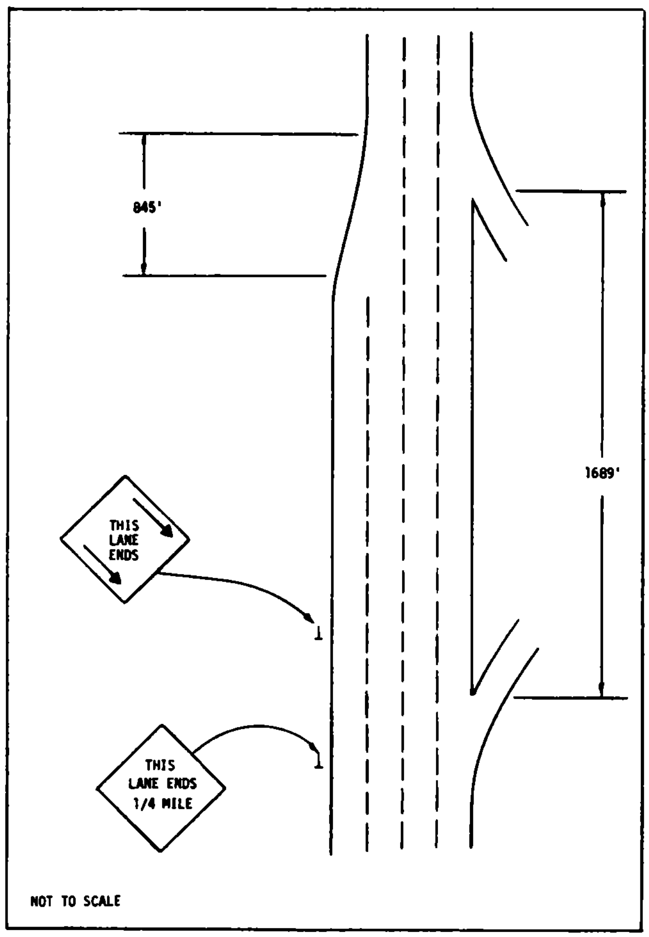
Operational Characteristics This left-hand taper works rather well Most vehicles seemed to make a smooth transition into the other lanes Only 4% of the total volume of traffic was in the left lane 3 mile upstream of the lane drop

Figure A-30.

A-63



A-65



A-66

Site 31

, Type: 3 - 2 lane drop left

Sight Distance 21 miles

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way:

Two-Way

5-Minute Count Time - 12 00 noon

Total 104

Trucks 20 , Percentage 19 %

Lane 1 38

Lane 2 56

Lane 3 10

Lane 4

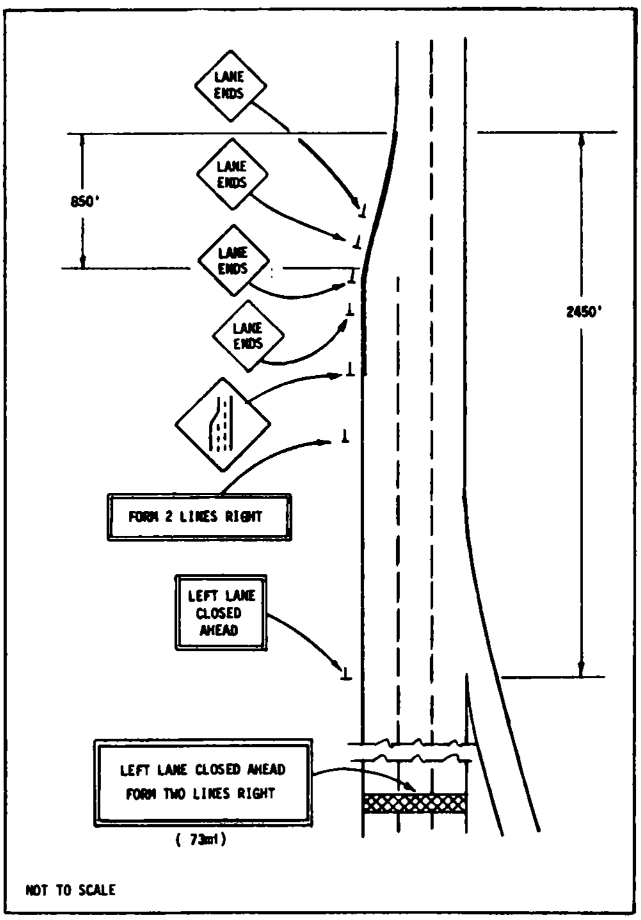
Lane 5

Accident Experience

Operational Characteristics Vehicles tend to wait until the last minute to merge right, regardless that traffic is light and that there are 8 signs The proximity of an upstream on-ramp and the fact that there are few problems in finding a suitable gap in traffic may be responsible for this behavior The State Highway Commission indicated that the site has been a problem and the extensive signing has been largely successful in solving the problem

Figure A-31

A-67



A-68

TYPE B -- ADD-DROP SITUATIONS

Site 18

, Type: 5 - 4 Trap-Right

Sight Distance 25 miles

Vertical Curvature little curvature

Horizontal Curvature Slight upgrade creating at 25 miles upstream

Pavement Type Concrete

ADT

One-Way: 149,000 (1968) Peak Hour 11,800

Two-Way:

5-Minute Count Time 9:00 AM

Total 633

Trucks 24 , Percentage 3 %

Lane 1 89

Lane 2 84

Lane 3 133

Lane 4 130

Lane 5 128

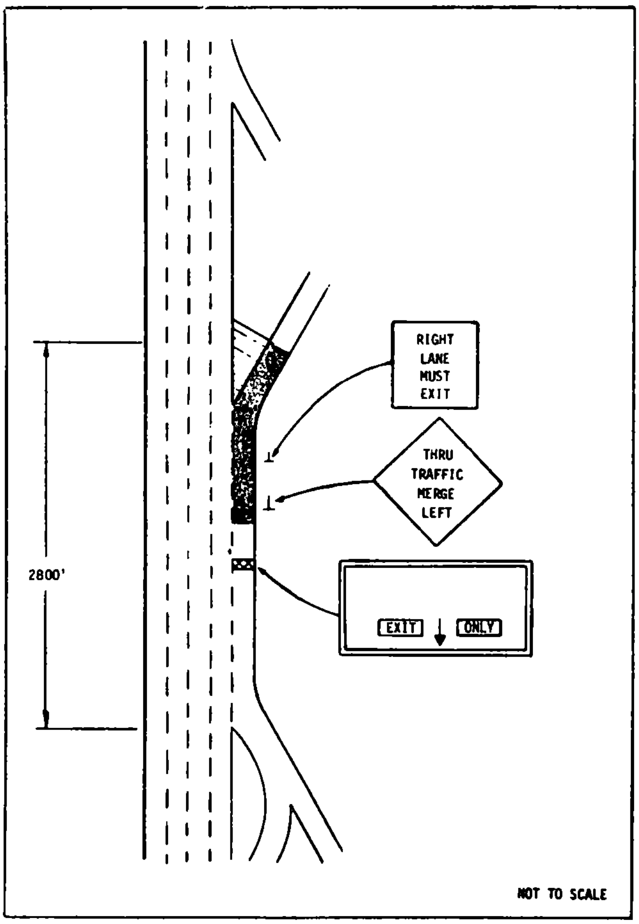
Ramp 69

Accident Experience

Operational Characteristics Very few erratic maneuvers were observed, however, 9 00 A M commuter traffic may well make up the majority of vehicles

Figure A-33

A-69



A-70

Site 27

, Type 5 - 4 Trap-Right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way 38,000

Two-Way

5-Minute Count Time - 11 40 A M

Total 369

Trucks 42, Percentage 11 %

Lane 1 75

Lane 2 60

Lane 3 70

Lane 4 61

Lane 5

Ramp 61

Accident Experience

Operational Characteristics A significant amount of last minute maneuvering occurs at lane drop

Figure A-32

A-72

Site 62

; Type: 3 - 2 Trap, right

Sight Distance 1 mile

Vertical Curvature Slight downgrade begins 8 miles

Horizontal Curvature Slight left hand curve at lane add

Right hand curve begins .3 miles

Pavement Type Concrete

ADT

One-Way.

Two-Way.

5-Minute Count Time - 3:55 p m

Total 203

Trucks 16 ; Percentage 7 %

Lane 1 74

Lane 2 70

Lane 3 59

Lane 4

Lane 5

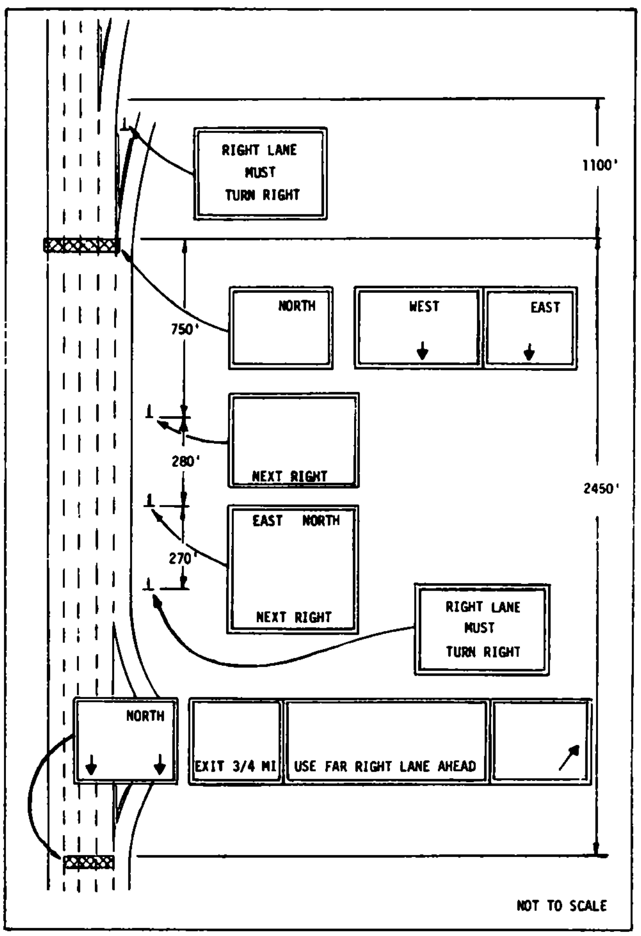
CM 2

Accident Experience

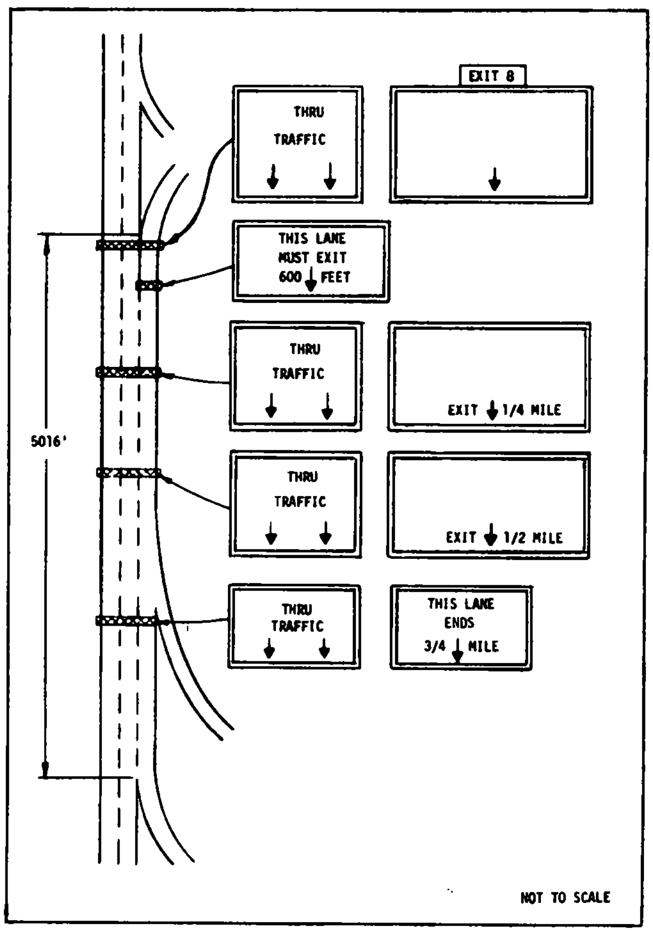
Operational Characteristics The site looks quite well even though geometric conditions are far from optimum. Both erratic maneuvers were caused by vehicles attempting to exit the freeway

Figure A-34

A-71



A-73



A-74

Site 63

, Type: 3 - 2 Trap, right

Sight Distance 1 mile

Vertical Curvature "

Horizontal Curvature Fairly sharp left curve ending at 3 miles upstream, followed by a sharp right curve

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count Time - 4 30 P M

Total 269

Trucks 17 , Percentage 6 %

Lane 1 16

Lane 2 116

Lane 3 137

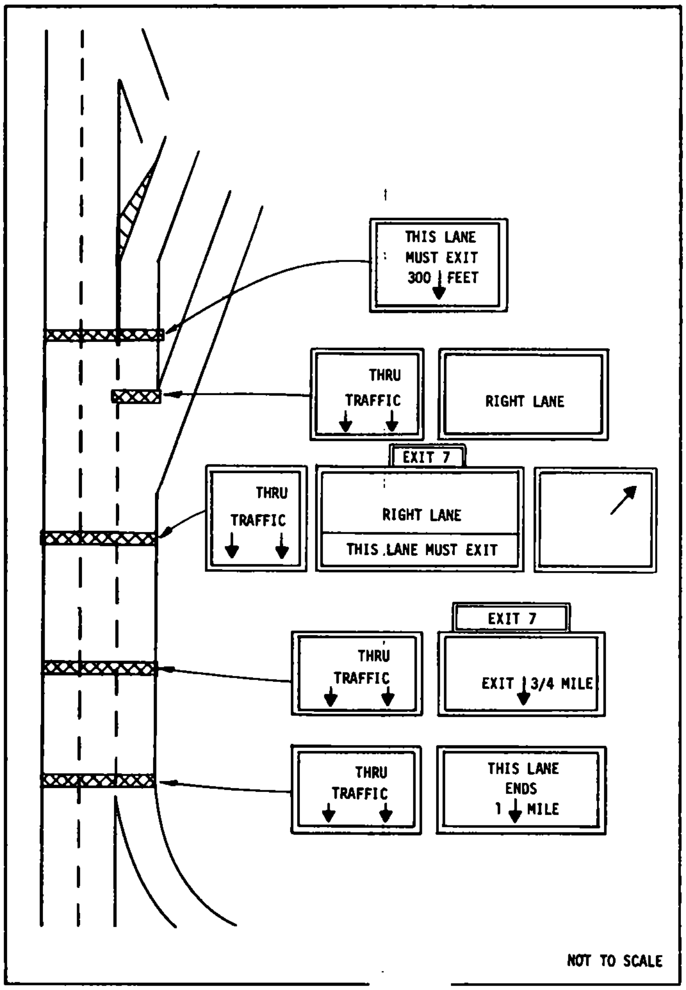
Lane 4

Lane 5

Accident Experience

Operational Characteristics Traffic volume was quite heavy, very few erratic manuevers were observed even though sight distance is minimal

Figure A-35



A-76

Site 07

; Type: 5 - 4 left taper with add-on left

Sight Distance 09 mile

Vertical Curvature Level

Horizontal Curvature Straight but lane drop tapers in a sharp left-hand curve about 40' downstream of last on-ramp

Pavement Type Concrete

ADT

One-Way

Two-Way: 195,500

5-Minute Count Time - 1:00 p m

Total 454

Trucks 55 , Percentage 12 %

Lane 1 64

Lane 2 99

Lane 3 123

Lane 4 134

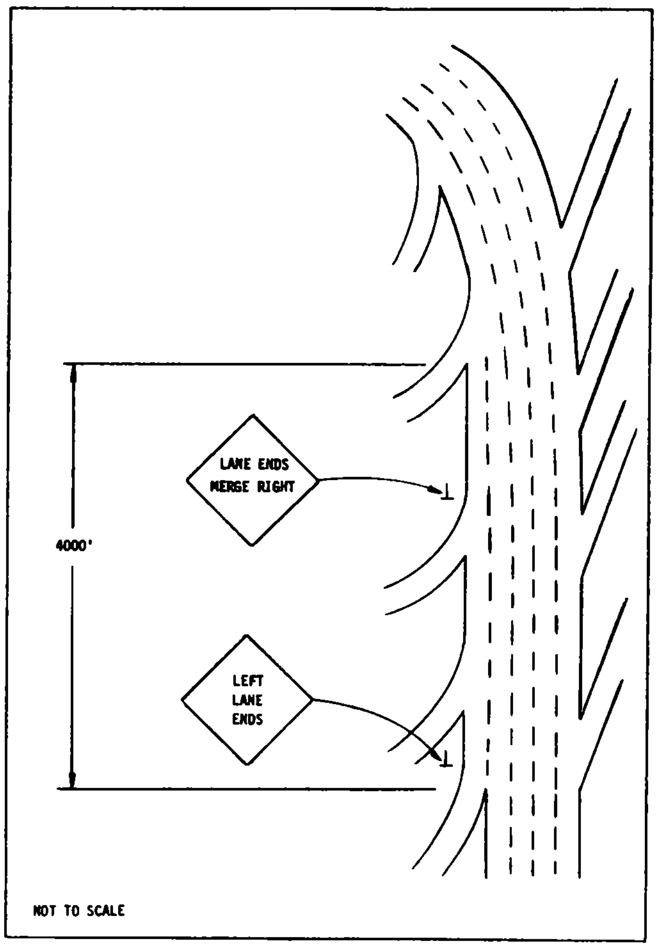
Lane 5 34

Accident Experience Accidents/Million Vehicle Miles 1964 = 0 30 1965 = 0 32
No of Fatalities: 1964 = 13 1965 = 11 Fatality Rate: 1964 = 1 55 1965 = 1.26

Operational Characteristics Many vehicles stop or nearly stop at lane drop Vehicles from ramp just before lane drop have much difficulty merging into through lanes

Figure A-36

A-77



A-78

Site 09

, Type 4 - 3 Trap. Right

Sight Distance

Vertical Curvature downgrade - 7 2 upgrade ends

Horizontal Curvature Slight left-hand curve

Pavement Type Concrete

ADT

One-Way

Two-Way 77,797 (1971)

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics Direct observation was not available, due to inaccessibility of site

Figure A-37

A-80

Site 12

; Type: 4 - 3 Double taper, left

Sight Distance 3 miles

Vertical Curvature Long - up grade

Horizontal Curvature

Pavement Type

ADT

One-Way:

Two-Way: 30,225 (1971)

5-Minute Count

Total

Trucks ; Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

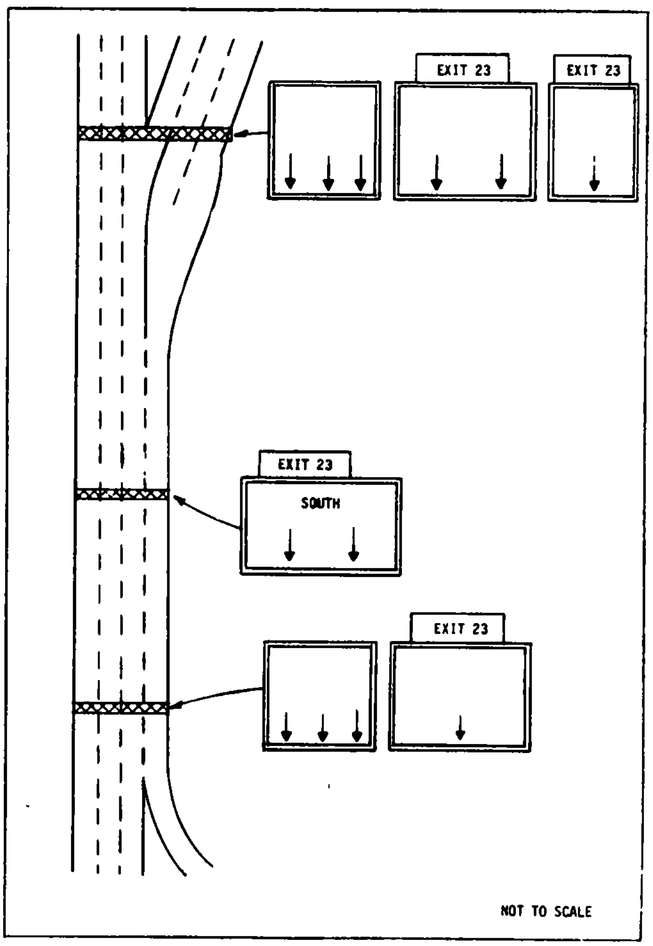
Lane 5

Accident Experience Several possible lane drop related accidents indicated

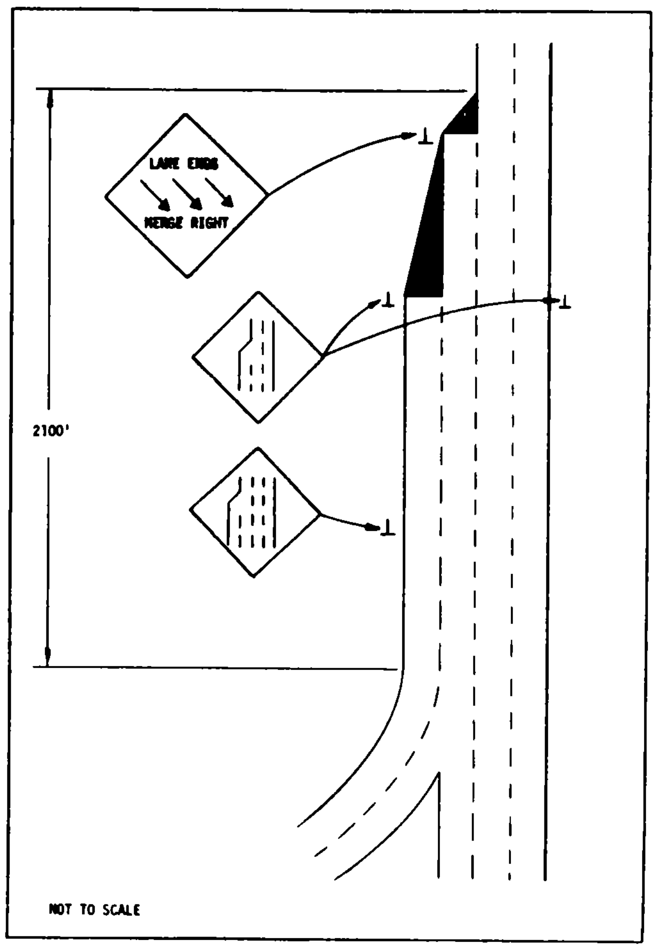
Operational Characteristics The second lane drop is difficult to see until just before the taper begins Vehicles entering from the on-ramp must merge rapidly into the two through lanes to avoid being trapped and slowed in the lane drop area

Figure A-38

A-79



A-81



A-82

Site 13

; Type: 4 - 3 Taper, right-left add-drop

Sight Distance .56

Vertical Curvature Long downgrade beginning at 58 miles upstream
Sag at 13 miles upstream

Horizontal Curvature Straight

Pavement Type Concrete

ADT

One-Way.

Two-Way: 76,250 (1971)

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience No accident material available

Operational Characteristics Driver confusion has been apparent. Many complaints (backed up by observation) indicate that drivers are not sure who has the right-of-way and who is responsible for merging.

Figure A-39

A-84

Site 45

, Type 4 - 3 Trap, right

Sight Distance .2

Vertical Curvature Slight upgrade, cresting at 1 miles

Horizontal Curvature Right hand curve begins 4 miles upstream

Pavement Type Concrete

ADT

One-Way 53,950

Two-Way

5-Minute Count Time 3 50 P M

Total 454

Trucks 28 , Percentage 6 %

Lane 1 30

Lane 2 133

Lane 3 131

Lane 4 160

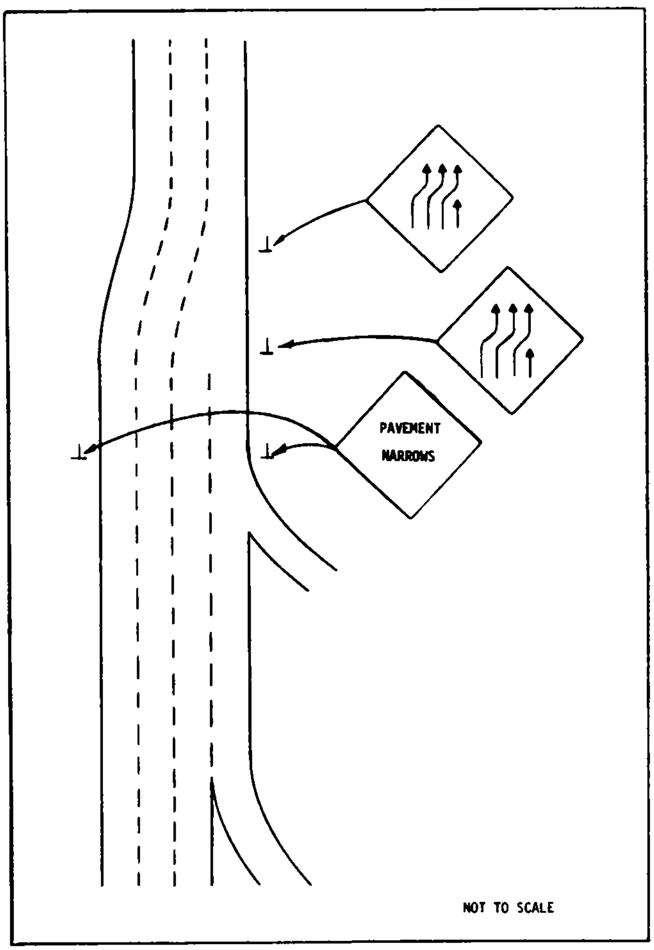
Lane 5

Accident Experience 1970 accident rate = 7 68 accidents/million vehicle miles.

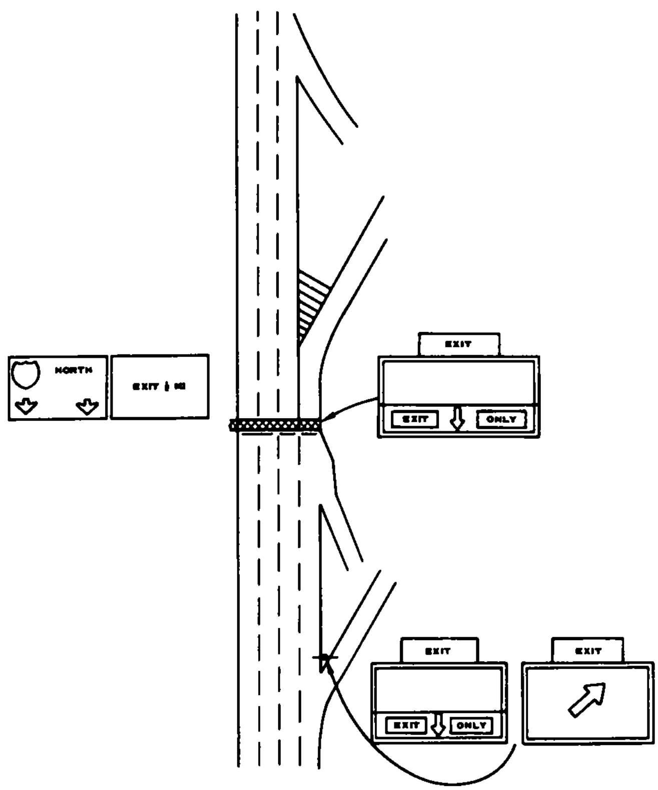
Operational Characteristics Much use of the escape lane is made. Traffic was quite heavy and definite merge problems occur in the lane drop area. Some vehicles are almost slowed to a stop before finding a gap to merge into the through lanes

Figure A-40

A-83



A-85



A-86

Site 37

, Type 3 - 2 Right to ramp

Sight Distance 07 miles

Vertical Curvature

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way 46,000 approaching 10,500 exiting

Two-Way

5-Minute Count Time - 9 30 A M

Total 199

Trucks 21 ; Percentage 10 %

Lane 1

Lane 2 93

Lane 3 64

Lane 4

Lane 5

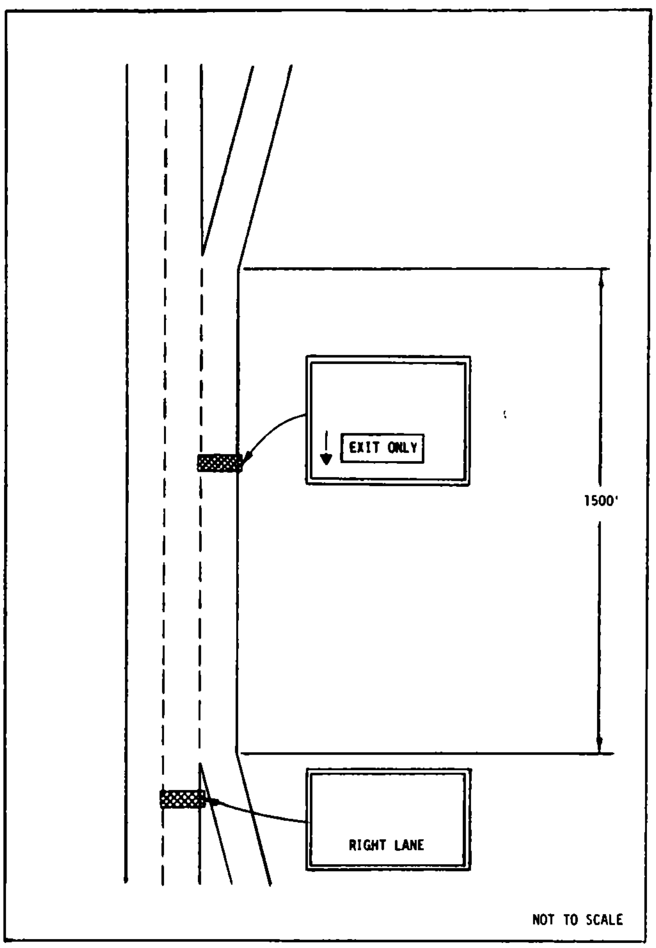
Ramp 42

Accident Experience Accident experience is heavy

Operational Characteristics The site is considered to be a hazardous location by many Collision attenuators have been installed in the gore area Many vehicles were observed to make last-minute lane changes

Figure A-41

A-87



A-88

Site 21

; Type: 4 - 3 Trap, right

Sight Distance

Vertical Curvature +1 45% grade

Horizontal Curvature Δ= 34°00'00" lt' D=3°00'00" R=1909 86

Pavement Type Concrete

ADT

One-Way

Two-Way 36,633 ADT

5-Minute Count

Total 139

Trucks 12 , Percentage 9 %

Lane 1 37

Lane 2 37

Lane 3 30

Lane 4 45

Lane 5

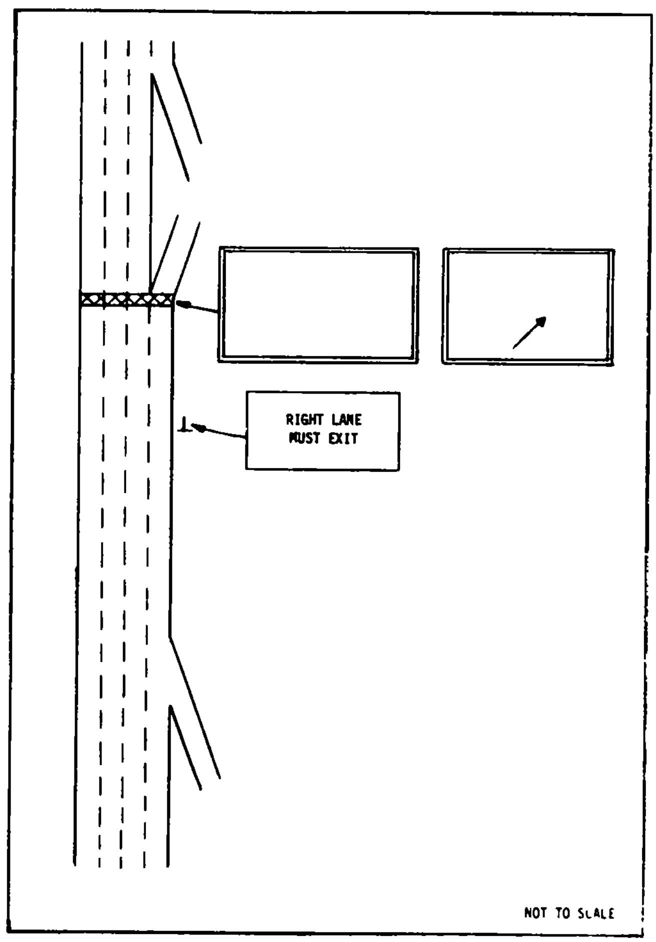
Accident Experience No accidents at gore area.

1969 - 11 . 1970 - 11 . 1971 - 14

Operational Characteristics Drop works well in morning. 1/4 traffic exits. all last minute maneuvers during this time period were exiters moving into the exit lane. Site is on a curve. Ramp moves off to right (straight line mainline continues through curve). Slight downgrade helps sight distance.

Figure A-42

A-89



A-90

Site 24

, Type: 4 - 3 Trap, right

Sight Distance .03 mile

Vertical Curvature -2 695% to +5 5% (1200' vertical curve)

Horizontal Curvature $\Delta = 5° 51' 56''$ Rt $D = 2° 30' 00''$ $R = 2291$ 83

Pavement Type Asphalt

ADT

One-Way.

Two-Way

5-Minute Count

Total 81

Trucks 4, Percentage 5 %

Lane 1 33 ramp

Lane 2 15

Lane 3 23

Lane 4 10

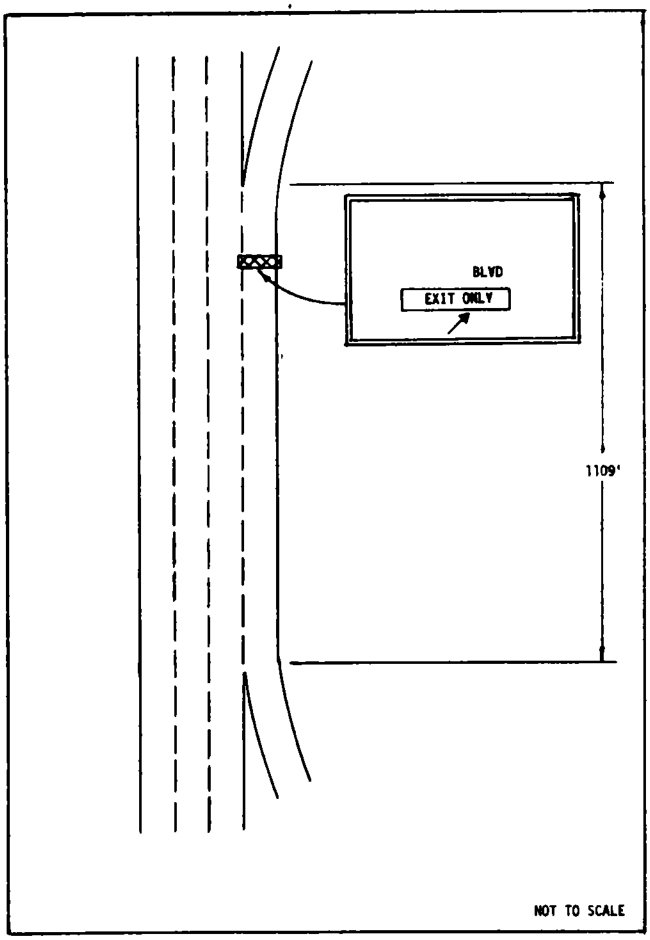
Lane 5

Accident Experience Several gore-located accidents have occurred

Operational Characteristics Lane drop is a problem even though volumes are light Vehicles entering from upstream ramp think they have a thru lane to travel in It abruptly ends Last minute maneuvers were mostly to avoid leaving freeway

Figure A-43

A-91



A-92

Site 32 -

, Type: 4 - 3 Trap, right

Sight Distance 37 miles

Vertical Curvature long upgrade cresting 2000' upstream, beginning of descent at -3.995% and leveling out at lane drop

Horizontal Curvature Slight curve to right downstream

Pavement Type Concrete

ADT

One-Way

Two-Way.

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

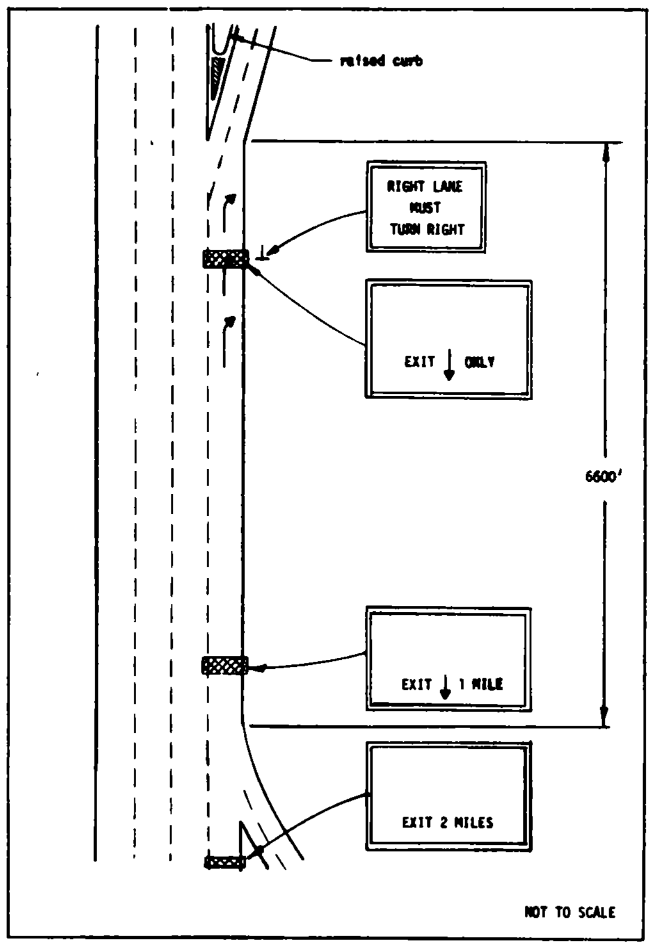
Lane 5

Accident Experience Many accidner- ' area, several may be lane drop related.

Operational Characteristics Traffic volumes were fairly light during mid-day. Some erratic manuevers were observed near the gore area.

Figure A-44

A-93



A-94

Site 33

, Type: Trap, left

Sight Distance 26 miles

Vertical Curvature

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks ; Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

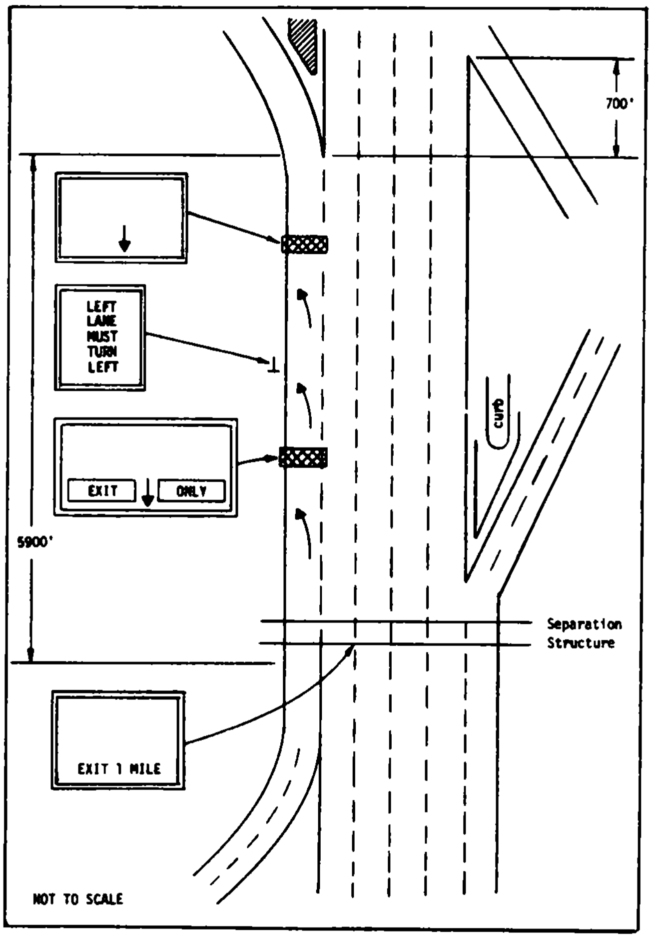
Lane 5

Accident Experience A three year study of accidents reveals 38 accidents occurred of which 3 were considered lane drop related

Operational Characteristics Traffic volumes are fairly light much maneuvering was observed in the section, however, direct observation of erratic maneuvers was not possible over a long period of time

Figure A-45

A-95



A-96

TYPE C — DROP-ADD SITUATIONS

Site 54

, Type 3 - 2 Drop-Add, left

Sight Distance 1 mile

Vertical Curvature very slight downgrade and upgrade, sag, at .4

Horizontal Curvature Slight right curve 40 - Sharp left curve .24

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

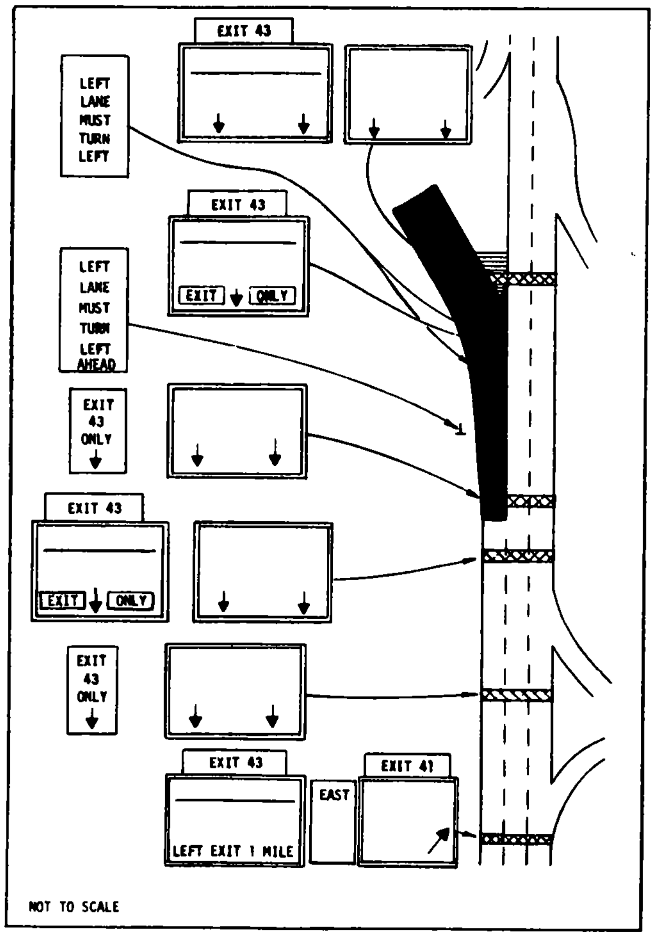
Lane 5

Accident Experience High accident location.

Operational Characteristics Many erratic maneuvers and operational problems have occured at this site. Site is due to be reconstructed to eliminate the lane drop

Figure A-46

A-97



A-98

Site 55

; Type: 4 - 3 left

Sight Distance

Vertical Curvature level

Horizontal Curvature Straight

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks ; Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics Construction barricades indicate that this is a construction zone and site operates accordingly Traffic is generally light

Figure A-47

A-100

Site 40

, Type: 4 - 3 Trap. w/escape route

Sight Distance

Vertical Curvature Slight downgrade

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way. 52,600

Two-Way.

5-Minute Count Time - 12:25 p.m

Total 314

Trucks 35 ; Percentage 11 %

Lane 1 59

Lane 2 68

Lane 3 88

Lane 4 73

Lane 5

Ramp 26

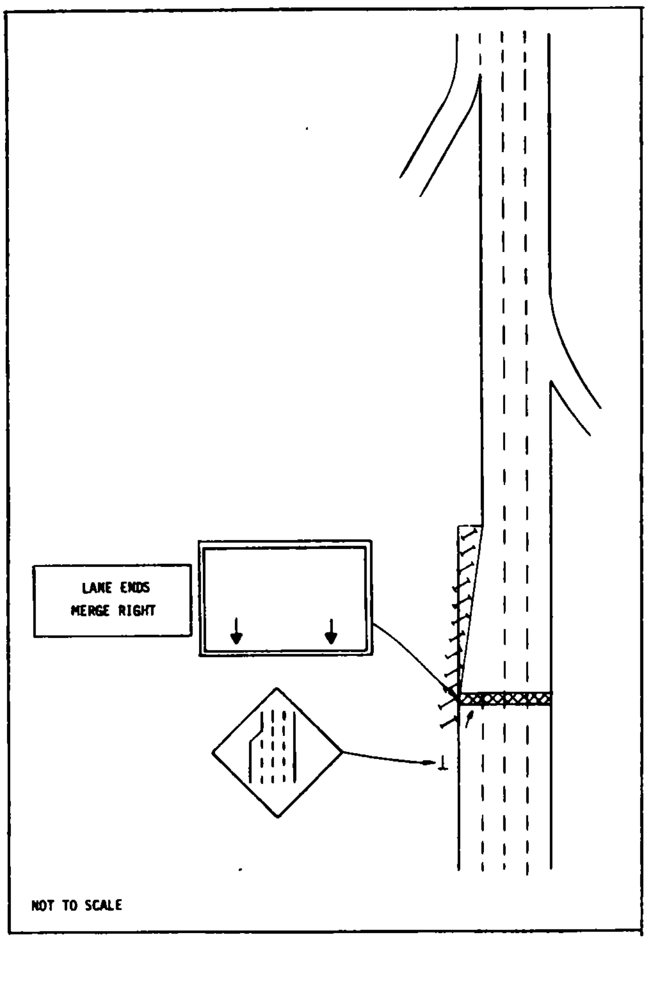
Accident Experience Total accidents: 1969--24, 1970--29, 1971--46 Avg --33

Accidents per 100,000,000 vehicles = 171.88 - see attached

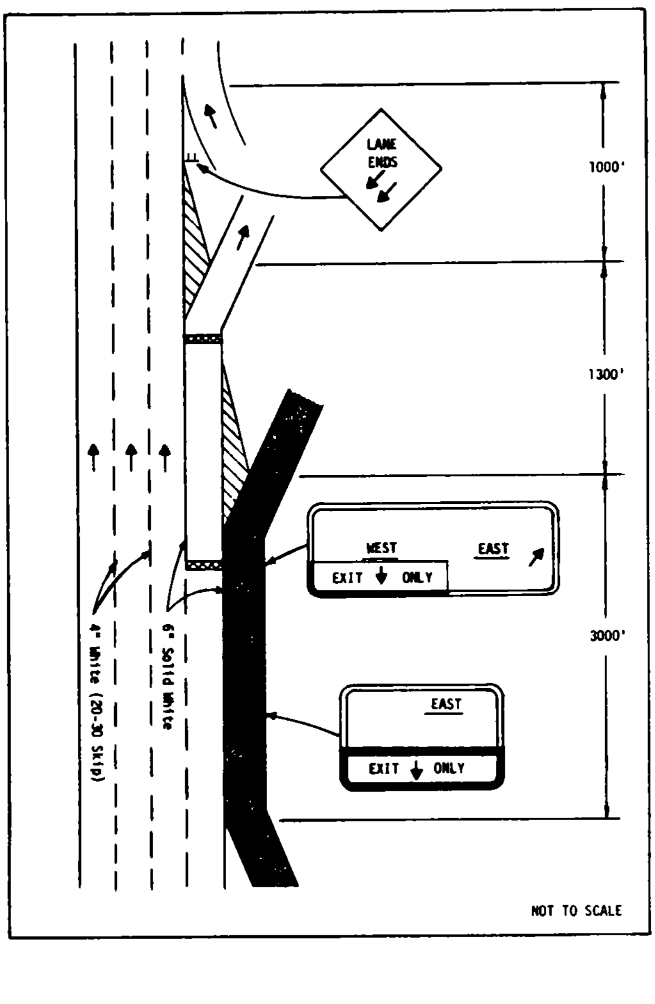
Operational Characteristics Capacity is exceeded during peak-hour afternoons Many vehicles use the escape lane It is being proposed that the fourth lane be continued through the interchange

Figure A-48

A-99



A-101



A-102

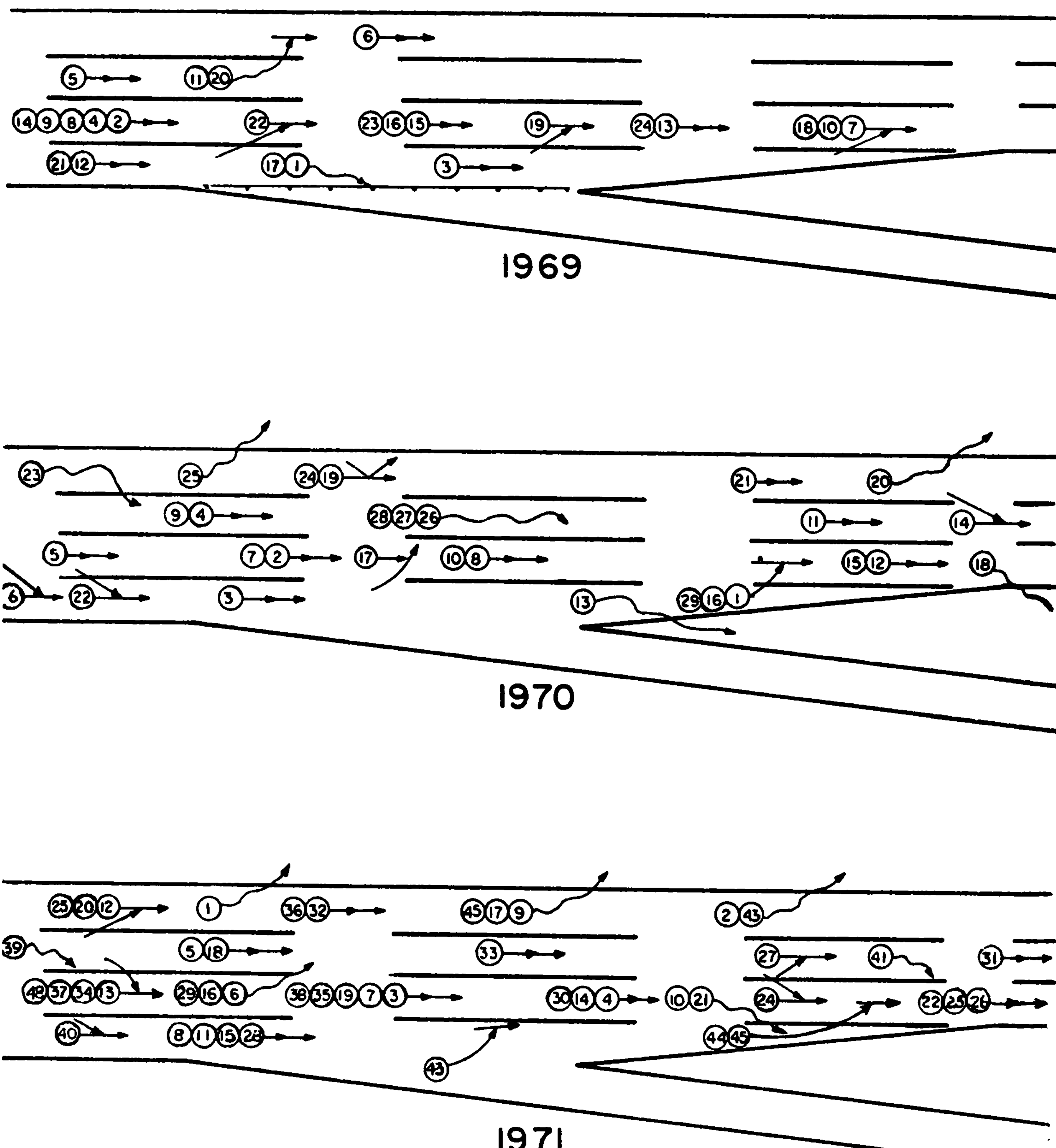


Figure A-48.

NORTHBOUND LANE DROP - ALL ACCIDENTS

	1969 INJ	1969 P D	1969 TOTAL	1970 INJ	1970 P D	1970 TOTAL	1971 INJ	1971 P D	1971 TOTAL	THREE YEAR TOTAL
Accident Types										
1 Rear End	5	10	15	5	7	12	9	11	20	47
2 Lane Change or Sideswipe	2	3	5	5	4	9	6	7	13	27
3 Out-of-Control	0	4	4	4	4	8	4	9	13	25
Total	7	17	24	14	15	29	19	27	46	99
Pavement Conditions										
1 Wet	1	2	3	3	8	11	7	14	21	35
2 Dry	6	15	21	10	8	18	12	13	25	64
Light Conditions										
1 Light	5	13	18	9	10	19	9	14	23	60
2 Artificial Illumination	2	4	6	3	7	10	10	13	23	39

Figure A-48

A-104

NORTHBOUND LANE DROP

Accidents Attributable to Bottleneck

	1970	1971
1) Total accidents between I -- and ---- Lane Drop	102	121
2) Total Accidents occurring during the peak hours (3 pm to 7 pm)	49	49
A Accidents attributable to the bottleneck and upstream delays	37	33
1 Accidents occurring at the bottleneck		
a) Rear End	11	15
b) Lane Change or Sideswipe	5	0
c) Out-of-Control	1	0
2 Accidents occurring upstream from the bottleneck		
a) Rear End	18	16
b) Lane Change or Sideswipe	2	2
c) Out-of-Control	0	0
3 Injury and Property Damage Accidents		
a) Injury	17	10
b) Property Damage	20	20

A-105

Site 41, Type: 4 - 3 trap, right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way 39,767

Two-Way

5-Minute Count Time - 1 50 p m

Total 220

Trucks 29, Percentage 13 %

Lane 1 67

Lane 2 68

Lane 3 40

Lane 4

Lane 5

Ramp 45

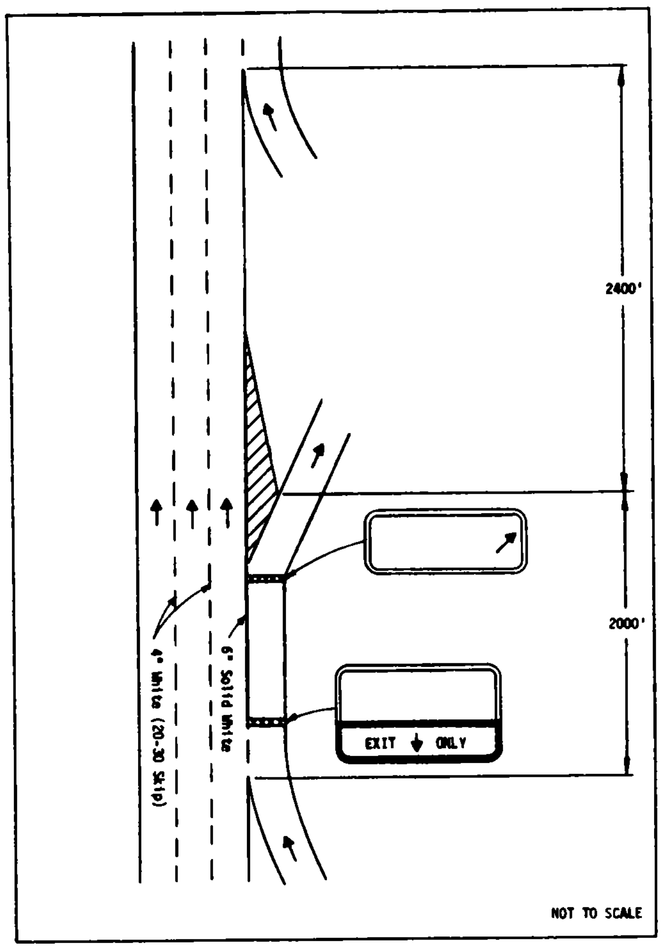
Accident Experience Total accidents: 1969 = 5 1970 = 3 1971 = 1 Avg = 3

Accidents per 100,000,000 vehicles = 20 67

Operational Characteristics Some vehicles tended to travel in the long escape lane for quite a distance The cross-hatching at the gore area does not necessarily convince drivers to merge into the through lanes

Figure A-49

A-106



A-107

Site 01
, Type 3 - 2 trap right
Sight Distance
Vertical Curvature

Horizontal Curvature

Pavement Type Concrete
ADT
One-Way 51,500 (1970) Peak Hour 3600 - 3650
Two-Way
5-Minute Count Time - 4 30 P M
Total 287
Trucks 23, Percentage 8 %
Lane 1 131
Lane 2 110
Lane 3 46
Lane 4
Lane 5

Accident Experience Heavy (per state estimate). Many accidents in area, primarily due to other factors, principally road curvature (compound curve)
Operational Characteristics Severe congestion in area due to causes other than lane drop Likewise, lane drop is not prime cause of accidents, although it probably contributes Speed limit recently lowered from 60 to 55 through the area Personal observation is that traffic is smoother - less speed differentials between vehicles

Figure A-50

A-109

Site 49
; Type: 4 - 3
Sight Distance
Vertical Curvature

Horizontal Curvature

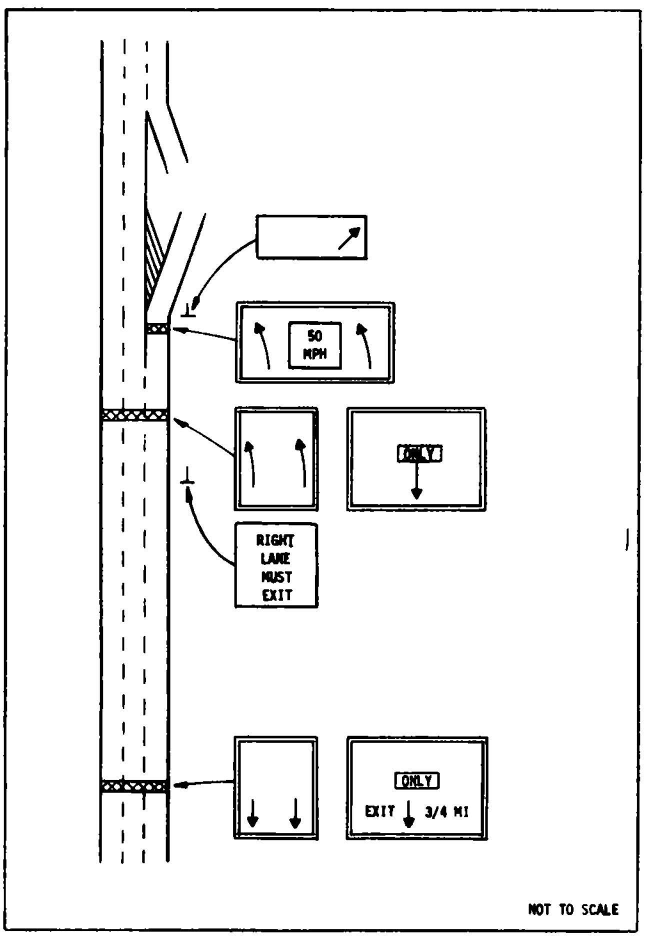
Pavement Type Asphalt/Concrete at 67 1
ADT
One-Way:
Two-Way:
5-Minute Count Time - 11:30 A M
Total 273
Trucks 0; Percentage % Trucks Prohibit
Lane 1 70
Lane 2 54
Lane 3 83
Lane 4 66
Lane 5
RM 10

Accident Experience

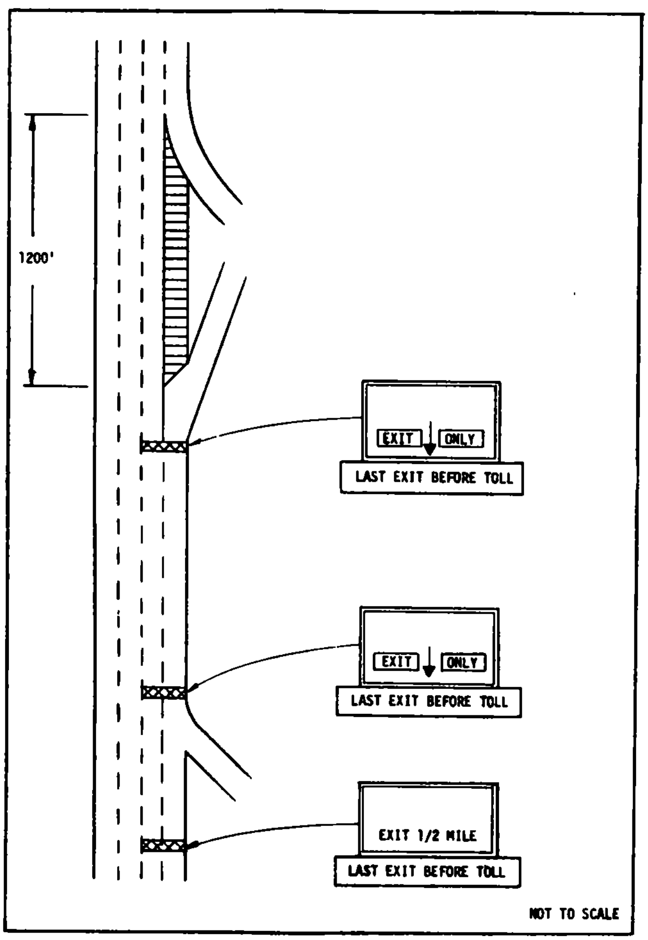
Operational Characteristics Many vehicles make last-minute maneuvers
Traffic composition included percentage of taxi-cabs

Figure A-51

A-108



A-110



A-111

Site 50

, Type* 4 - 3 Trap-Right

Sight Distance .24 miles

Vertical Curvature level

Horizontal Curvature Sharp right, Slight left curve

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count Time - 12 20 P M.

Total 217

Trucks 0 , Percentage %

Trucks Prohibited

Lane 1 22

Lane 2 55

Lane 3 70

Lane 4 70

Lane 5

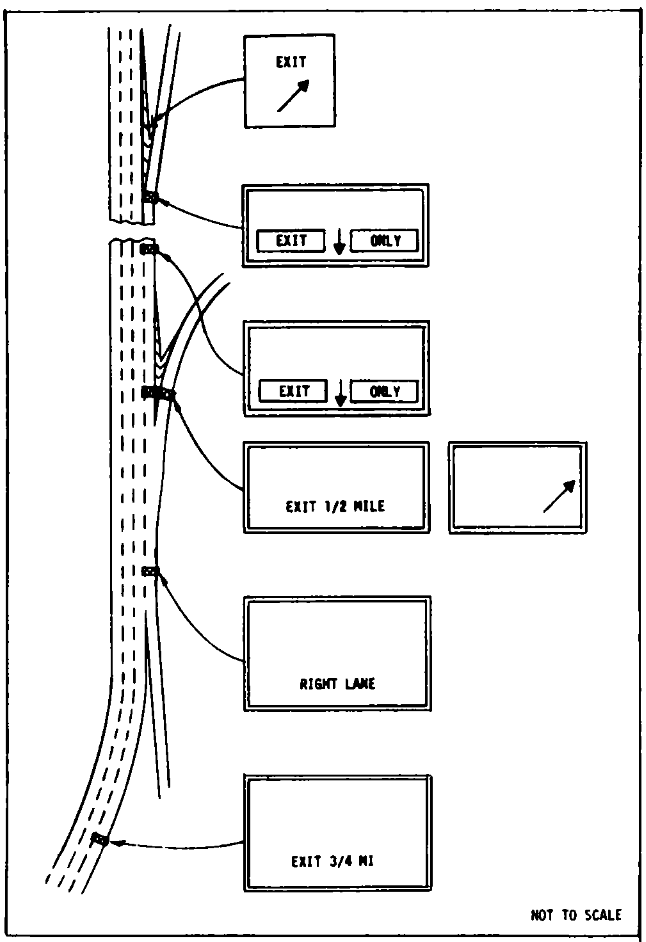
EM 10

Accident Experience

Operational Characteristics Many erratic manuevers occur at this site Violations of the operational lane drop are noticable during peak hour traffic

Figure A-52

A-112



A-113

Site 42

, Type* 3 - 2 Trap, right

Sight Distance .1 mile

Vertical Curvature level

Horizontal Curvature left hand sweeping curve ending 1 mile

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count Time- 1:35 P M

Total 130

Trucks 27 , Percentage 20 %

Lane 1 24

Lane 2 60

Lane 3 46

Lane 4

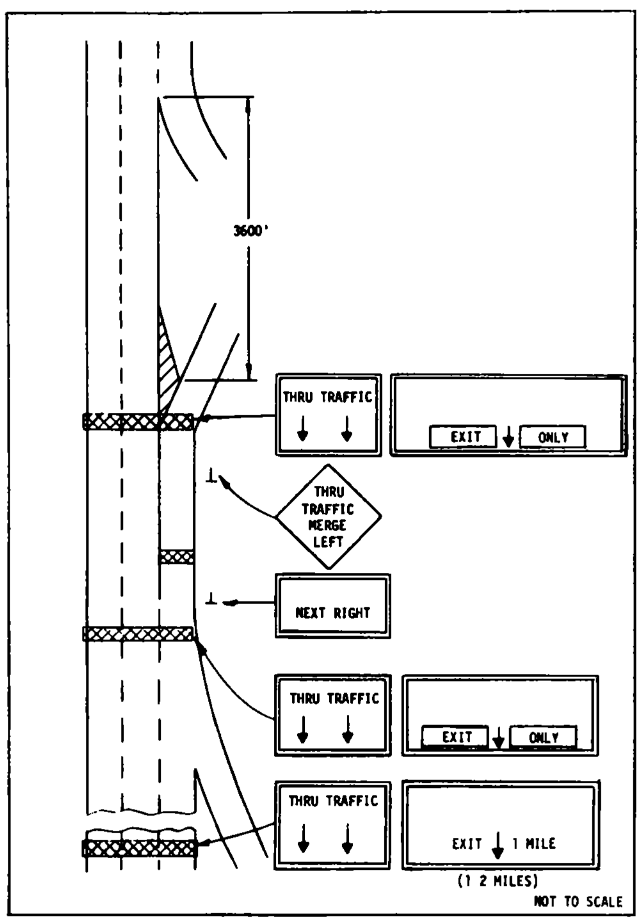
Lane 5

Accident Experience

Operational Characteristics A number of erratic maneuvers were observed.

Figure A-53

A-114



A-115

Site 30

, Type 4 - 3 Trap, right

Sight Distance 1 miles

Vertical Curvature

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way 72,200

Two-Way

5-Minute Count Time 5 30 P M

Total 313

Trucks 17 , Percentage 5 %

Lane 1 47

Lane 2 95

Lane 3 127

Lane 4 44

Lane 5

Accident Experience 1971 accident rate per MVM = 2 1, only one accident was judged to be lane drop related, 18 were congestion related.

Operational Characteristics Many last minute lane changes were observed Sight distance is restricted

Figure A-54

A-117
TYPE D -- STEP-OVER SITUATIONS

Site 15

; Type: 4 - 3 Trap right, add-on left

Sight Distance 1,500'

Vertical Curvature Level

Horizontal Curvature

Pavement Type

ADT

One-Way

Two-Way. 144,000 (1968) peak hour 11,200

5-Minute Count Time - 2:10 p m

Total 469

Trucks 70 ; Percentage 15 %

Lane 1 56

Lane 2 140

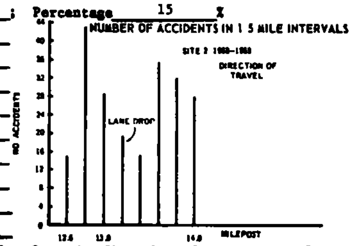
Lane 3 122

Lane 4 105

Lane 5

3 - 4 247

1 - 2 222



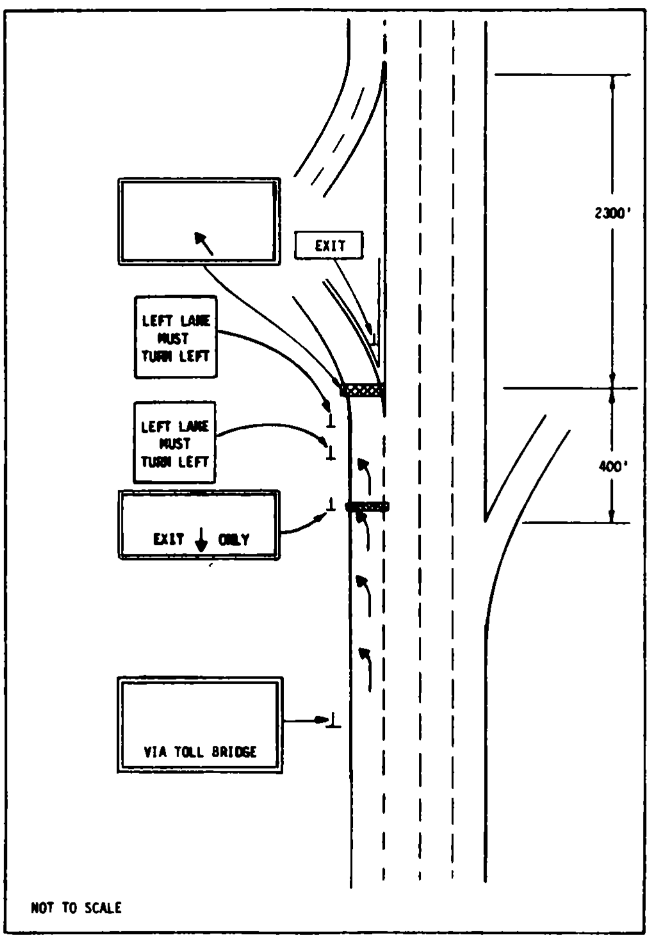
Accident Experience

Operational Characteristics The results from the first lane drop contract for this site, in which the left two lanes are merged, show a uniformity of behavior at all flow levels The two lanes that merge at the lane drop show a severe decrease in speeds; however, the right lane has virtually no speed drop and lane 2 drops only slightly The disturbances in speed in all lanes increases as the flow increases The traffic flow rate curves indicate that vehicles in the left lane follow the signing and start to merge right upstream of the lane drop, then are forced back to the left by the pavement markings in the lane drop taper area Flows in the right two lanes remain relatively undisturbed, except for the influx of a very few vehicles from the on-ramp upstream of the lane drop

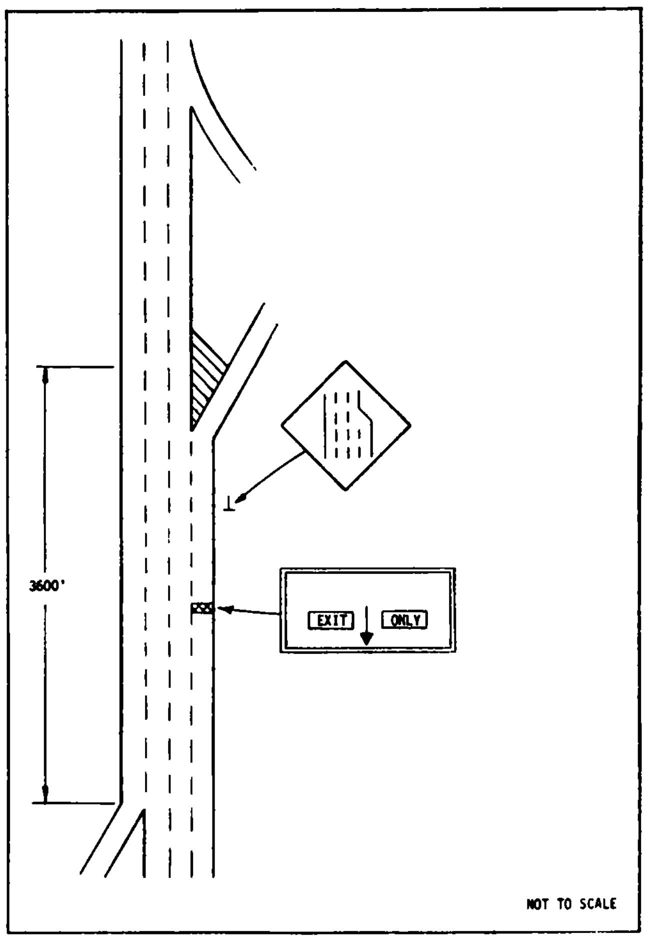
The slight speed increase in the right two lanes at the upstream end of the lane drop taper was observed during all three film periods, but no explanation of its cause has been found

Figure A-55

A-116



A-118



A-119

Site 56 -

, Type 3 - 2 Trap-Left

Sight Distance 05 mile

Vertical Curvature 15

Horizontal Curvature Slight curve to the right 22

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics Minimal sight distance causes many last minute manuevers Gore area is not very well defined

Figure A-56

A-121

Site 10

; Type: 3 - 2 left-taper

Sight Distance 32 miles

Vertical Curvature level

Horizontal Curvature Straight

Pavement Type Concrete

ADT

One-Way

Two-Way: 48,500 (1971)

5-Minute Count

Total 264

Trucks 18 ; Percentage 6 %

Lane 1 118

Lane 2 129

Lane 3 17

Lane 4

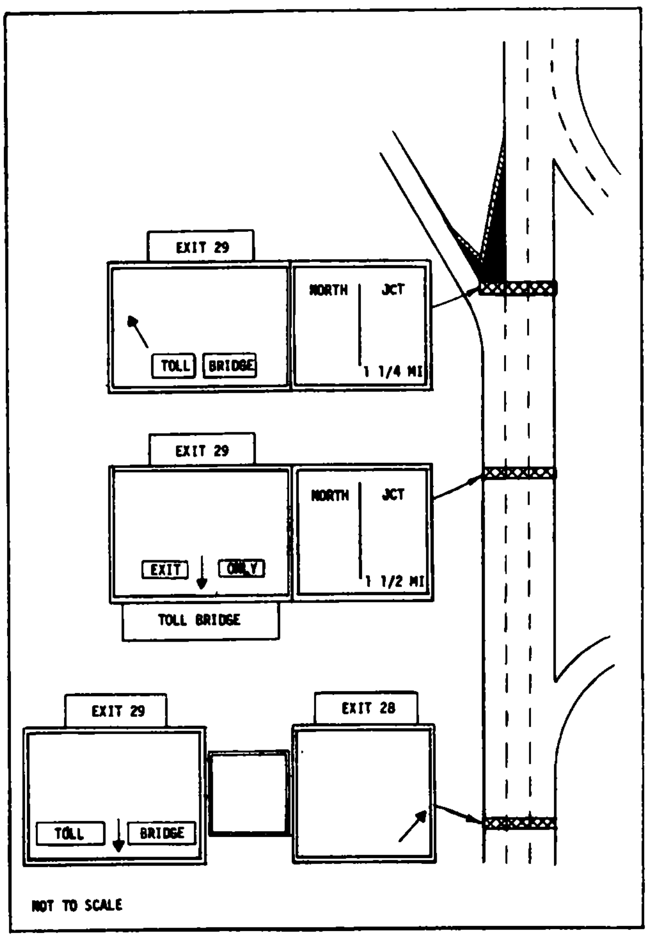
Lane 5

Accident Experience number of accidents 1971 14 (5 were in the immediate lane drop area)

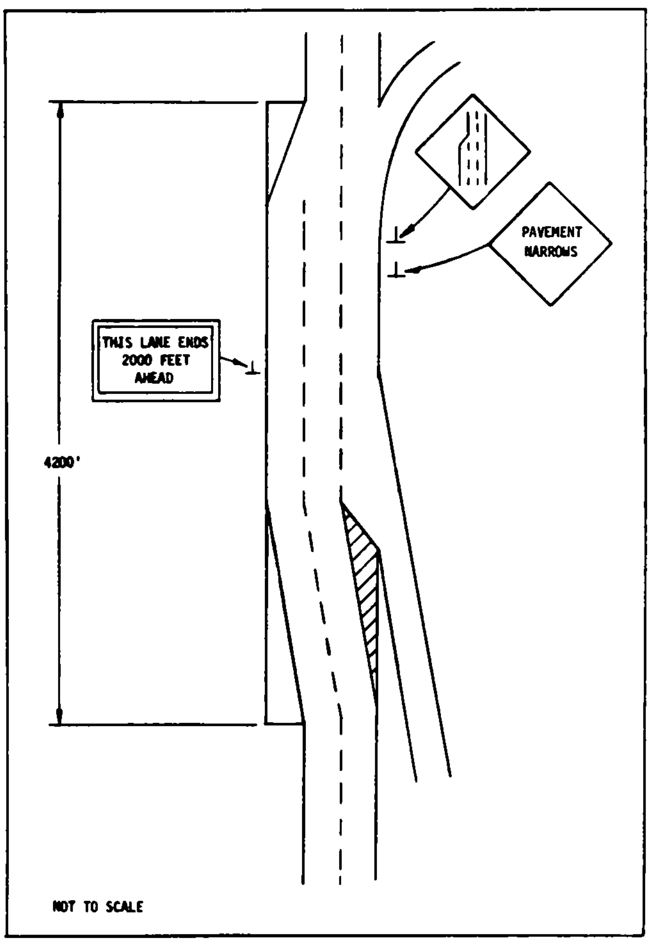
Operational Characteristics This site is heavily congested during the AM peak-hour Many last minute maneuvers were observed

Figure A-57

A-120



A-122



A-123

Site 11

; Type: 3 - 2 Taper, left

Sight Distance

Vertical Curvature Slight downgrade (65)

Horizontal Curvature

Pavement Type Concrete

ADT

One-Way:

Two-Way: 48,500 (1971)

5-Minute Count

Total

Trucks ; Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience Number of accidents 1971: 5 - at least one might be considered lane drop related.

Operational Characteristics This site is comparable to site 10, they are at the same location on opposite directions of travel. Many last minute, erratic manuevers were observed, even at low traffic volumes.

Figure A-58

A-125

Site 03

, Type 3 - 2 left

Sight Distance 700 feet

Vertical Curvature level

Horizontal Curvature tangent

Pavement Type Concrete

ADT

One-Way 51,500 (1970)

Two-Way 75,325

5-Minute Count Time - 5:00 P.M.

Total 313

Trucks 23 , Percentage 7 %

Lane 1 110

Lane 2 109

Lane 3 94

Lane 4

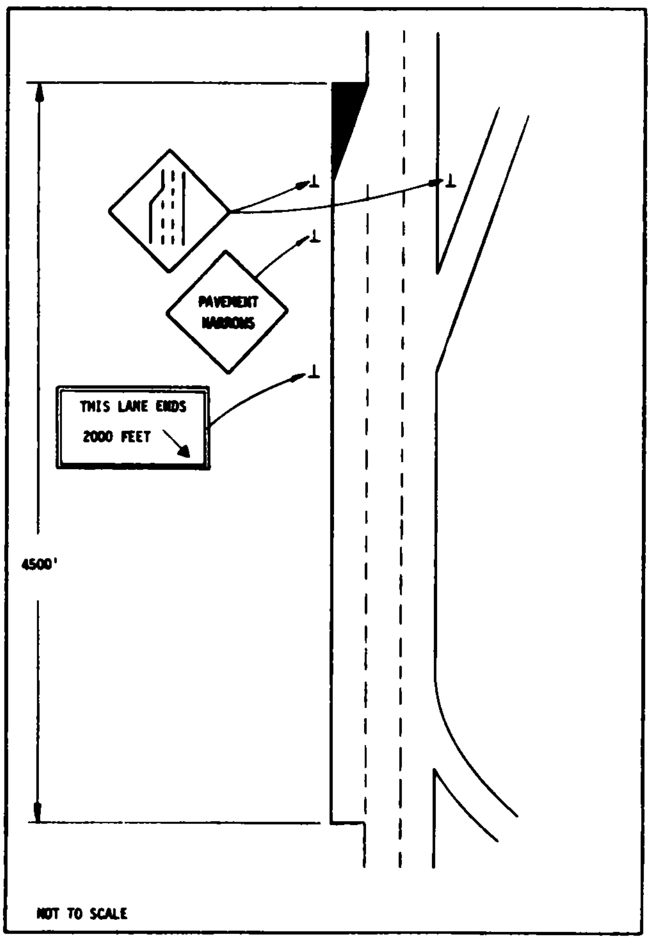
Lane 5

Accident Experience Light to moderate (average) - Few accidents.

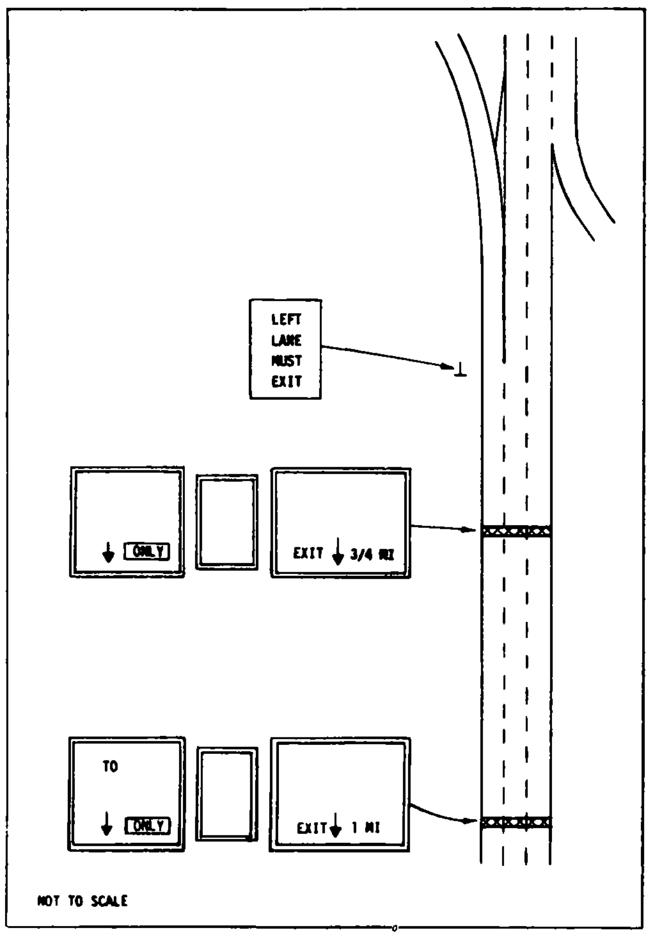
Operational Characteristics Suprisingly good operation considering trapped lane is around a horizontal curve, over a vertical curve, has limited sight distance to the gore, and exit is on the left. Speeds affected by relatively heavy truck volumes in left lane (Left exit leads to a truck terminal area) Geometry due to restricted R/W & planned connection to future crosstown freeway extending across the river

Figure A-59

A-124



A-126



A-127

Site 46

; Type: 4 - 3 Trap, left

Sight Distance 1,000'

Vertical Curvature Slight upgrade beginning at 95 miles upstream

Horizontal Curvature Right-curves at gore area; lane drop ramp to tangent

Pavement Type Concrete/asphalt at .3 mile

ADT

One-Way: 64,680

Two-Way:

5-Minute Count

Total

Trucks ; Percentage %

Lane 1

Lane 2

Lane 3 No counts available

Lane 4

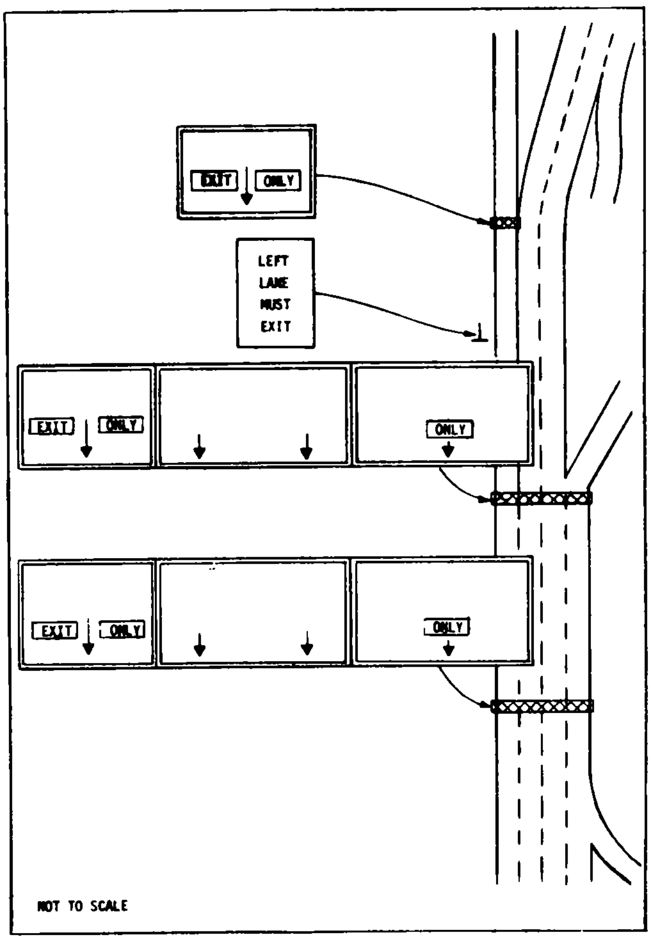
Lane 5

Accident Experience Accident rate in 1970 = 4.8 accidents/million vehicle miles

Operational Characteristics This site is known to be a service accident location The left lane seems to be unloaded well before the lane drop but congestion was apparent at 4:30 p.m. Breakdown may be due to capacity problems. The left tangent off-ramp lane drop combined with a sharp curve on the ramp produces a key hazardous location

Figure A-60

A-128



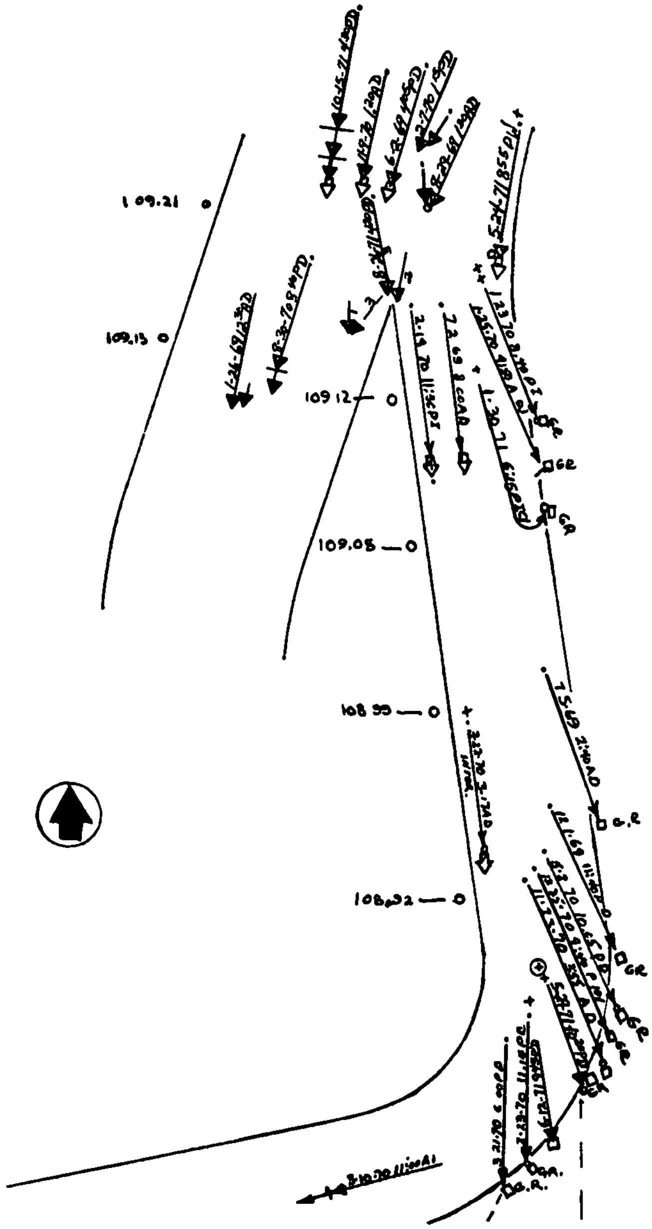


Figure A-60.

A-130

Site 29

; Type: 3 - 2 Trap, left

Sight Distance 11 mile

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way 7200 52,900

Two-Way

5-Minute Count Time - 9 30 a m

Total 224

Trucks 23 , Percentage 10 %

Lane 1 62

Lane 2 111

Lane 3 51

Lane 4

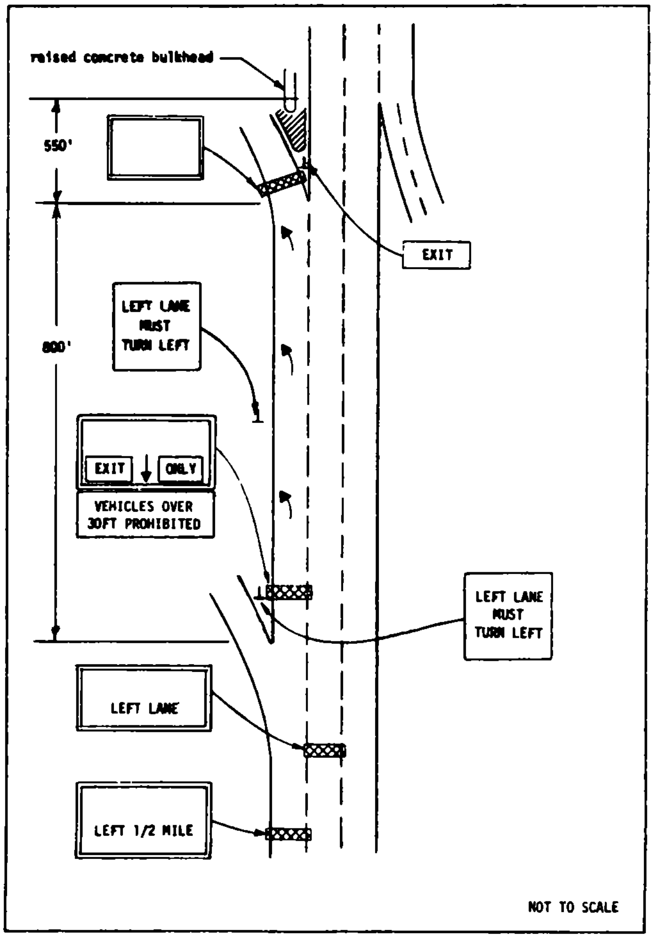
Lane 5

Accident Experience See attached

Operational Characteristics The site is considered to definitely be a high-accident location There is no escape lane from the trapped lane at the off-ramp Collision attenuators have been placed in the gore area Signing is poor because another left-hand exit to the freeway's express lanes is located only 1100' upstream of the lane drop. The signs located on the right probably are not terribly effective Hence the only two signs prior to the lane drop are within one-fifth mile of the exit

Figure A-61

A-131



A-132

ACCIDENT SUMMARY

Drop Lanes
1971 Accidents

Location Milepost	NB off 165.10 - 165.60	SB off 168.30 - 168.80
Property Damage Accidents	25	19
Injury Accidents	13	17
Fatal Accidents	1	0
Total Accidents	39	36
Persons Injured	24	28
Fatalities	1	0
Property Damage	$ 31,000	$ 27,000
Economic Loss	$141,000	$102,000
Accidents per MVM	4.0	2.1
ADT	52,900	72,200
Drop Lane Related Accidents	1	1
Rear-end Accs Due to Congestion	29	18

1971 average statewide rate for urban interstate roadway is 2 1.

Figure A-61

A-133

TYPE E -- LANE SPLIT SITUATIONS

Site 64

; Type: 3 - (2-1) Split

Sight Distance .2 mile

Vertical Curvature Slight downgrade

Horizontal Curvature Right hand curve

Pavement Type Concrete

ADT

One-Way

Two-Way:

5-Minute Count

Total

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience

Operational Characteristics The site had operational problems when the middle lane was an optional lane forming a 3 to 2-2 split The majority of the traffic uses the left fork of the split The site was restriped to force the left two lanes left only and the right lane right only According to the Department of Transportation, operations have improved considerably since the restriping

Figure A-62

A-135

Site 06

; Type: 5 to 3 (1/2 split) after add-on, right

Sight Distance

Vertical Curvature Slight downgrade upstream of lane split

Horizontal Curvature Generally straight, slight right-hand curve 6 miles upstream

Pavement Type Asphalt

ADT

One-Way

Two-Way: 159,700

5-Minute Count Time - 7:30 a m

Total 559

Trucks , Percentage %

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

1 - 3 286

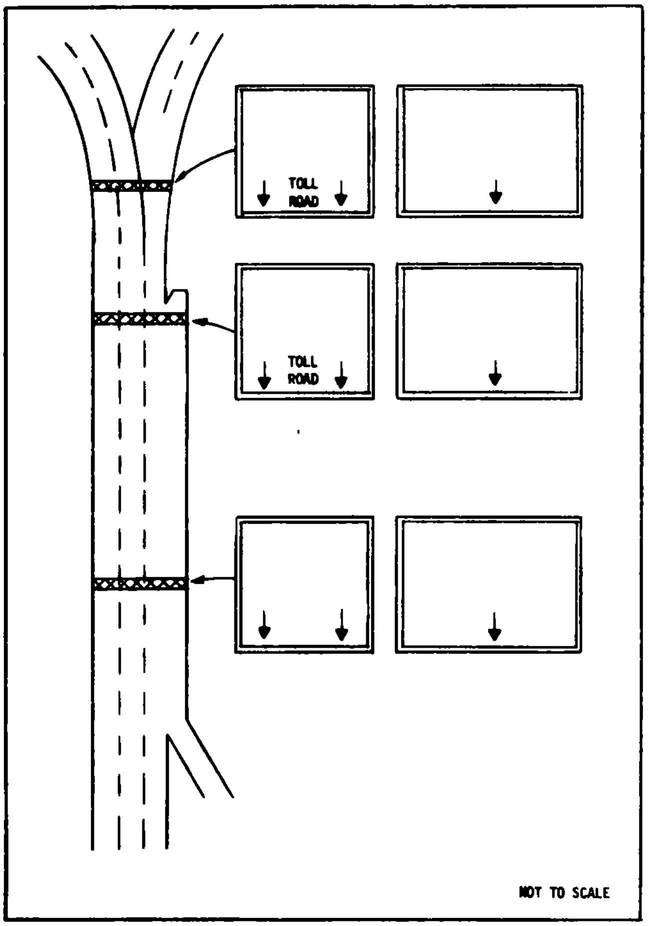
4 - 6 273

Accident Experience Accidents/Million Vehicle Miles 1964 = 86 1965 = 47
No of Fatalities 1964 = 6 1965 = 7 Fatality Rate 1964 = 0 79 1965 = 0 92

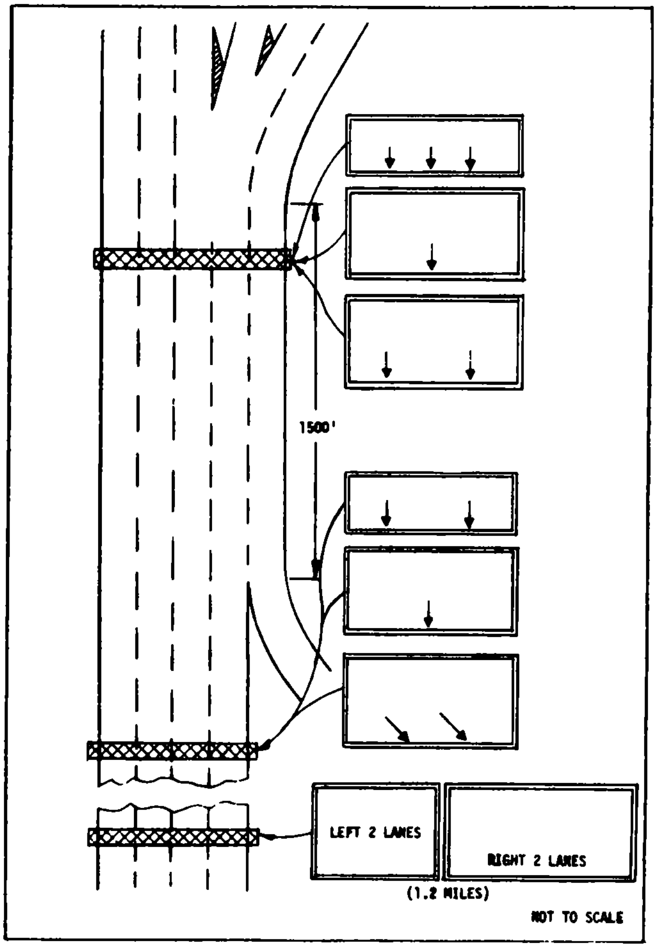
Operational Characteristics This site has congestion problems throughout most of the day Many last minute lane changes were observed Ramp traffic unable to merge downstream backs-up into lane drop site.

Figure A-63

A-134



A-136



A-137

Site 43

, Type 3 - (2-2) Split

Sight Distance 39 miles

Vertical Curvature Slight upgrade cresting at .94 miles upstream, slight downgrade leveling off at 59 miles upstream

Horizontal Curvature Slight

Pavement Type Concrete

ADT

One-Way

Two-Way

5-Minute Count Time 5 30 P M

Total 222

Trucks 5, Percentage 2 %

Lane 1 61

Lane 2 105

Lane 3 56

Lane 4

Lane 5

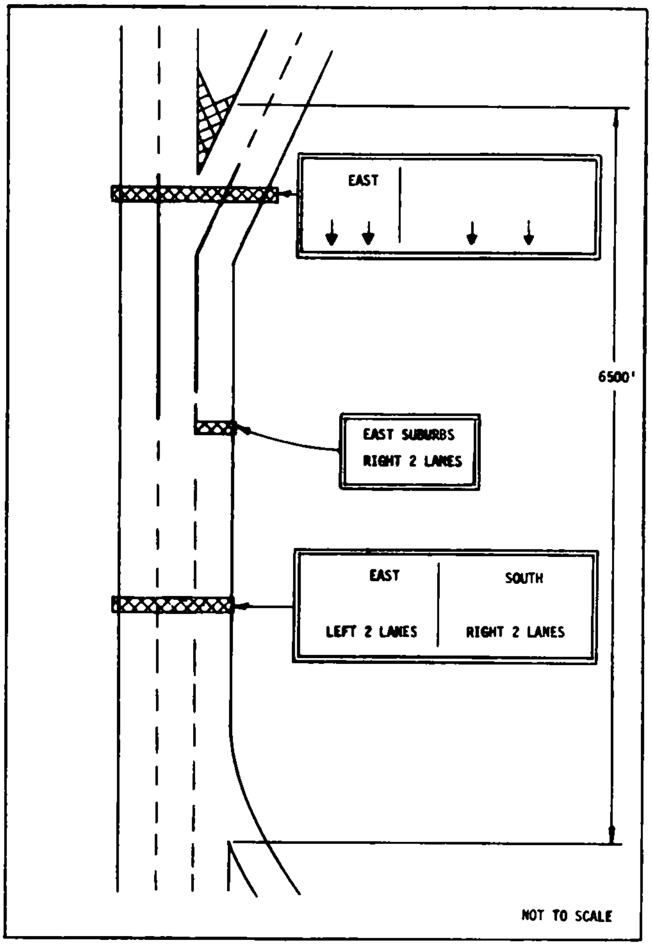
Right Fork 101

Accident Experience

Operational Characteristics Traffic volume splits evenly. There were a few erratic maneuvers observed, however, traffic generally flowed smoothly.

Figure A-64

A-138



A-139

Site 22

, Type: 4 - (2-2) split

Sight Distance 1 mile

Vertical Curvature +0.52% grade

Horizontal Curvature no curve

Pavement Type Concrete

ADT

One-Way

Two-Way 19,482

5-Minute Count

Total 256

Trucks 21; Percentage 8 5 %

Lane 1, Lane 2: 160 to I-15

Lane 3, Lane 4: 96 to I-80

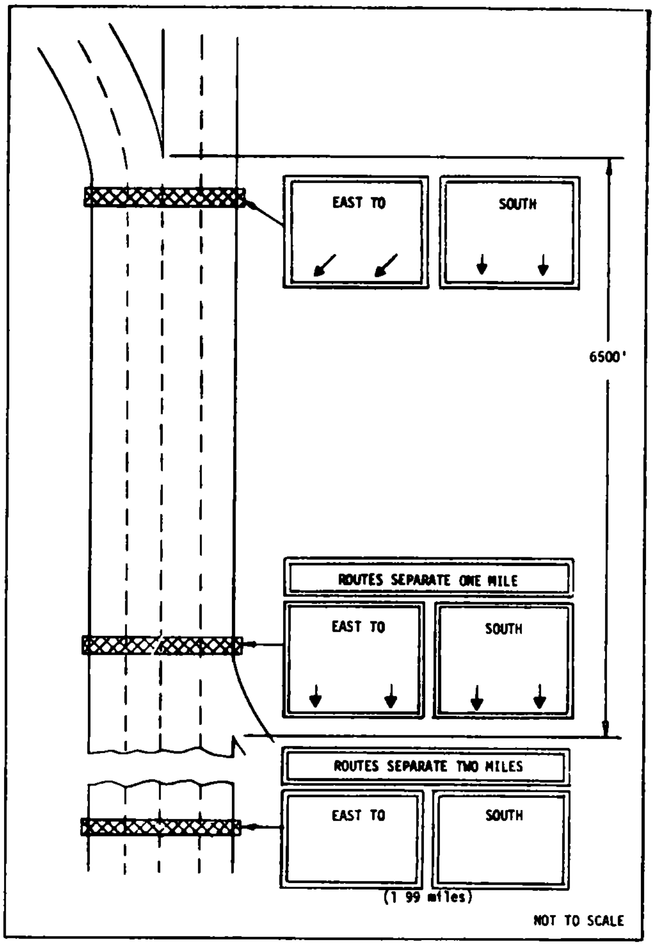
Lane 5

Accident Experience High accident experience indicated No actual data obtained

Operational Characteristics The gore area seems to appear very suddenly (almost unexpected) Last-minute maneuvers were observed with some frequency

Figure A-65

A-140



B-1

APPENDIX B - DATA COLLECTION FORMS USED IN PHASE I SITE VISITS

Appendix B consists of data forms developed for gathering lane drop information from State and Metropolitan agencies and at lane drop sites during Phase I efforts.

PHONE INTERVIEW SHEET

State ______ Date ______ Phone No ______

Person contacted ______ Position ______

Approximately how many lane drops are in your state? ______

Are any of them considered to be problems, in terms of high accident rates or unusual congestion? ______ How many? ______

Which ones? ______

How does your state determine problem locations? ______

Does your state have any documented lane drop design policies and practices? ______

How do problem locations deviate from the established design policies and practices? ______

B-2

Can SDC obtain plans of lane drops, accident and traffic counts, photographs, or other data? ______

Is there anyone else in your state (in a regional office perhaps?) who might have knowledge of lane drops there? ______

Can we visit you to collect data, discuss design policies and observe traffic at some of your lane drops? ______

Date of personal interview ______

Areas in state to be visited ______

Letter sent ______

Comments ______

B-3

OPERATIONS FORM

Organization ______ Date ______

Interviewed ______ Location ______

	Name	Title
1		
2		
3		
4		
5		

Where are your problem sites located?

1 ______
2 ______
3 ______
4 ______
5 ______
6 ______
7 ______
8 ______
9 ______
10 ______

B-4

-2-

Have you done any studies at these sites? If so, what kind, and what were the results? ______

Do you have any sites which you feel work well? ______

If so, where are they located?

1 ______
2 ______
3 ______
4 ______
5 ______

What type of accident record information and volume information can be made available for these sites (good and bad)? ______

What is the best method for obtaining this information? ______

B-5

POLICIES & PROCEDURES FORM

State ______________ Date ______________

Interviewed Location ______________

Name	Title
1 ______________	______________
2 ______________	______________
3 ______________	______________
4 ______________	______________
5 ______________	______________

Do you conform to the AASHO's red book guidelines? ________

Do you have a State Manual on Signing, striping, and geometric design ______ and does it conform to current practices? ________

Are there any lane drop sites in your state which conform to current design specifications? ________ If so, where are they? ______________

____

What has been your experience with their operating characteristics?

____

____

Briefly describe current guidelines for striping, signing & geometric design (Attach handouts)

____

____

____

B-6

____

____

____

____

____

Have there been any lane-drop studies done in your State? ________,

If so, are there reports available? ________

Are there any studies currently in progress? ________

If so, when will they be completed and can copies of any reports be made available to us? ________

Are there geometric plans and signing and striping inventories availabl: for sites? ________

What is the best method for obtaining this information?

____

B-7

SITE FORM

Site No ________ Route Designation ________

LOCATION State ______________, City ______________,
Route No ________

Characteristics upstream of lane drop

Geometric Design

Distance to closest ramp ________

Name of ramp ______________

Type of ramp ______________ (on, off, direct, loop, etc)

Number of freeway lanes ________, Width of lane ________

Width of median ________, Width of shoulder ________

Gradient ________

Length of graded section ________

Begin point ________ End point ________

Curvature ________

Begin point ________ End point ________

Pavement type ______________

Sight Distance ______________ (to end of taper or lane)

Characteristics downstream of lane drop

Geometric Design

Distance to closest ramp ________

Name of ramp ______________

Type of ramp ______________ (on, off, direct, loop, etc)

B-8

Number of freeway lanes ________, Width of lane ________

Width of median ________, Width of shoulder ________

Gradient ________

Length of graded section ________

Begin point ________ End point ________

Curvature ________

Begin point ________ End point ________

Pavement type ______________

Sight distance ______________ (to end of taper or lane)

Lane drop characteristics

Which lane physically dropped? ________

Which lane operationally dropped? ________

Type of lane drop ________

Type of lane split ________

Length of physical taper ________

Length of operational taper ________

Provide sketch of area

B-9

OPERATIONAL CHARACTERISTICS

Site No _______ Route Designation (memorial name) ____________________

Location State ______________, City ____________________

Route No ______________, Direction ______________

ADT ____________ for the year ________

Overall accident experience ______________

Date of site visit ______________

Day of week _______, Time of day ________ to ________

5-minute counts

Time

	Lanes						
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______
______		______	______	______	______	______	______

B-10

Odometer readings & speeds

Time of day 1st pass 2nd pass

____________ ____________

	Location	Speed	Speed
Nearest upstream ramp	____________	________	________
Beginning of taper	____________	________	________
End of taper	____________	________	________
Ramp gore (trapped lane)	____________	________	________
Nearest downstream ramp	____________	________	________
Sign location 1	____________	________	________
Sign location 2	____________	________	________
Sign location 3	____________	________	________
Sign location 4	____________	________	________
Sign location 5	____________	________	________

Sight distance to end of taper or gore ____________

Comments about operational characteristics of site

____

____

____

____

____

____

____

B-11

SIGNING

Type ______________

Message ______________

Color background __________, letters __________

Size width ____________, height ____________

Location above ground ____________

Location in relation to freeway ____________ (1-ft, right, overhead)

Distance to lane drop ____________

PAVEMENT MARKINGS

Location begin point __________ end point __________

Type of marking ______________________________

Color __________

C-1

APPENDIX C - BEFORE/AFTER STUDY AT A METROPOLITAN LANE DROP LOCATION

A "before-and-after" study was conducted at an urban lane drop site to determine if traffic operations and safety at the site could be improved through the implementation of traffic control devices

In June, 1972, a left-hand lane drop was created near an off-ramp of a northbound freeway. Because traffic volumes are very heavy in the left lanes during peak-hour operation, it was decided that the lane drop should be accomplished by operationally merging the right two lanes upstream of the physical lane drop An operational right-lane taper was installed for this purpose. Subsequent problems with this configuration resulted in the transforming of this lane drop into an operational exit ramp drop in January 1973. Both "before" and "after" data were collected at the site The data support the subjective opinion that improvement in operations and an apparent lessening of driver confusion resulted from the change.

"Before" Site Configuration

The lane drop was created when a fifth lane was added in the median of a four-lane section of freeway The fifth lane was continued from a left-hand on-ramp connection from another freeway approximately three miles upstream of the selected off-ramp The lane was physically dropped on the left, but operationally the two right lanes were merged by moving the four left lanes of traffic to the right one lane-width through pavement striping Advance signing and pavement markings instructed an approaching driver in the right lane to merge left. Figure C-1 illustrates the geometric configuration and traffic control devices at the lane drop site.

C-2

"After" Site Configuration

On January 28, 1973, the site was reconfigured to drop the right lane operationally at the selected off-ramp An existing short up-grade between the off-ramp and the beginning of the old operational taper was effectively used to hide the physical continuation of the right lane from the approaching right lane driver. Figure C-2 illustrates the "after" design configuration.

Analysis of Configurations in Terms of Lane Drop Design Principles

In the main body of the report, eight lane drop design principles were outlined It was expected that if these principles were violated, poor traffic operations would result; conversely, if these principles were obeyed, lane drop operations would be satisfactory A listing of the design principles and the adherence of both design configurations to these principles follows.

1 THE LANE DROP SHOULD BE PLACED WHERE THE SURFACE OF THE ROADWAY REMAINS VISIBLE CONTINUOUSLY FOR A SIGNIFICANT AMOUNT OF TIME

	-Before-		-After-
NO	Sight distance is 650'; a vertical curve hides the operational lane drop.	YES	Sight distance is 1650'; the operational lane drop is on a slight up-grade

C-3

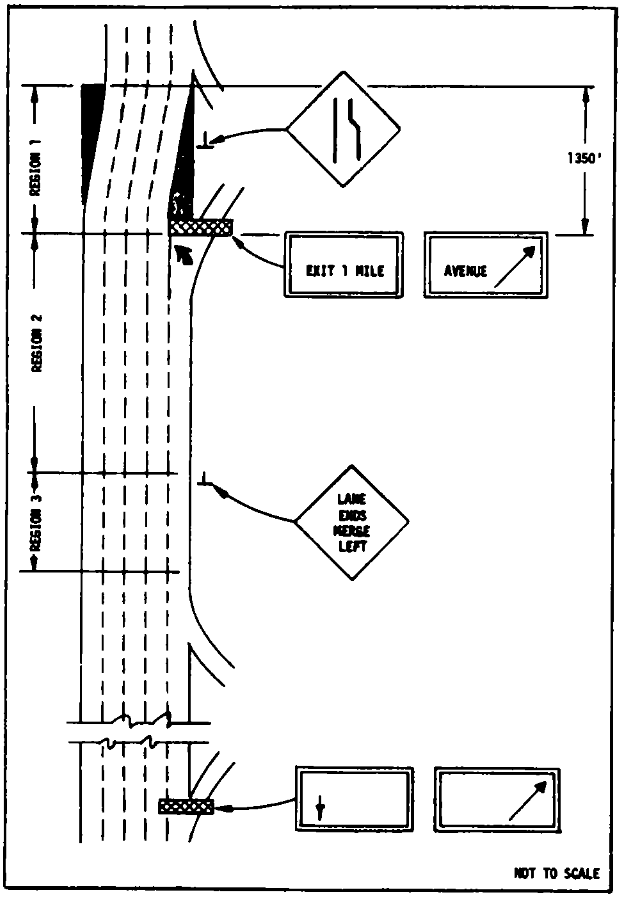


Figure C-1. Schematic Drawing of "Before" Configuration

C-4

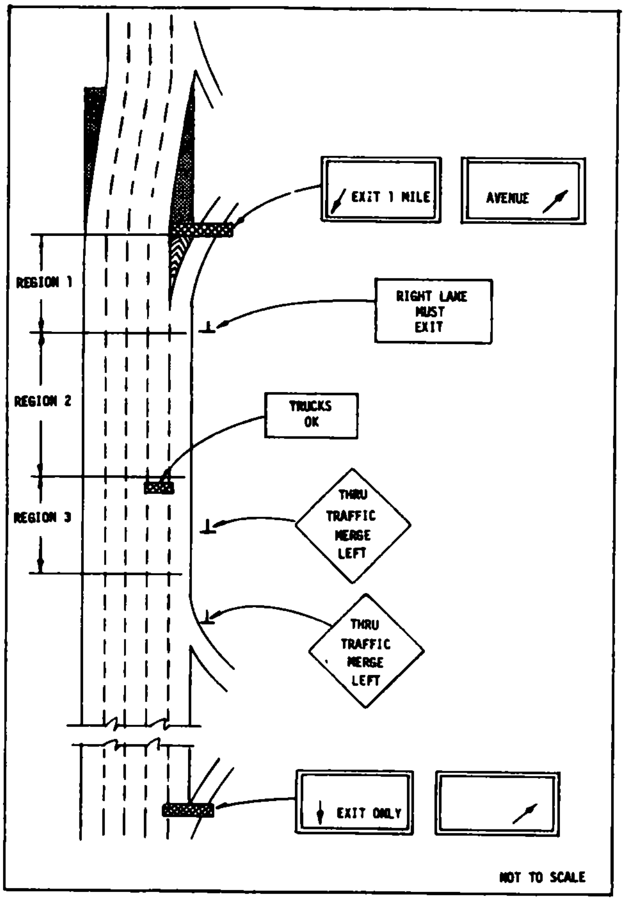


Figure C-2. Schematic Drawing of "After" Configuration

C-5

2 THE LANE DROP SHOULD BE PLACED AWAY FROM ATTENTION-DIVIDING CONDITIONS, SUCH AS RAMPS OR COMPLICATED DIRECTIONAL SIGNING

	-Before-		-After-
NO	The off-ramp is situated in the middle of the lane drop signing sequence, 650' upstream of the beginning of the taper	MAYBE	The off-ramp is now part of the lane drop, an on-ramp 3850' upstream of the lane drop might cause problems for entering drivers If so, an additional sign on or near the on-ramp might help

3 THE LANE DROP TAPER SHOULD ALLOW FOR A SMOOTH TRANSITION FOR DRIVERS TO MAKE A LANE CHANGE IN THE TAPER AREA AND SHOULD PROVIDE ADEQUATE VISUAL CUES WHICH INFORM THE DRIVER THAT HIS LANE IS ENDING

	-Before-		-After-
NO	The 50 1 taper is probably adequate but visual cues are very misleading, the lane physically continues in a straight line		Not applicable, lane drop is at an exit ramp

C-6

4 THE LANE DROP SHOULD BE PLACED ON THE BETTER SIDE OF FREEWAY FOR GIVEN TRAFFIC AND GEOMETRIC CONDITIONS

	-Before-		-After-
YES	Constructionally the lane drop should be on the left, operationally on the right It is so placed.	YES	Same as "Before "

5 THE LANE SHOULD APPEAR TO PHYSICALLY END ON THE SAME SIDE OF THE FREEWAY AS THE OPERATIONAL LANE DROP

	-Before-		-After-
NO	The right lane appears to, and does physically, continue through the lane drop area	YES	The vertical up-grade hides the sighting of the right lane downstream of the lane drop area from the operational lane drop viewing point

6 WHEN A LANE DROPS AT AN EXIT RAMP, AN ESCAPE AREA OF ADEQUATE DIMENSIONS SHOULD BE PROVIDED TO ALLOW FOR A SMOOTH TRANSITION INTO THROUGH LANES

	-Before-		-After-
	Not applicable	YES	The operational gore extends for 300' and the unused old through lane continues for 650' before the beginning of the physical taper area

C-7

7 WHEN A LANE IS ADDED AT AN ON-RAMP AND DROPPED AT A NEARBY OFF-RAMP, THE ENTERING DRIVERS SHOULD BE NOTIFIED THAT THE LANE THEY ARE TRAVELING IN IS NOT A CONTINUOUS LANE FOR THROUGH TRAVEL

	-Before-		-After-
	Not applicable		Not applicable

8 CONSISTENT AND APPROPRIATE TRAFFIC CONTROL DEVICES (TCDs) SHOULD BE USED IN ADVANCE OF A LANE DROP

	-Before-		-After-
NO	TCDs inform the driver that his lane is physically ending, which is inconsistent with the fact that the lane is visible after the lane drop The first TCD is 1300' upstream of the beginning of the taper, not much notice to make a smooth transition out of the lane	YES	Signing, which begins just over 1 mile upstream, and skip-striping, which begins 1/2 mile upstream, give adequate and consistent warning that the lane is for exiting vehicles only Notice that there is no mention of the lane physically ending, only that the lane is reserved for exiting vehicles

In summary, the original lane drop violated several of the design principles, but the current lane drop seems consistent with most of these principles

C-8

Presentation of Data

"Before" data were collected on two different occasions On Thursday, July 20, 1972, afternoon peak-hour traffic was observed, and on Wednesday, January 24, 1973, midmorning off-peak traffic was observed Volume counts, lane distributions, traffic composition, and ramp volumes were collected on both days Due to the development of new data collection and analysis techniques in the interim between the two data collection efforts, peak-hour counts were made 600 feet downstream of off-peak hour counts

Peak-hour and off-peak-hour data were again collected at the site after the changes were made Since a change in configuration (from a taper to a ramp drop) was made, approximately four weeks was allowed for the settling down of the site before data were collected

Table C-1 summarizes average six-minute volume counts, lane distribution, traffic composition, and ramp volumes both before and after the change during peak-hour and off-peak-hour operation

C-9

TABLE C-1 - "BEFORE" AND "AFTER" AVERAGE SIX-MINUTE COUNTS

	Total	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Off-Ramp	Trucks
Before Peak-Hour* 7/20/72 (Thurs) 3 30-5 00 PM	809	-	157	179	166	191	116	22
After Peak-Hour* 3/1/73 (Thurs) 3 30-5 00 PM	831	-	173	178	187	203	90	21
After Peak-Hour 3/1/73 (Thurs.) 3 30-5 00 PM	773	107	131	181	175	179	-	20
Before Off-Peak-Hour, 1/24/73 (Wed) 10.30-11 00 AM	480	86	111	107	103	73	46	32
After Off-Peak-Hour 2/23/73 (Fri) 10 30-11 30 AM	468	50	105	122	106	85	44	33

*These counts were made approximately 600' downstream of the other counts

In addition, lane change information was obtained in the off-peak data collection activity. For this purpose, the site was divided into three regions. Region 1 contained the area from the selected exit gore to the end of the taper area, Region 2 contained the area from the LANE ENDS MERGE LEFT sign to the exit gore, Region 3 contained the area from 2800 feet upstream of the taper to the sign. These regions are indicated in Table C-1 Six-minute counts were made of vehicles changing either into or out of the lane drop lane for each region. These average counts are contained in Table C-2 If a vehicle did not move out of lane 1 by the end of the taper area, it was still counted as moving out of lane 1 in region 1.

C-10

TABLE C-2 - "BEFORE" AND "AFTER" SIX-MINUTE LANE CHANGE COUNTS

	Region 1		Region 2		Region 3	
	Into Lane 1	Out Of Lane 1	Into Lane 1	Out Of Lane 1	Into Lane 1	Out Of Lane 1
Before Off-Peak-Hour 1/24/73 (Wed) 10·30-11 30 AM	0	33	1	6	12	7
After Off-Peak-Hour 2/23/73 (Fri) 10 30-11 30 AM	0	0	0	11	7	18

Table C-2 indicates a significant change in where vehicles move out of the dropped lane However, since the operational lane drop was moved upstream approximately 650 feet, it is reasonable to readjust the region locations to account for the change in configuration. This was done (the new region locations are illustrated in Figure C-2) and additional volume and lane change data were collected on Friday, March 16, 1973. Table C-3 summarizes the volume and lane change data from that effort compared with the "before" data. Note that the regions and volume count locations are relative to the location of each lane drop configuration and, therefore, counts were not taken at the same physical location. Refer to Figure C-1 and C-2 for the locations of region boundaries

C-11

TABLE 3 - "BEFORE" AND "AFTER" VOLUME AND LANE CHANGE AVERAGE SIX-MINUTE COUNTS

	Total	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Off-Ramp	Nearest Upstream On-Ramp	Trucks
Before 1/24/73 (Wed) 10 30-11 30 AM	480	86	111	107	103	73	46	-	32
After 3/16/73 (Fri) 10:00-11:00 AM	459	54	104	100	110	91	44	42	38

	Region 1		Region 2		Region 3	
	Into Lane 1	Out Of Lane 1	Into Lane 1	Out Of Lane 1	Into Lane 1	Out Of Lane 1
Before 1/24/73 (Wed) 10 30-11 30 AM	0	33	1	6	12	7
After 3/16/73 (Fri) 10 30-11 00 AM	1	5	6	15	8	16

Analysis of "Before"/"After" Data and Site Observations

"Before" traffic operations during both peak-hours and off-peak hours were judged less than optimum Through observation of traffic it was concluded that two undesirable traffic patterns were taking place:

(1) Many drivers made erratic maneuvers in moving out of the lane drop area and

(2) Many more drivers refused to leave the operational drop lane at all and continued in a straight-line direction, while all other traffic moved to the right one lane-width

C-12

Erratic maneuvers were observed with some frequency These maneuvers were generally either reduction in speed (indicated by brake light illumination) or the acceptance of small gaps to accomplish a lane change just prior to, or in, the taper area. It is felt that several factors caused drivers to misunderstand what was expected of them and, therefore, made erratic maneuvers to compensate

First, advance warning was accomplished by a LANE ENDS MERGE LEFT sign approximately 1350 feet upstream of the taper and 750 feet upstream of the exit ramp In addition, several white pavement arrows were located between the exit ramp and the lane drop taper Apparently the advance warning did not effectively inform the drivers of the impending lane drop, because many vehicles, including large commercial trucks, did not move out of the lane in advance of the lane drop area

Secondly, sight distance was restricted by the presence of a short up-grade beginning at the exit-ramp gore and cresting near the beginning of the lane drop taper This sight distance, approximately 650 feet, does not allow many drivers to observe and react to the lane drop without making an erratic maneuver

Finally, the lane drop itself could be misleading to a driver because he can see that a through traffic lane continues in his line of sight downstream of the lane drop This may cause confusion as to whether he should believe the traffic control devices and merge left or believe his eyes and continue straight

Many drivers in this situation continued straight through the lane drop area, causing a second type of operational conflict The straight-through traffic forced a fight for lane position with the drivers following lane lines and, therefore, moving over from the left In some cases when two vehicles in adjoining lanes arrived simultaneously at the lane drop merge area, an erratic maneuver was committed by one or both drivers to avoid an accident

The change in configuration seems to have improved the lane drop site considerably Drivers appear to be moving out of the drop lane further upstream and in a safer manner

Traffic volumes, traffic compositions and off-ramp volumes were consistent between the "before" and "after" data collection activities The lane distributions did change somewhat, but this is to be expected if drivers are moving out of the drop lane earlier

In addition, it should be noted that although drivers moved out of the drop lane well in advance of the gore area in off-peak-period operations, many conflicts and late lane changes were observed during peak-period operation This is probably due to the lack of suitable gaps for merging in heavy traffic, but the number of such instances was sharply reduced after the lane drop was reconfigured

A graph, as shown in Figure C-3, of cumulative percent lane changes out of the drop lane was produced for several metropolitan area lane drops A more convex curve indicates that most drivers are leaving the drop lane well in advance of

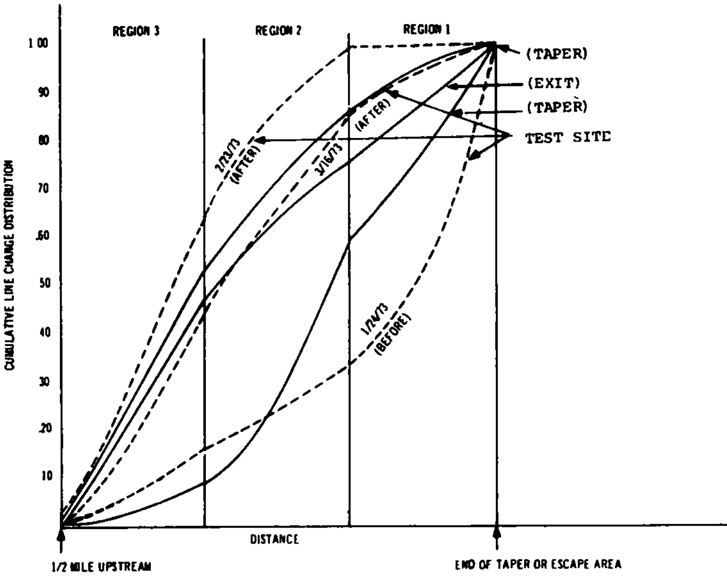


Figure C-3 Cumulative Lane Change Curves at Several Lane Drop Locations

the taper or gore area and thus is considered a well-working lane drop. Conversely, a concave curve will indicate a poorly working lane drop. In this study, three curves were generated, representing the "before" condition, the "after" condition using regions identical to the "before" condition, and the "after" condition using regions similar in nature, but not location, to the "before" condition These curves are superimposed over similar curves for other lane drop sites.

A quick comparison of the curves indicates the relative effectiveness of the site before and after change in configuration. Two different curves are developed for the "after" configuration, because the location of the operational lane drop was changed It is felt that when the location of the lane drop is changed that two sets of curves should be developed, one comparing the "after" configuration directly with the "before" configuration by using the same region boundaries locations and the other to compare the relative effectiveness of the configurations using region boundary locations appropriate for each configuration It can be seen from the three curves that an improvement in lane change behavior was made by the change in configuration. In addition, by comparing the "before" and "after" configurations to other lane drops in the area, it can be seen that the site improved relative to other sites as well.

<u>Conclusions</u>

A right-hand operational merge at a left-hand physical lane drop located just downstream of the selected exit of the freeway in the area resulted in several

problematic maneuver patterns during both peak and off-peak period operation The major problems seemed to stem from two sources, 1) little advance warning, compounded by an interfering right-hand exit ramp located 650' upstream of the beginning of the operational taper, and 2) the visual continuation of the operational drop lane past the merge area Many drivers made last minute or erratic lane changes out of the operational taper area, and many additional drivers continued through the operational taper forcing a downstream conflict with traffic moving from the left into their path of travel

A change in configuration using traffic control devices transformed the operational taper lane drop into an operational exit lane drop at the off-ramp A short up-grade which formerly impaired the lane drop taper sight distance became the focal point of an operational gore extending 300' upstream of the physical gore The up-grade also aided in hiding the physical lane continuation from approaching right lane drivers.

Data collected before and after the change in configuration during both peak and off-peak period operations confirm the subjective opinion that most through drivers now leave the right lane well upstream of the lane drop In addition drivers only rarely remain in the right lane beyond the operational gore area Merging conflicts were still observed during peak-period operations after the change in configuration, but were most likely the result of the near-capacity volumes rather than the configuration Finally it should be noted that the improvement in site operations is not necessarily due to one configuration type inherently being better than the other (i e., an exit lane drop vs. a taper lane drop) More likely, the improvement results from the adherence to the design principles

D-1

APPENDIX D - BEFORE/AFTER STUDY AT A LANE DROP LOCATION

A "before-and-after" study was conducted at a lane drop site in a moderate-size city to determine the effect of the implementation of changes in traffic control devices upon traffic operations and safety In March, 1973, a left hand lane drop was changed to a right-hand lane drop through the use of traffic control devices This change was prompted by the observation by the Division of Highways that during peak-hour flow, Sunday afternoon returning recreational traffic, an uneven lane distribution was causing premature capacity breakdown at the location

"Before" and "after" data were collected at the site during off-peak hour operation as well as peak-hour operation The change in traffic control devices had a significant effect on both peak and off-peak operations, causing peak hour operations to improve considerably but causing many conflicting driver patterns, at times with undesirable results, to emerge during off-peak operations

"Before" Site Configuration

The lane drop was created due to a stage construction on a three-lane freeway Two lanes of the freeway were initially constructed along the eastern length of the section A third lane is being constructed in stages From a construction point of view, it was wise to add pavement in the free-way median, thus decreeing a left-hand physical lane drop Figure D-1 illustrates the lane drop as it appeared in December 1972

D-2

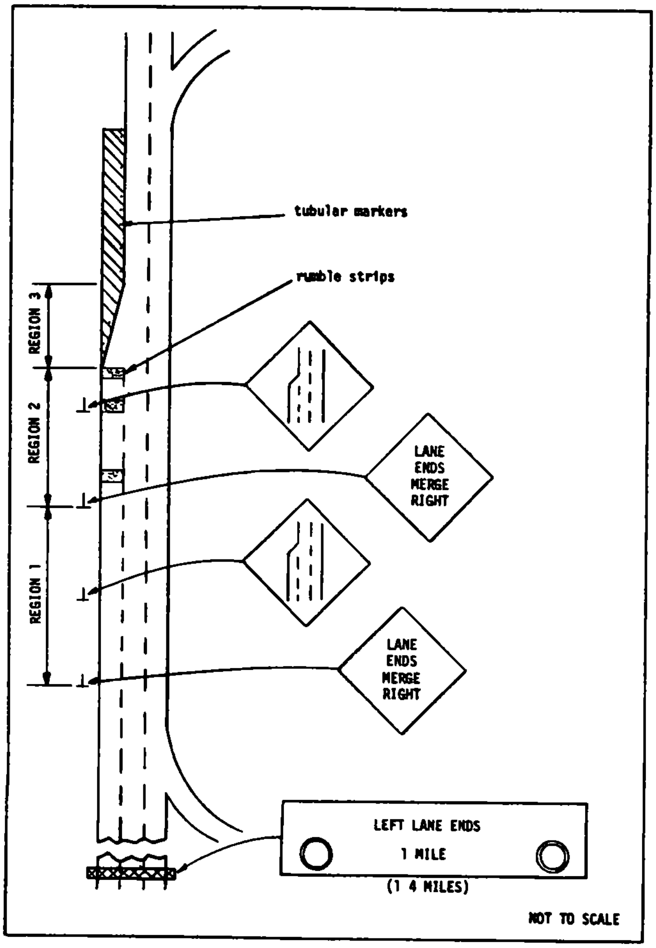


Figure D-1. Schematic Drawing of "Before" Configuration

D-3

After" Site Configuration

On March 9, 1973 the site was reconfigured to improve an uneven lane distribution observed during peak hour operation Tho physical lane drop remained on the left but resigning and striping operationally attempted to merge the two right lanes Figure D-2 illustrates the "after" configuration

Analysis of Configurations in Terms of Lane Drop Design Principles

Fight tentative lane drop design principles were outlined in the main body of the report It was expected that if these principles were violated, poor traffic operations would result Conversely, if the principles were obeyed, lane drop operations should be satisfactory. A listing of the design principles and the adherence of both design configurations to these principles follows

1 THE LANE DROP SHOULD BE PLACED WHERE THE SURFACE OF THE ROADWAY REMAINS VISIBLE CONTINUOUSLY FOR A SIGNIFICANT AMOUNT OF TIME

-Before-	-After-
YES Sight distance is about 1/2 mile, the lane drop is on a level section of free-way after a downgrade	YES Same as "before"

D-4

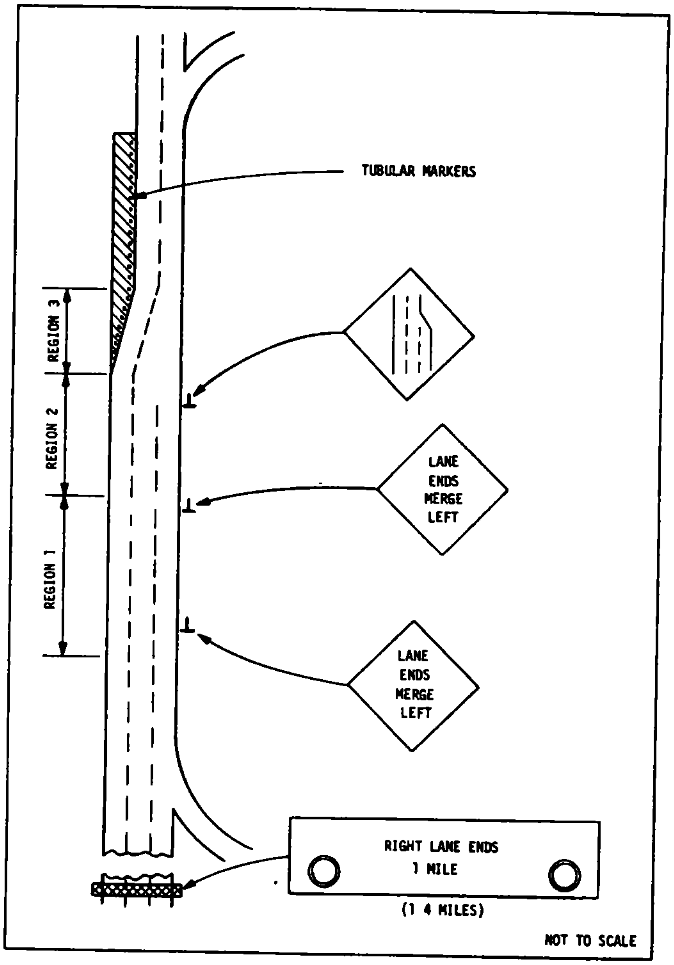


Figure D-2. Schematic Drawing of "After" Configuration

D-5

2 THE LANE DROP SHOULD BE PLACED AWAY FROM ATTENTION-DIVIDING CONDITIONS, SUCH AS RAMPS OR COMPLICATED DIRECTIONAL SIGNING

-Before-

YES Closest upstream on ramp is 1 mile, Closest downstream off-ramp is 1600 feet

-After-

YES Same as "before".

3 THE LANE DROP TAPER SHOULD ALLOW FOR A SMOOTH TRANSITION FOR DRIVERS TO MAKE A LANE CHANGE IN THE TAPER AREA AND SHOULD PROVIDE ADEQUATE VISUAL CUES WHICH INFORM THE DRIVER THAT HIS LANE IS ENDING

-Before-

YES The 50 1 taper length results in smooth transitions for most drivers making lane changes in the taper area

-After-

NO Visual cues are contradictory to signing and striping cues

4 THE LANE DROP SHOULD BE PLACED ON THE BETTER SIDE OF FREEWAY FOR GIVEN TRAFFIC AND GEOMETRIC CONDITIONS

D-6

-Before-

NO Physically, the lane should be dropped on the left and is, but operationally, uneven peak hour distribution caused premature breakdown problems

-After-

YES During peak hour operation capacity flows in both lanes occur before breakdown from downstream ramp back-up into area. Physically the lane should be dropped on the left and is

5 THE LANE SHOULD APPEAR TO PHYSICALLY END ON THE SAME SIDE OF THE FREEWAY AS THE OPERATIONAL LANE DROP

-Before-

YES The physical and operational lane drop are both on the left

-After-

NO Signing informs the right lane driver that his lane ends It does not, and does not appear to do so

6 WHEN A LANE DROPS AT AN EXIT RAMP, AN ESCAPE AREA OF ADEQUATE DIMENSIONS SHOULD BE PROVIDED TO ALLOW FOR A SMOOTH TRANSITION INTO THROUGH LANES

-Before-

Not applicable

-After-

Not Applicable

D-7

7 WHEN A LANE IS ADDED AT AN ON-RAMP AND DROPPED AT A NEARBY OFF-RAMP, THE ENTERING DRIVERS SHOULD BE NOTIFIED THAT THE LANE THEY ARE TRAVELING IN IS **NOT** A CONTINUOUS LANE FOR THROUGH TRAVEL

-Before-

Not Applicable

-After-

Not Applicable

8 CONSISTENT AND APPROPRIATE TRAFFIC CONTROL DEVICES (TCDs) SHOULD BE USED IN ADVANCE OF A LANE DROP

-Before-

YES TCDs correctly indicate that the left lane ends and that the traffic in this lane should merge right

-After-

NO Signing informs the driver in in the right lane that his lane ends, but he can see it does not Striping indicates that the center lane is merging into the right lane and the longitudinal pavement joints indicate that both the right and the center lanescontinue

D-8

In summary, the "before" configuration violated one lane drop principle; traffic operations indicated that a right-hand lane drop would result in merging the two lighter traveled lanes conflicting with the installed left-hand physical lane drop design The "after" configuration, even though adhering to this principle, violated several other design principles

<u>Presentation of Data</u>

"Before" data were collected on several different occasions Off-peak operations were observed on Wednesday, December 20, 1972 Lane volumes, lane change counts, and traffic composition were tallied, and approximately one hour of 2-second interval 35mm film was shot from a nearby overcrossing On February 4, 1973 and March 4, 1973 peak hour data were collected by the Division of Highways, using 16mm time-lapse, color photography and traffic counters. Lane volumes and distributions were noted

"After" data were collected during off-peak operations on Tuesday, April 10, 1973 and peak-hour operations on March 18, 1973 Since a change in configuration was made, time was allowed for the settling down of the site before data were collected

Table D-1 summarizes average six-minute volume counts, lane distribution and traffic composition both before and after the change during peak-hour and off-peak hour operation

D-9

TABLE D-1 - "BEFORE" AND "AFTER" AVERAGE SIX MINUTE COUNTS

	Total	Lane 1[a]	Lane 2	Lane 3	Trucks
Before off-peak[b] 12/20/72 (Wed) 10 00-12 00 Noon	207	76 (37%)	110 (53%)	21 (10%)	13 (6%)
After off-peak[b] 4/23/73 (Mon) 10 00-12 00 Noon	214	51 (23%)	96 (45%)	69 (32%)	32 (15%)
After off-peak[c] 4/10/73 (Tues) 10·00-12 00 Noon	171	110 (65%)	61 (35%)		
After peak[c] 3/18/73 (Sun) 2 00-4 00 PM	315	172 (55%)	143 (45%)		
Before peak[c] 2/4/73 (Sun) 2 00-4 00 PM	312	108 (35%)	202 (65%)		

[a]Lane 1 is the shoulder lane.
[b]These counts were taken 1500' upstream of the lane drop transition
[c]These counts were taken downstream of the lane drop transition

In addition, in the off-peak data collection activities lane change information was produced In one experiment the test site was divided into three regions Region 1 contained the area from the location of the third rumble strip to the overcrossing, region 2 contained the area from the first rumble strip to the third rumble strip (see Figure D-1 for relative locations). Six minute counts were made of vehicles changing either into or out of the lane drop lane for each region These average counts are contained in Table D-2 If a vehicle did not move out of the drop lane by the end of the taper area, it was counted as moving out of the drop lane in region 1.

D-10

TABLE D-2 - "BEFORE" AND "AFTER" SIX MINUTE DROP LANE CHANGE COUNTS BY REGION

	Region 1		Region 2		Region 3	
	Into Drop Lane	Out of Drop Lane	Into Drop Lane	Out of Drop Lane	Into Drop Lane	Out of Drop Lane
Before off-peak 12/20/72 (Wednesday) 10 00-12 00 Noon		5		13		22
After off-peak 4/10/73 (Tuesday) 10 00-12 00 Noon	1	1 (+ 33 not leaving lane)	2	2	6	9

Because several distinct lane change patterns were observed in the "After" configuration, additional counts were obtained.

During the "after" data collection activities, it was observed that the traffic in lane 2 (the center lane) could be divided into several distinct traffic patterns Counts were taken of the number of vehicles traveling in each of the patterns It was found that during off-peak operations, 9% of the lane 2 vehicles made definite lane change maneuvers into lane 1 (the outside lane), 75% of the vehicles followed their left lane line pavement marking, thereby gradually merging into the physical lane 1 (as defined by the longitudinal pavement joints), 9% of the lane 2 vehicles remained physically in lane 2, thus following the straight line of sight and pavement joints and crossing over the lane line pavement markings into the left-hand operational lane (the downstream median lane), and 7% of the center lane vehicles choose to make definite lane changes into lane 3 (the upstream median lane) and then gradually merge back into the physical lane 2 when the

D-11

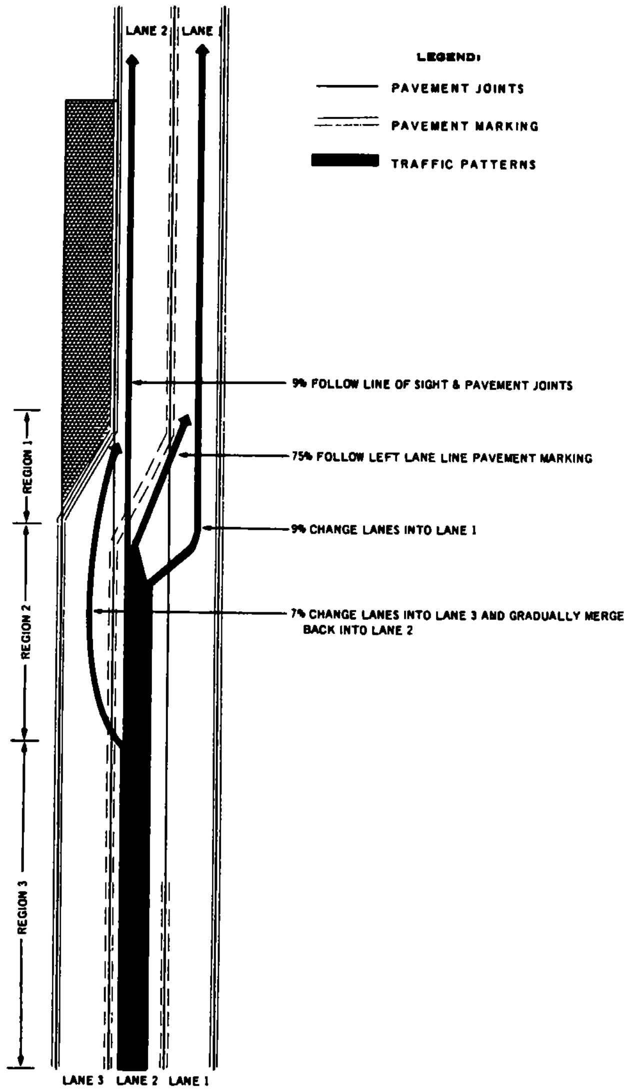


Figure D-3. Traffic Patterns

D-12

physical lane 3 was ended Figure D-3 illustrates these various traffic maneuvers.

Analysis of "Before"/"After" Data and Site Observations

"Before" traffic operations during off-peak hours were judged to be satisfactory even though the lane distribution was uneven Almost all drivers moved out of the left lane well in advance of the lane drop taper The uneven lane distribution did not cause significant problems as traffic volumes were low and opportunities to merge were num erous However, during peak-hour operation, the uneven lane distribution caused significant problems for returning Sunday afternoon recreational traffic. Capacity was quickly reached in the median lane, even when the shoulder lane was running well below capacity This caused a premature breakdown of the system

The change in configuration improved this peak-hour situation by merging the two lighter traveled lanes of traffic The lane distribution was almost equal (55% lane 1; 45% lane 2) Much less queuing was observed and fewer shock waves were noticed Eventually, breakdown did occur from the downstream off-ramp congestion backup

During off-peak hour operation, the change in configuration apparently caused confusion to drivers and led to a situation of unpredictability Two major changes in traffic behavior were noticed First, the majority of the drivers in the shoulder lane did not merge out of that lane, as requested by the advance warning signs, but instead continued straight

D-13

through the lane drop area, forcing the center lane traffic to compete with them for the shoulder lane

Secondly, several traffic patterns were observed in this configuration, whereas in the "before" configuration only one traffic pattern was observed (i e almost all vehicles in the median lane changed lanes into the center lane and almost all traffic in the shoulder and center lanes remained in their respective lanes) As noted above, the majority of the traffic in the shoulder remained in that lane throughout the lane drop area However, a fraction of the drivers did obey the advance warning signs and merged into the center lane Thus, two distinct traffic patterns were observed for the shoulder lane drivers The center lane traffic can be divided into four traffic patterns. These have been described in the previous section of this report and are illustrated in Figure D-3

D-14

Conclusions

The analysis of the data indicates that the uneven lane distribution which adversely affected peak-hour operations has been corrected by the change in configuration However, since the lane drop site has been reconfigured, an increase in traffic patterns through the section has been observed This increase obviously reduces the predictability of any vehicle traveling through the section It is thus desirable to determine a method for lessening the off-peak hour driver confusion observed in this configuration while maintaining the peak hour operation improvement experienced with this configuration.

It is apparent then that the two right lanes of traffic should remain those to be merged In the design principles outlined earlier in this paper, it was seen that the "after" configuration violated three of these principles A solution to the problems encountered in the "after" configuration may be found in the following discussion

Driver confusion is probably the main source of the varying patterns of traffic behavior In other words, the site is ambiguous Many different cues, often conflicting, are presented to each driver The shoulder lane driver's first cue is the advance warning signs warning that the right lane is ending and that he should merge left. The next cue he receives is from the roadway itself which appears not to end at all Additional cues may also be received from the behavior of other vehicles The center lane driver's first cues are also the advance warning signs, but in his case the

D-15

signs indicate that the lane he occupies is continuous and that he should expect shoulder lane traffic to merge into his lane The next cue the center lane driver receives is from the lane line pavement marking which begins gradually moving to the right into the shoulder lane In addition, at the same time, the longitudinal pavement joints indicate that both the shoulder and center lanes continue in a straight line Other vehicles may also provide cues.

The situation violates the design principles by not providing adequate visual cues which inform the driver that his lane is ending (principle 3), by not making the lane appear to end physically as well as operationally (principle 5), and by not providing consistent and appropriate traffic cont control devices (principle 8).

The solution should be found by correcting the difficulties described in the preceding paragraphs. One apparent method is described in Appendix C The site will then line up affirmatively with all design principles As at the site described above, the left lane was physically dropped and the two right lanes were merged. To correct the current deficiencies of this site the two right lanes should be merged upstream as illustrated in Figure 24

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