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IMPROVING THE TRAFFIC OPERATIONS AND SAFETY OF FULL CLOVERLEAF INTERCHANGE

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Final Report

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16. Abstract

Development of criteria for altering existing full cloverleaf interchanges to improve the traffic operations and safety of this particular configuration. Only the standard cloverleaf configuration with a loop ramp and an outer connection in each quadrant was considered in this study. The data base from the Interstate System Accident Research-Study II project was used to describe the spatial distribution of accidents within the interchange and its relationship to increasing traffic volume. Highway Capacity Manual procedures were used to describe the capacity characteristics of the various junction points within the standard cloverleaf. The results of these two analyses were combined to describe the range of traffic situations that could cause a breakdown in operations on any standard cloverleaf. A survey of ten major states having experience operating full cloverleaf interchanges led to the identification of two problem situations that are the most likely to lead to operational breakdowns on a standard cloverleaf interchange.

The first problem situation identified dealt with the operation of the weaving section as it approached capacity. The second situation dealt with the operation of the free-flow ramp terminals onto a multi-lane, non-access-controlled crossroad with strip development in close proximity to the terminals. Solutions that retained, modified or eliminated the standard cloverleaf flow pattern were examined. The results indicated that solutions involving the redesign and reconstruction of the interchange (modify or eliminate rather than retain) provide the only acceptable level of effectiveness.

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IMPROVING THE TRAFFIC OPERATIONS AND SAFETY OF FULL CLOVERLEAF INTERCHANGES

Final Report

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CHAPTER I

The full cloverleaf interchange is a common interchange normally occuring at high speed and/or high traffic volume locations. Its frequency of use is due to the fact that the cloverleaf is the only four-leg, single grade separation pattern without at-grade, left turns. It is also the least expensive of the free-flow interchange patterns. However, there are some serious drawbacks to the use of the full cloverleaf interchange.

Research results by Cirillo et al (1969) indicated that two-thirds of all accidents on a freeway system occur at or near interchanges and that the accident rate on full cloverleaf interchanges without C-D roadways is greater than the rate on all other standard types of interchanges studied. Those results also demonstrated that variation in the mainline traffic volume accounted for almost all of the variability in the accident rate.

Large traffic volumes also result in serious operational problems in the full cloverleaf interchange without C-D roadways. Large volume weaving movements result in considerable friction and reduction in the speed of the traffic. The AASHTO Blue Book and the Highway Capacity Manual contain discussions of the limit to the amount of traffic that can be moved through a given weaving section without congestion. Mulinazzi (1973) indicates that most state highway design engineers accept the analysis of Pinnel and Buhr (1966) giving the capacity of a weaving section to be 1,000 vph without a C-D roadway and 1,500 vph with one. Another limiting factor in the operation of the full cloverleaf interchange is the inclusion of loop ramps. The AASHTO Blue Book estimates the capacity of the loop ramp to be between 800 vph and 1,200 vph, with the higher figure applicable only where there are no trucks and the design speed for the ramp is 30 mph or higher. Since the cloverleaf has both loop ramps and weaving sections, it is the recommended and generally accepted practice to not use the full cloverleaf interchange as a major freeway-to-freeway connection or anytime large turning movements are expected. Mulinazzi (1973) indicates that most design engineers agree that cloverleafs should not be used without C-D roadways on the mainline.

However, a considerable number of cloverleaf interchanges are in operation today without C-D roadways. Many of these interchanges were built during or prior to the early Interstate construction boom. Given the vehicle-mile increases that our country has experienced during the last fifteen years, it is possible that many of these interchanges are experiencing many of the safety and capacity prob-

lems described by Cirillo et al (1969) and the AASHTO Blue Book. If this is the case, then there is a need to examine alternative methods of improving the safety and capacity of these interchanges.

Purpose

The objective of this project was to develop criteria for altering existing full cloverleaf interchanges to improve the traffic operations and safety of this particular configuration.

The full cloverleaf interchange as defined in this study is limited to those four-quadrant interchanges with a loop ramp and a diagonal ramp in each quadrant. This was the basic definition of the full cloverleaf interchange that was employed in the study by Cirillo et al (1969) which served as a partial justification for this project.

Work on the project was restricted to attempting to improve the safety and operation of the cloverleaf through making alterations to the highway rather than the driver or the vehicle. Driver-oriented solutions such as driver training or driver aiding and vehicle-oriented solutions such as automatic longitudinal or lateral control were considered to be outside the scope of this project.

CHAPTER II

The overall research plan for this project was to first determine the expected operating characteristics of the interchange. With these characteristics known, it would then be possible to identify those situations requiring improvement and to then design and analyze improvements suited to these situations.

These situations could not be identified and understood until the basic operating and safety characteristics of the cloverleaf interchange were first identified and understood. Therefore, the initial efforts in the project were designed to produce descriptions of the expected safety performance and the expected operating characteristics for the full cloverleaf interchange. Given these descriptions of the expected operating and safety characteristics, a survey of engineers with design and operations experience was conducted in order to obtain a current assessment of the overall cloverleaf performance and a description of the conditions associated with those cloverleafs that are not performing in a satisfactory manner. The survey results served as the principle input to the task of identifying those situations or conditions which could be considered to be "problems", thereby requiring the imposition of "solutions".

Safety Characteristics

Since the principal justification for this project was the research results indicating that the cloverleaf interchange experiences more accidents than any other standard type of interchange, this effort was designed to expand on the results of the study by Cirillo et al (1969). Those results produced a relationship between total accidents within the entire interchange area and the traffic flow on the mainline through the interchange. However, no attempt was made to isolate the accident experience for the interchange elements or unit types within the interchange. Therefore, the data base used in the original study by Cirillo was obtained for further examination. That data was used because it included data submitted by participating state highway departments in over twenty states and represented more data than could possibly be collected with this research effort.

The results of the research by Cirillo et al (1969) indicated that full cloverleaf interchanges are experiencing significantly higher accident rates than other types of interchanges. Figure 1 has been reproduced from that research report and demonstrates the relationship between the average number of accidents per year and

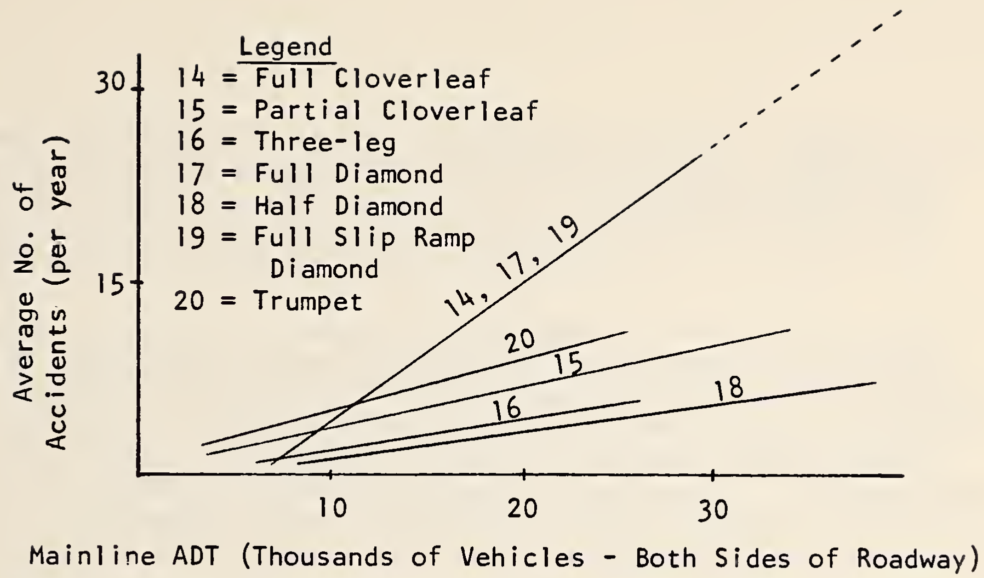


FIGURE 1. Effect of Mainline ADT on Interchange Accident Frequency

Average Daily Traffic (ADT) on the mainline for the various types of interchanges included in the study. It can be seen that once the mainline ADT exceeds 10,000, the accident frequency for the full cloverleaf interchange exceeds the frequency for the other types of interchanges, with the difference steadily increasing with increasing ADT. It should be noted that the relationship between accident frequency and ADT derived for the full cloverleaf interchange also described the ADT-accident frequency relationship derived for the other two types of full interchange designs included in the study; the full diamond interchange and the full slip ramp diamond interchange. However, the ADT experienced by these interchanges did not exceed 25,000.

The actual relationship derived in the study was the following:

$Y = -3.7 + 1.3 X_1 - 0.025 X_2$, where

Y = average number of accidents per year

X_1 = average daily traffic (ADT) in both directions on the mainline

$X_2 = X_1$ (x) percent commercial vehicles per day

This relationship accounted for 80 percent (R^2) of the variation in the accident frequency with ADT accounting for over 79 percent of the 80 percent. This relationship was developed from data collected for 186 interchange-years. The average ADT for these interchanges was 20,000 with the average exiting volume being 6,500. All crossroads at these interchanges had four or more lanes. The average number of

accidents experienced at these interchanges was 19.3. However, no attempt was made to compare the various interchange elements (such as weaving area, loop ramp, etc.) to this relationship developed for the entire interchange area. Therefore, this same data base was obtained from FHWA for further examination.

Upon obtaining the data base from FHWA, it was edited, definitions of interchange elements were established and final data base was formulated. Appendix A provides greater detail on this process. The final data base consisted of data for 32 interchanges scattered over nine states. The number of years of accident data available for each interchange varied from two to seven years. With the annual number of accidents at each interchange forming a single data point, a total of 169 data points (i.e., interchange-years) were available for analysis.

The annual number of accidents for each interchange were then distributed to the various interchange elements comprising the entire interchange, thereby resulting in 169 data entries for each element. Each interchange was subdivided into eleven distinct elements for the majority of the analysis. These elements, shown in Figure 2, were the following:

1) mainline-accel area
2) mainline-decel area
3) accel half of weave area
4) decel half of weave area
5) mainline between ramps
6) loop off-ramp
7) loop on-ramp
8) O-C on-ramp
9) O-C off-ramp
10) ramp terminal at crossroad
11) crossroad within interchange

For the purposes of analysis, accidents occuring on the mainline outside the physical limits of the interchange (prior to the start of deceleration lane of the O-C off-ramp and beyond the end of the acceleration lane on the O-C on-ramp) were eliminated from the data base.

The analysis began with a partitioning of the total number of accidents recorded for each interchange across the various design elements. Figure 3 displays the results of this partitioning of the data. The data in this form serves no real purpose except to indicate the relative balance in the distribution of accidents among the mainline elements and among the ramp-type elements.

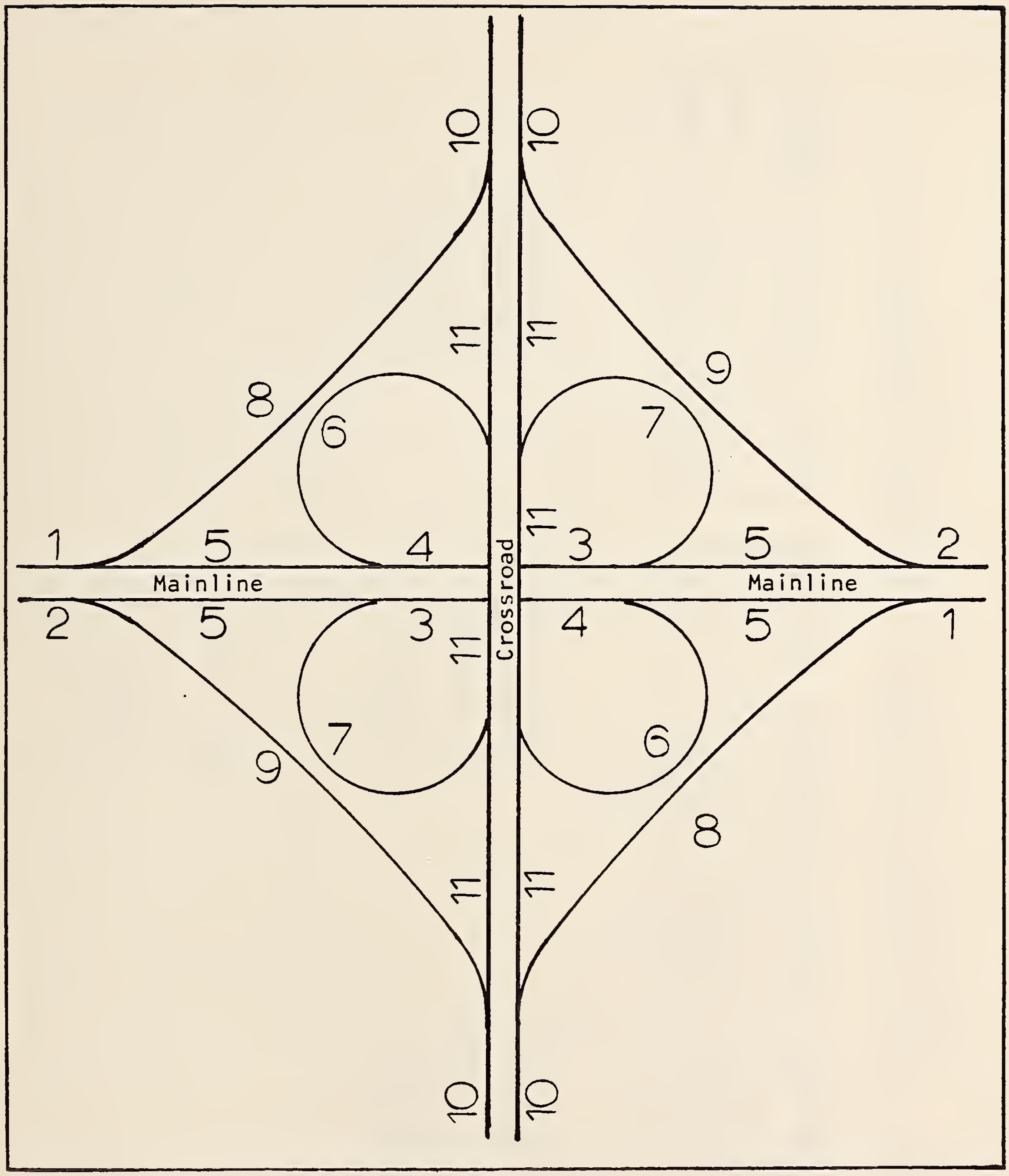


FIGURE 2. Interchange Schematic Denoting Design Elements

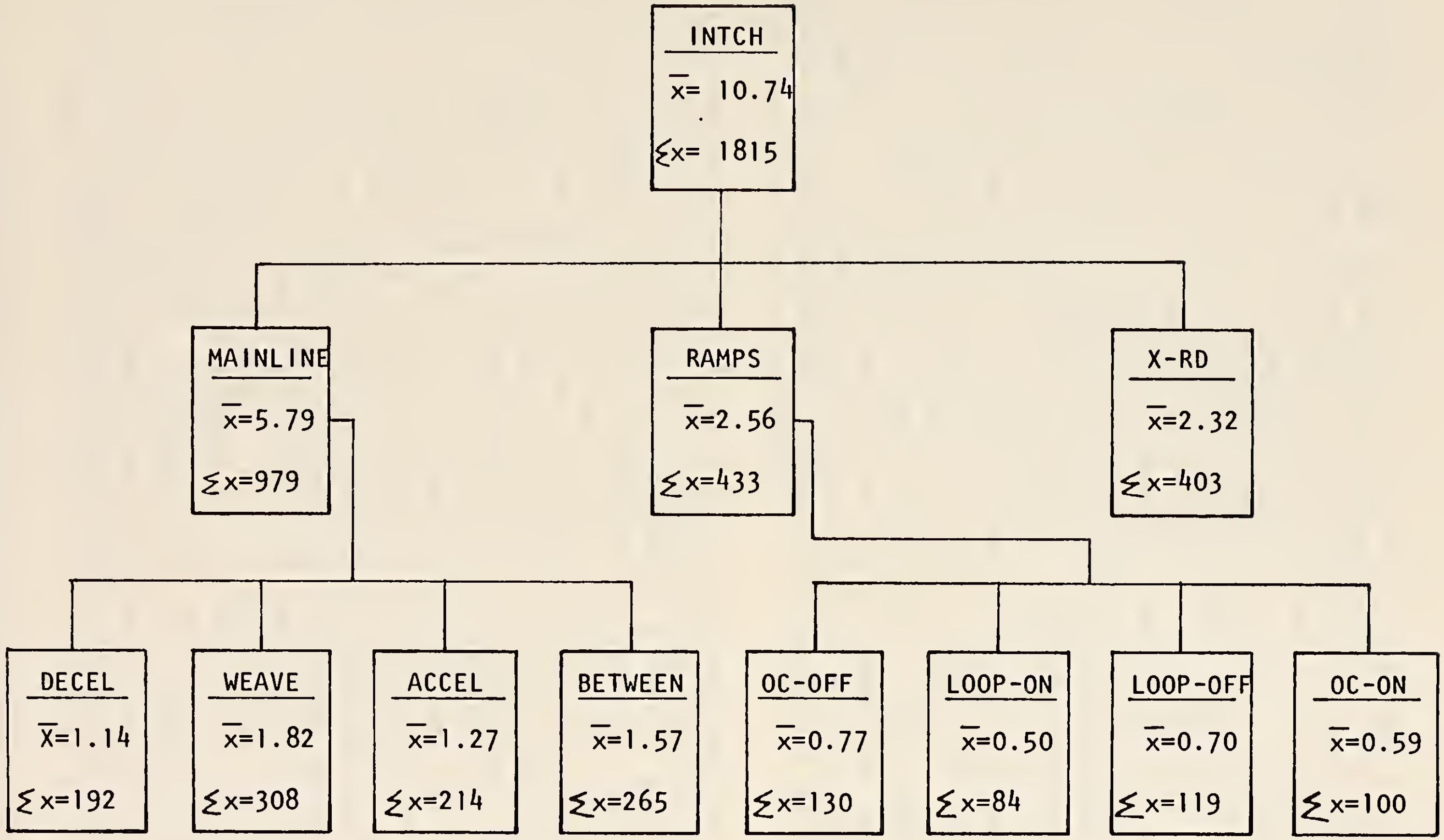


FIGURE 3. Distribution of the Total Number of Accidents in ISAR Data Base by Location Within the Full Cloverleaf Interchange (N=169)

Since the results of the original study indicated that the mainline traffic volume was highly correlated with the interchange accident frequency, the interchanges were divided into two groups, one with a peak one-way ADT of less than 16,000 vehicles and the other with an ADT equal to or exceeding 16,000 vehicles. The figure of 16,000 ADT was arbitrarily selected based on a visual review of scatter plots of the data points on which each interchange was uniquely identified. Figures 18 through 26, in Appendix A, display the accident data for the various design elements against the mainline ADT. These data demonstrate that the interchanges appear to fall into two distinct groups characterized by mainline ADT. Figure 4 describes the distribution of the total number of accidents within the interchange among the various design elements for both the high and the low volume groups. Figures 5 and 6 present the same distributions, but expressed in terms of the total number and the average number of accidents per interchange. The implication of the data described in these figures is that there is not a major shift in the distribution of accidents among the mainline elements or among the ramp elements. It does appear that as the mainline traffic volume increases, the mainline design elements experience the greatest increase in the numbers of accidents.

In order to statistically test the indication that the distribution of the average number of accidents for the mainline units was not different for the two volume groups, a profile analysis using multi-variate statistical techniques was used. Figure 7 displays the data for the two volume groups. The results of the analysis indicated that the distribution of accidents among the design elements was not the same for the two groups. Visual examination of Figure 7 indicates the "between element" sections exhibit a disproportionate difference between the two groups, relative to the other elements. Since there are four "between element" sections per interchange as compared to only two sections per interchange for the other elements, and since all elements are additive with respect to the mean, the test was repeated after removing the data for the "between elements" sections. The results comparing the accel, decel and two halves of the weave element indicated that the distributions are not different for the two groups. Similar testing was performed on the data for the four ramps (Figure 8) and identical results were obtained. The implication of these results was that only one of the two volume groups needed to be examined further since the intra-relationships were unaffected by the increases in traffic volume. Since the low volume group had three times as many interchanges as the high volume group, it was selected for further analysis.

The next analysis series was designed to determine the influence of several discreet variables that past research results have indicated

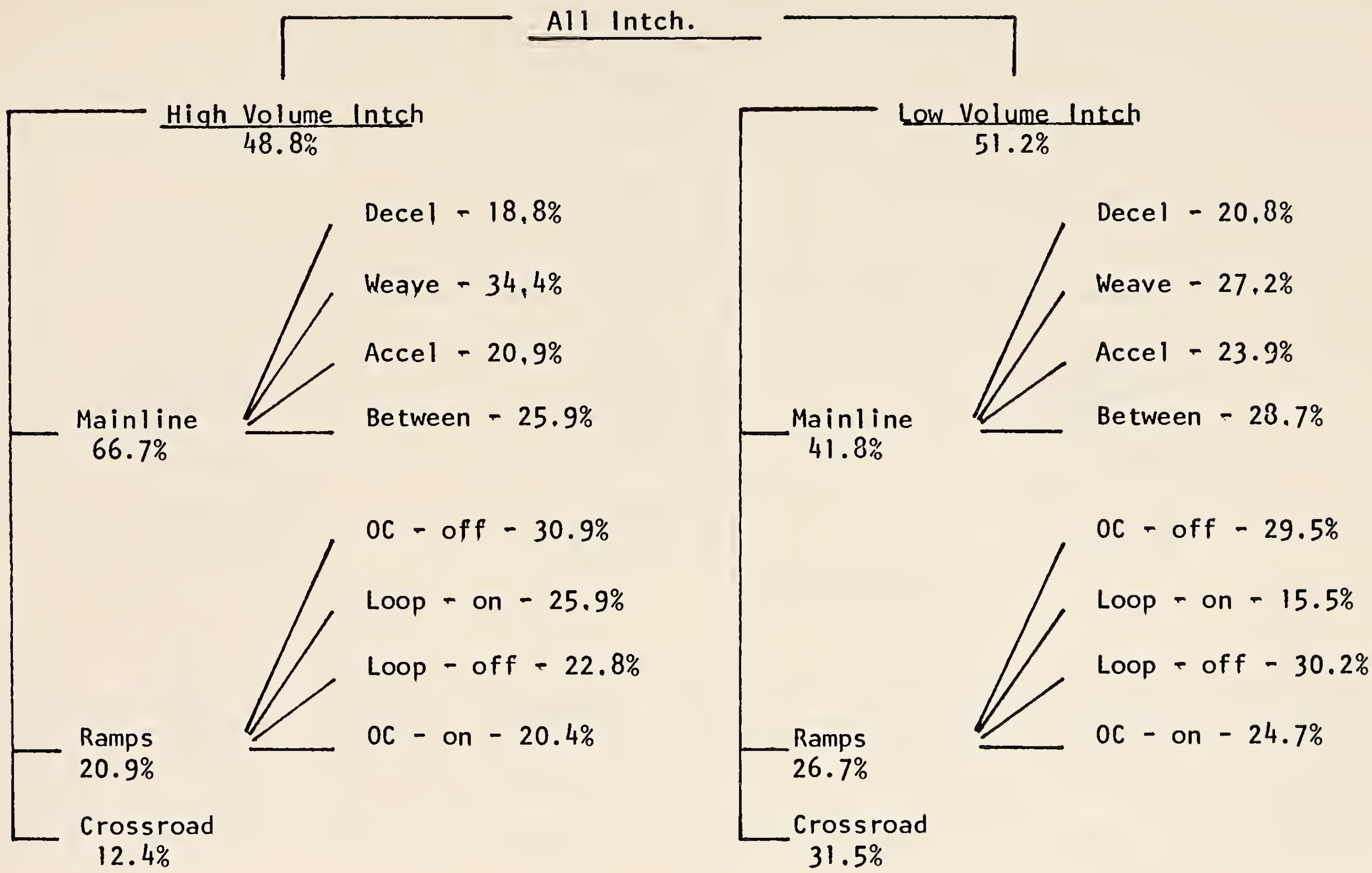


FIGURE 4. Percentage Distribution of Accidents by Location Within Interchange (N=169)

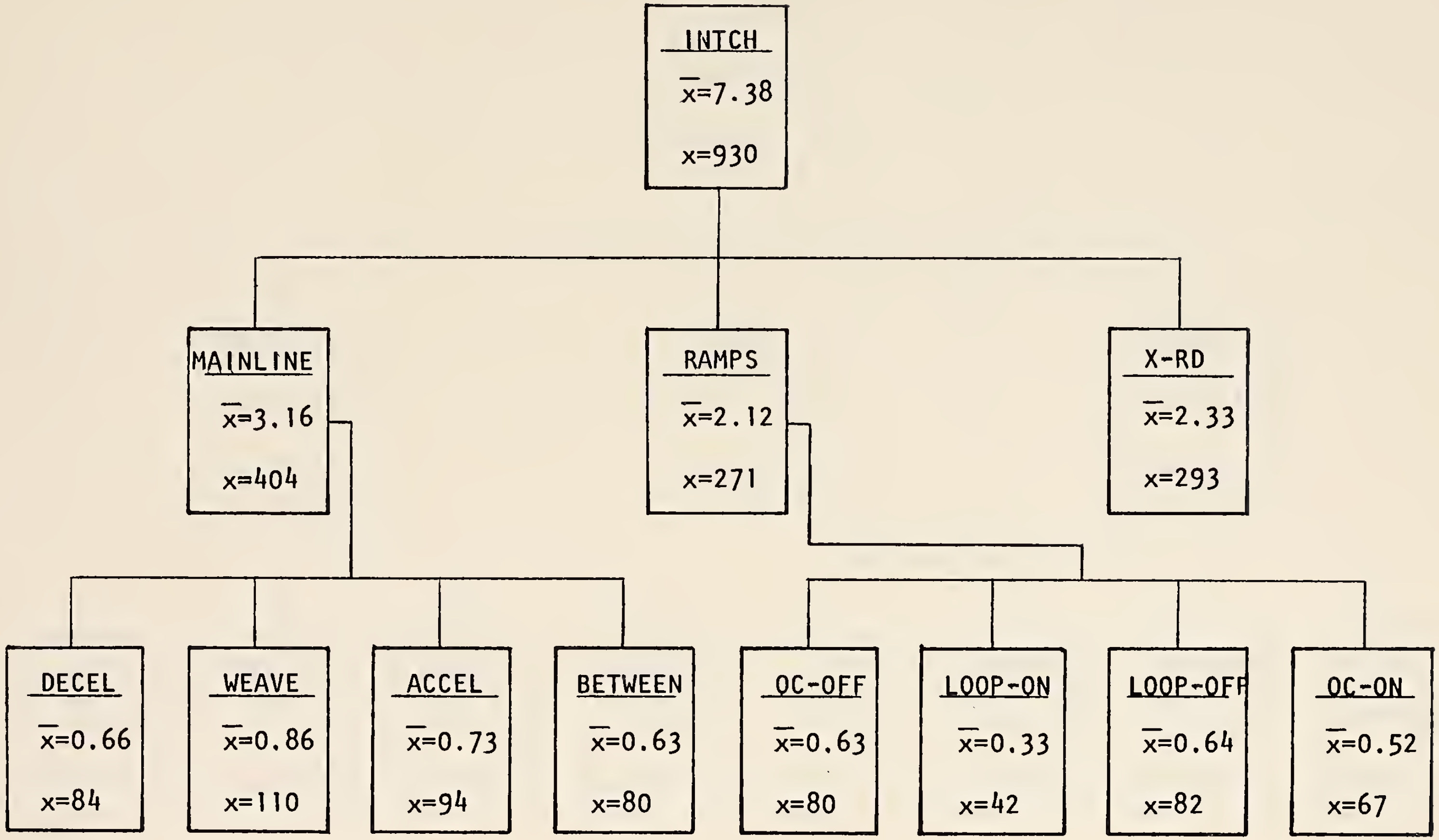


FIGURE 5. Distribution of the Total Number of Accidents by Location Within the Full Cloverleaf Interchange (ADT   16,000 and N=128)

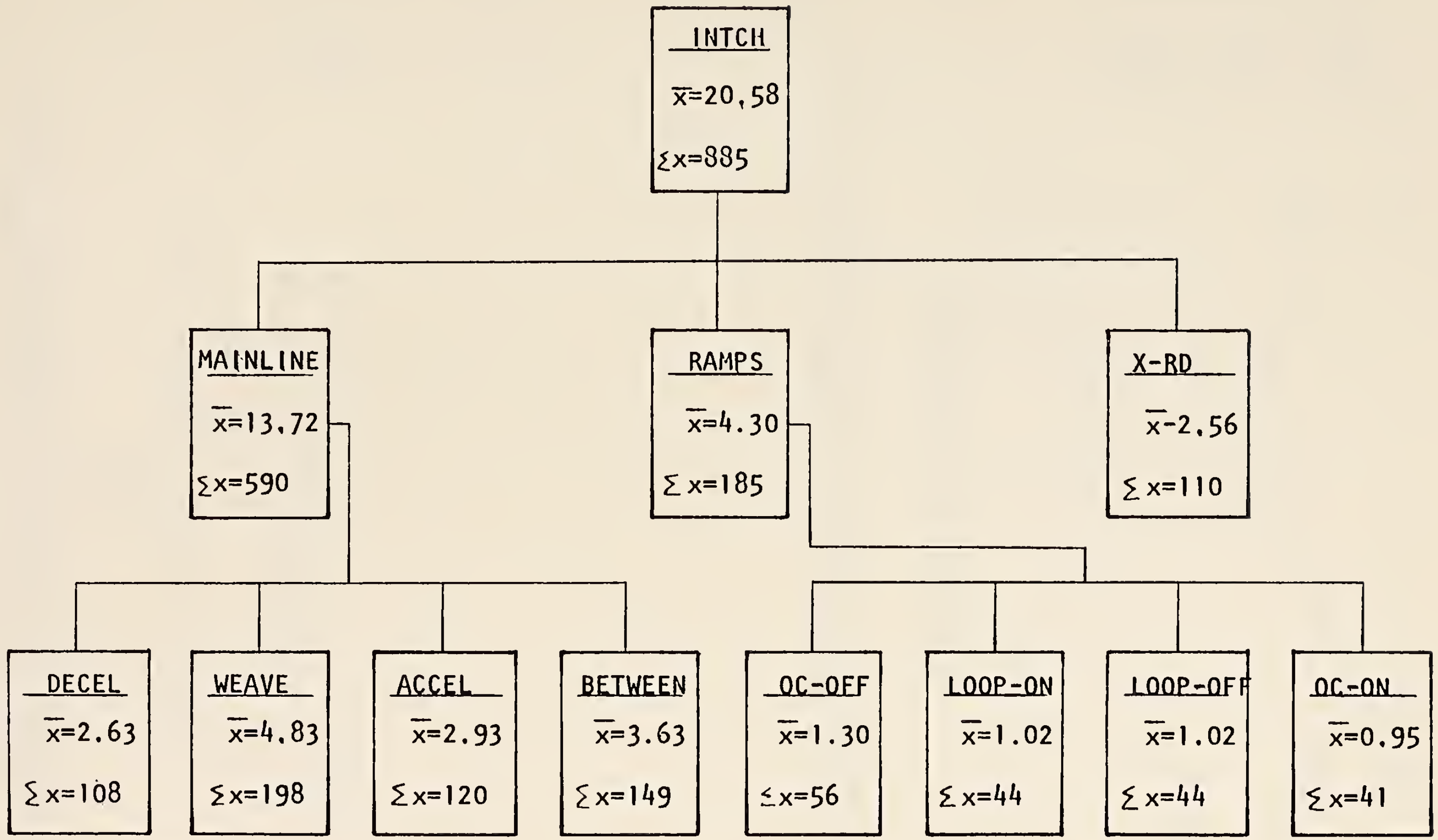


FIGURE 6. Distribution of the Total Number of Accidents by Location Within the Full Cloverleaf Interchange (ADT 16,000 and N=41)

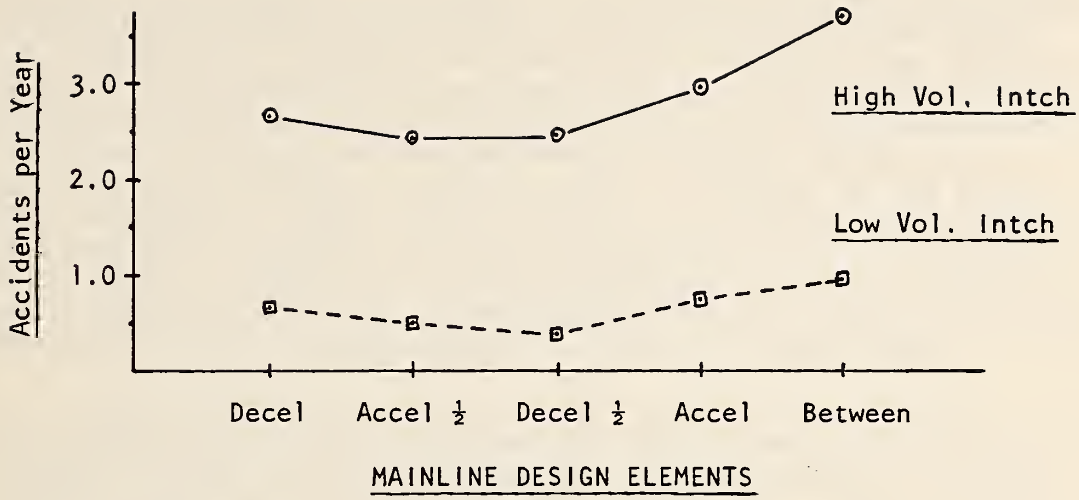


FIGURE 7. Average Number of Accidents on Mainline Design Elements for High vs Low Volume Interchanges

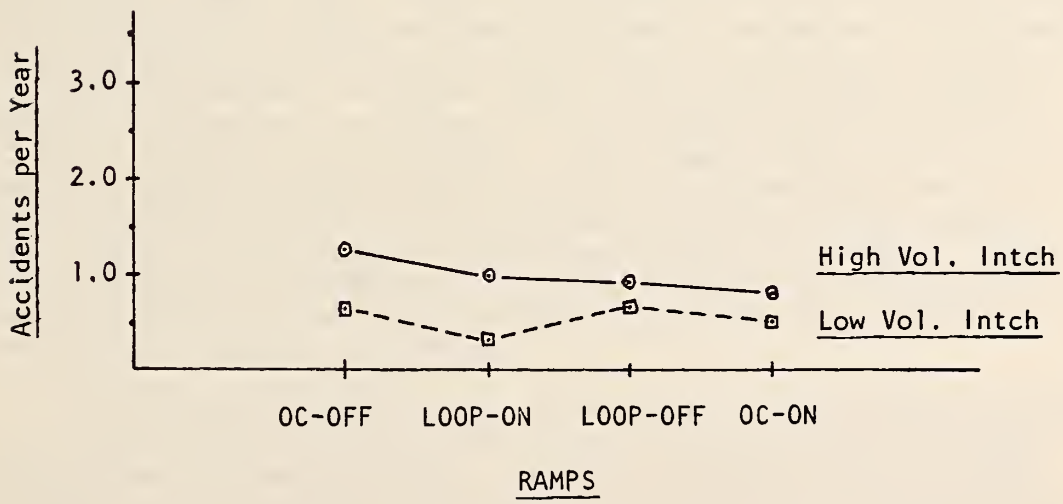


FIGURE 8. Average Number of Accidents on Interchange Ramps for High vs Low Volume Interchanges

as possible sources of influence. The initial analyses using MANOVA (Multivariate Analysis of Variance) had indicated that the factors of structure type (overpass and underpass), crossroad type (divided and undivided), and area (urban and rural) were associated with changes in average number of accidents occurring in the weave section including loop ramps and the accel-decel sections including the outer connection ramps. However, further investigation led to the fact that each of these factors was highly correlated with mainline and ramp ADT. Therefore, it was concluded that the volume parameters influenced the effect of the other independent variables under investigation and that further investigation of the effect of the factors of structure type, crossroad type, and area was unwarranted.

Since these factors were no longer under consideration, the two interchange groups were recombined (N=169) and the relationship between mainline (and ramp) volume and the mean number of accidents on the various mainline sections was investigated. Table 1 contains the correlation coefficient (R) between the various dependent variables and with the other independent variables. Several points can be made regarding the data in the table. First, the correlation between the number of accidents on any mainline unit and any other mainline unit is always greater than it is with the number of accidents on the contiguous ramp. Second, the correlation between the number of accidents on each mainline study unit and the volume entering the interchange is very similar to the correlation between the accidents and volume on that same unit. Third, the number of accidents on a specific mainline section has little correlation with the volume on the contiguous ramp. These facts imply that the ADT entering the interchange can reliably be used to estimate the number of accidents on the mainline, which of course represents the majority of accidents in the interchange. They also suggest that the accident experience for the various mainline elements can be combined for each interchange since they are correlated. Some attempts were made to define paths through the interchange, such as the deceleration lane plus outer-connection-off-ramp path, and then model the relationship between these paths and the various traffic and geometric variables. These attempts were only moderately successful and the reason appears to be the fact that only the mainline elements experience any consistent variation in accident frequency.

Having concluded that the mainline design elements experience the majority of the accidents within an interchange and that the number of accidents on the mainline is primarily dependent on the volume, attempts were then made to refine this relationship through the use of multiple regression analysis. The stepwise procedure with a 0.1000 significance level for inclusion was used in the development of these regression models. Each of the mainline design elements were modeled separately and then collectively. The independent variables always

TABLE 1. Correlation Coefficient (R) Between the Number of Accidents on Each Design Element and the Accident and ADT Variables for All Other Design Elements

Correlation Coefficients (R)		R for Number of Accidents on					
		ACCEL	DECEL	ACCEL ½ of WEAVE	DECEL ½ of WEAVE	BETWEEN	ALL MAINLINE
R for Number of Accidents on	ACCEL	1.00	0.469	0.494	0.423	0.574	0.759
	DECEL		1.00	0.509	0.493	0.438	0.743
	ACCEL ½ of WEAVE			1.00	0.585	0.633	0.810
	DECEL ½ of WEAVE				1.00	0.567	0.764
	BETWEEN					1.00	0.841
	ALL MAINLINE						1.00
	CONTIGUOUS RAMP	0.138	0.217	0.422	0.258	NA	NA
R for ADT on	SAME DESIGN ELEMENT	0.625	0.657	0.703	0.712	0.646	NA
	CONTIGUOUS RAMP	0.158	0.364	0.186	0.277	NA	NA
	ADT ENTERING INTCH	0.601	0.657	0.637	0.655	0.340	0.810

included the entering ADT and then various combinations of the length and ADT on the design element being modeled and the length and ADT on the ramp contiguous to the element. The dependent variable was always the annual number of accidents. However, the independent variables were used as they appeared in the data base and they were also scaled by the entering ADT. Table 2 contains the final equation for each model and the square of the multiple correlation coefficient (R^2).

These results are essentially consistent with those reported in the earlier analysis of the ISAR data base by Cirillo et al. These results demonstrate the dominant effect of the mainline traffic flow on the accident frequency. The best results were of course obtained for the estimation of the number of accidents on the entire mainline.

The overall conclusion that was drawn from the results of this series of analyses is that the cloverleaf design does not have any one design feature, such as the loop ramp, which experiences an accident frequency disportionate to that of the other design features. The increase in interchange accident frequency that occurs with increasing mainline traffic volume is experienced primarily on the mainline. The weave section, when defined to consist of both the accel-half and the decel-half, does experience the greatest increase in accident frequency with increasing ADT of the various mainline elements. This, of course, is not unexpected since this portion of the interchange must accommodate both entering, exiting, and through traffic. However, given the fact that all of the mainline design elements experience significant increases in accident frequency, it seems reasonable to conclude that the safety problem with the cloverleaf interchange is not an accident problem resulting from a hazardous design but rather a capacity problem resulting from a design inadequate for high-speed, high-volume operation.

Operational Characteristics

The goal of this phase was the description of the operating characteristics of the critical design elements within the interchange. Level of service, a qualitative measure defined in the Highway Capacity Manual, was selected as the evaluation criterion. After evaluating the individual elements under a variety of operating conditions, it became possible to assess the effect that flow restrictions originating on a single element would have on the interchange as a whole.

The principles and procedures of Chapters 7, 8 and 9 of the HCM were used to evaluate the operating characteristics. The relationship between level of service and quality of flow is described in Chapter 7 and was utilized in the overall evaluation of the weaving section.

TABLE 2. Tabulation of Best-Fit Equations for Mainline Design Elements

LEGEND

x_1 = Entering Volume (peak, one-way, ADT)

x_2 = Peak ADT on "mainline plus accel" section

x_3 = Peak ADT on OC off-ramp

x_4 = Peak ADT on loop off-ramp

x_5 = Peak ADT on OC on-ramp

x_6 = Peak ADT on loop on-ramp

x_7 = Length (in 10's) of "mainline plus accel" section

x_8 = Length (in 10's) of OC off-ramp

x_9 = Length (in 10's) of "mainline plus decel" section

x_0 = Total length (in 10's) of all mainline sections

y = Annual number of accidents per interchange

"Mainline plus Accel" Section ($R^2 = 0.442$)

$$y = -0.27849 + 0.0000128 x_7 x_1 - 0.0000050\, x_5 x_1 + 0.0000004\, x_1 x_1 + 0.005042\, x_5$$

"Entire Weave" Section ($R^2 = 0.656$)

$$y = 0.116565 + 0.0000056\, x_6 x_1 - 0.0000167\, x_4 x_1 + 0.001806\, x_1$$

"Mainline plus Decel" Section ($R^2 = 0.545$)

$$y = 0.097271 + 0.0000259\, x_9 x_1 + 0.0000026\, x_3 x_1 - 0.0000079\, x_8 x_1$$

"Between OC and Loop Ramp" Section ($R^2 = 0.417$)

$$y = -0.379804 + 0.002503\, x_1 - 0.0000046\, x_0 x_1$$

Entire Mainline Considered as Single Unit ($R^2 = 0.697$)

$$y = 0.917214 + 0.0000016\, x_1 x_1 + 0.009235\, x_3$$

Chapter 8 procedures were used in determining the merge, diverge and ramp junction service volumes and capacities. Chapter 9 procedures accomplished the same task for the basic sections on the freeways and expressways. Computer adaptations of these procedures contained in the FHWA battery of programs titled "Urban Transportation Planning" were used to perform the actual calculations.

In order to analyze cloverleaf interchange operating characteristics, a range of upstream freeway volumes (V_f) was established. Those values were defined by using the Highway Capacity Manual service volumes (Table 9.1, HCM) over a range of levels of service from B to E including the variance in peak-hour factor from 0.75 to 1.00. The merge and diverge analyses were conducted over a range of values from 200 vph to beyond the actual capacity of the ramps. The weaving characteristics were represented by a 1,400 vph by 1,400 vph matrix. The matrix represented all possible combinations of entering and exiting vehicles in increments of 100 vph. The weaving lengths studied ranged from 400' to 1,000' in increments of 100'. Over 33,000 calculations were performed.

The output of the calculations are presented in Appendix B in the form of a series of charts and graphs. Using these data, the general relationships between level of service and merging length, diverging length, weaving length, weaving volume, etc. could be examined. It was also possible to demonstrate the effect on level of service that the factors of peak-hour factor, percent truck traffic and percent grade have on the calculations. Since the merging, diverging and weaving sections control the efficiency of traffic movement on the through lanes, they were examined in greater detail.

When a section of roadway is operating at or near capacity, it is reasonable to assume that an interchange can improve or relieve the flow on the highway proper in only one of the three possible situations which exist. That is, if there is significantly more traffic exiting from the freeway proper than there is entering the freeway proper, then an improvement in downstream operations is likely. However, if the flow is balanced or there are more vehicles attempting to enter than exit, then the freeway proper which is already approaching unstable flow will further breakdown and soon reach a status of forced flow or level of service equal to "F". In summary, when volumes are sufficiently high on the freeway, the interchange, be it cloverleaf or other, can not represent an encumbrance or bottleneck in the overall freeway system. In fact, the most significant effect it can have is the effect of being an improvement or point of relief within the system.

As the amount of traffic occupying the through lanes is reduced, it becomes feasible that an interchange can represent an encumbrance on the freeway system. It is that local and significant drop in level of service that is the concern of this project. A significant or

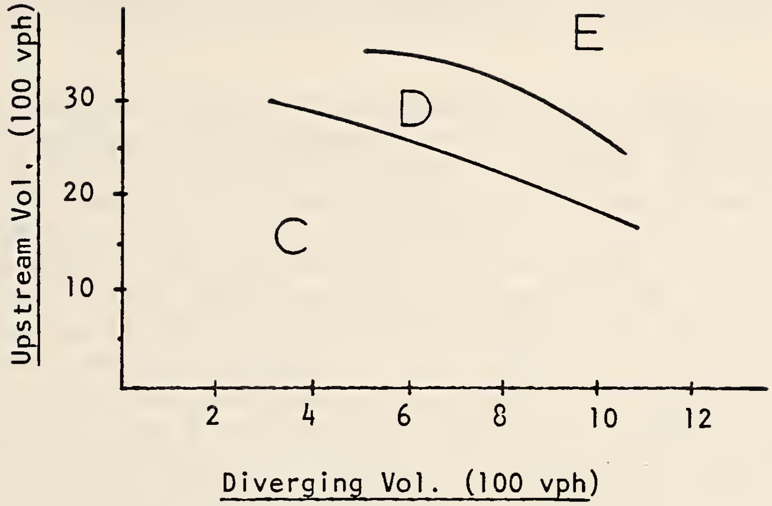


FIGURE 9. Effect of Diverging Volume on the Level of Service of a Two-Lane, One-Way Roadway

critical drop will be defined as a drop of two levels of service or more. More specifically, attention should be directed at those cases where the traffic stream is changing from stable flow to unstable flow. Moskowitz and Newman (1963) stated, "When the input exceeds the capacity of a bottleneck, the freeway upstream from the bottleneck becomes a storage area and rate-of-flow in terms of cars per hour has no meaning. The rate-of-flow upstream of the bottleneck is independent of the geometric conditions at this location since it is bound to be equal to the rate-of-flow at the bottleneck". This describes the situation that will exist when an interchange becomes a bottleneck.

Upon entering a cloverleaf interchange area, the first location of potential turbulance encountered is the outer connection exit terminal. As the percentage of the total traffic which chooses to exit increases, the ensuing turbulance causes more frequent conflicts, slower speeds, more erratic maneuvers, and the expected drop in level of service. If that drop is severe enough to be considered critical, then any alternate configuration must include an improvement in the capacity of the exit terminal and the entire outer connection ramp. Diverge service volumes and ramp capacities are discussed in detail in Chapter 8 of the Highway Capacity Manual. Capacity is reached when the volume in lane one immediately upstream from the exit ramp is equal to 2,000 vph. That volume includes both through vehicles and prospective exit-ramp vehicles and is too unstable to represent desirable operation. Figure 9 demonstrates the relationship between

level of service and flow across all lanes. However, operation at the ramp junction is almost solely dependent on traffic volume in lane one.

Weaving performance is basically dependent on the length and width of the weaving section and the composition of traffic, as well as the total amount of traffic. As stated before, a computer adaptation of the procedures of Chapter 7 of the Highway Capacity Manual were used for the computations of the weaving sections. The graph in Figure 7.4 of the HCM defines the relationship between length of section and total weaving volume and is an important tool in the procedure. By observing the variations in slope of the family of curves in that figure it can be seen that changes in the length of the weaving have a decreasingly significant effect as the quality of flow varies from I to V. Quality of flow V corresponds with level of service E and can be considered to define the capacity of the weaving section. Therefore as one approaches capacity, increasing the length of the section will not provide a significant improvement in operations. This fact supports the supposition made in the HCM, that, the total number of vehicles passing through a weaving section, if all must perform a weaving maneuver more or less simultaneously, cannot exceed the capacity of a single lane, regardless of the length of the weaving section. Further support resulted from the analyses of this report which indicate that for V_f's in the 2,000 to 3,000 vph range, given a total weaving volume, virtually the same level of service is provided over the entire range of weaving lengths from 400' to 1,000' (see single line in Figure 10).

As the upstream freeway volume increases from zero to capacity, the percentage of non-weaving traffic, and therefore the total number of vehicles, in lane one increases. Logically the increased lane one through traffic represents a hinderance to the merge, diverge, and weaving operations which by necessity require access to lane one. It follows that increasing the width of the section should provide room so that a higher percentage of through traffic will travel outside of lane one, thereby allowing increased freedom of movement to and from lane one. The procedures in the HCM predict the corresponding improvement in operations. However, it should be noted that weaving traffic alone can reach capacity, at that point no amount of widening will help, since the weaving must take place in basically two lanes. This particular deficiency in the HCM procedures is well documented by Pignataro (1972).

As with diverge sections, the most critical element in the evaluation of entrance ramp capabilities is the availability of sufficient time-space in the lane one traffic stream. The capacity of both a merging section and a diverging section has been established as 2,000 vph. Figure 12 presents the "across all lanes" level of level of

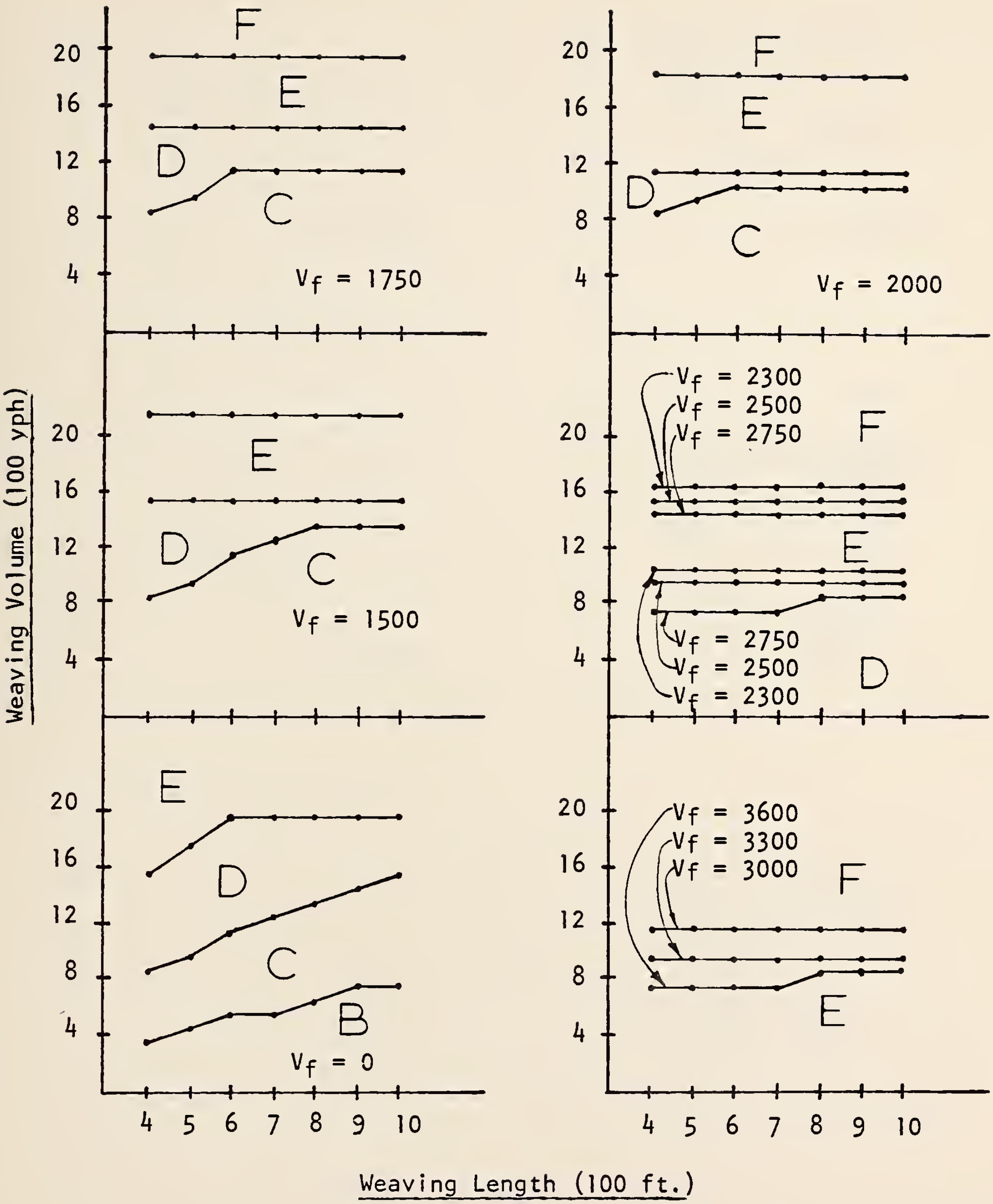


FIGURE 10. Effect Upstream Volume (V_f), Weaving Length and Balanced Weaving Volume on the Level of Service of a Two-Lane, One-Way Roadway with an Auxiliary Lane

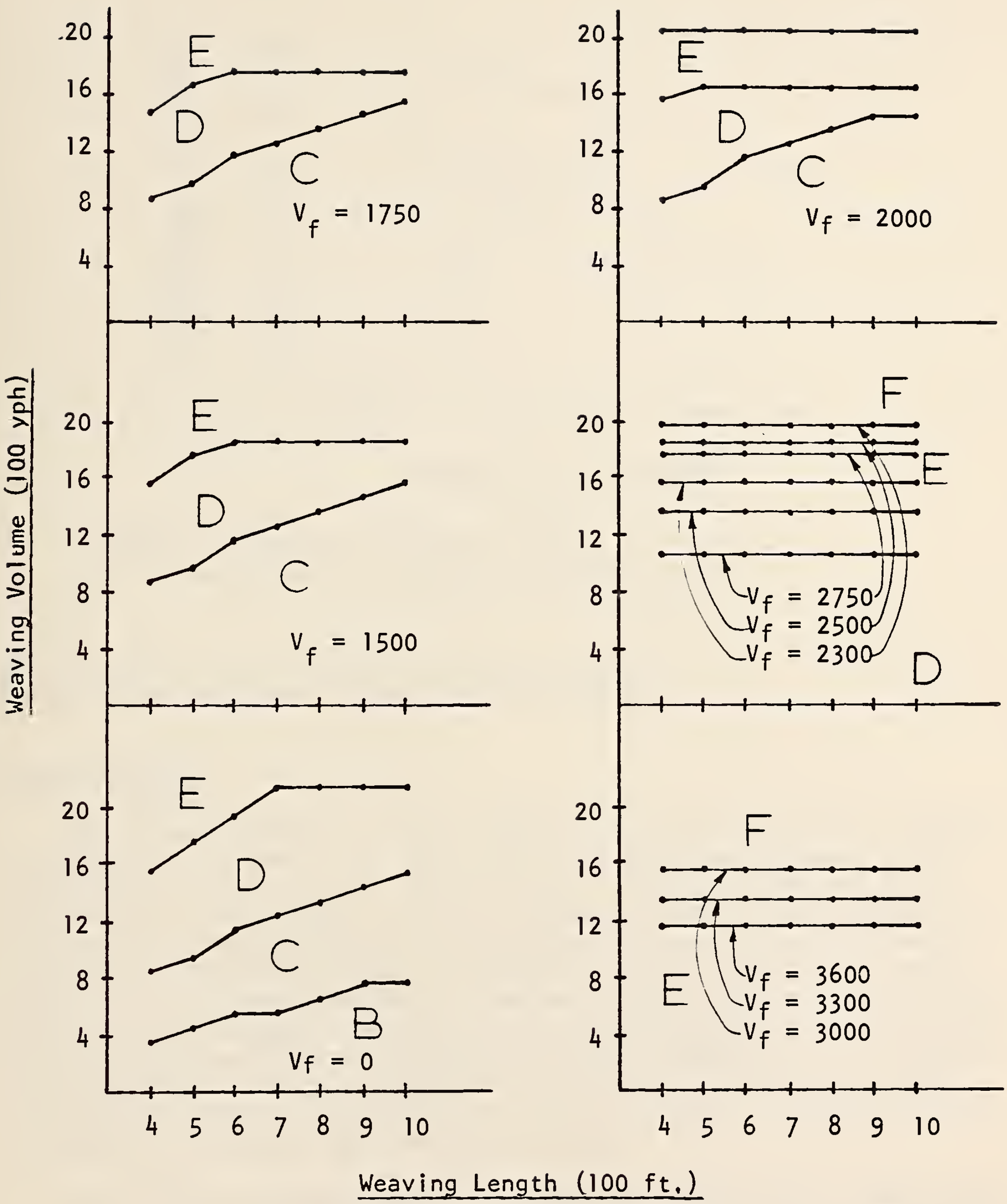


FIGURE 11. Effect of Upstream Volume (V), Weaving Length and Unbalanced Weaving Volume on the Level of Service of a Two-Lane, One-Way Roadway with an Auxiliary Lane

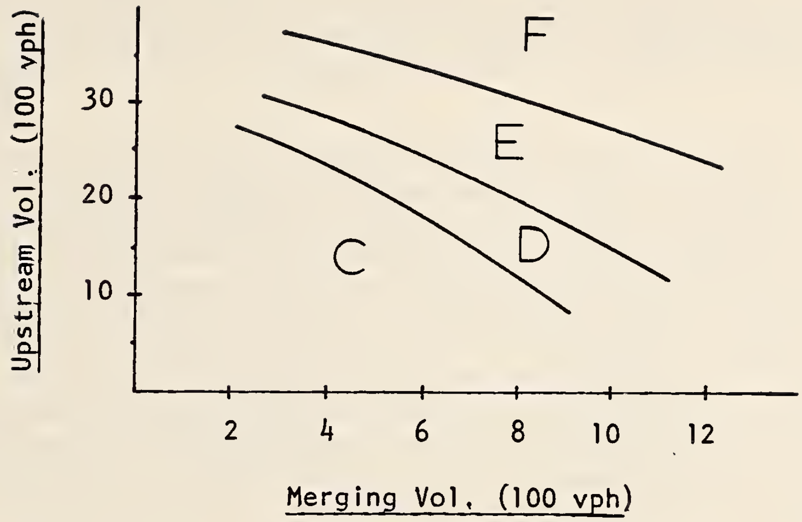


FIGURE 12. Effect of Merging Volume on the Level of Service of a Two-Lane, One-Way Roadway

service, but it was derived by making assumptions about lane distribution given the total through traffic volume.

Survey Results

The primary purpose of the survey was to first determine if there is a specific problem or series of problems being encountered in the operation of all cloverleaf interchanges without C-D roadways and to then identify the various types of treatments that are being employed to alleviate these problems. In the event that only certain cloverleafs are experiencing problems, the goal of the survey was to obtain a description of the conditions under which these specific interchanges experience operational breakdowns and to then identify those treatments that are being employed to improve interchange operation. The secondary purpose was to obtain a general indication of the extent or severity of the problem by determining if the agency had a program planned or underway to improve the problem locations.

The survey procedure generally conformed to the "elite" interviewing procedure rather than the "standardized" interviewing procedure. With the standardized, poll-type survey, a list of questions is generated based on a strict definition of the problem. Then, the answers sought with the questions will then fall within the bounds set by the presuppositions used in preparing the list of questions. However,

with the elite interviewing procedure, the expert or person being interviewed is free to define the problem as he perceives it. Since this survey was intended to solict the views of a limited number of "experts" from ten or less states, the elite interviewing procedure was selected.

The survey involved ten states and consisted of telephone interviews with traffic operations personnel and/or design personnel from each of these states. Generally, the engineer responsible for traffic operations was interviewed first and if he felt that problems existed at one or more interchanges, then the engineer responsible for design was interviewed in order to obtain a description of the interchange geometrics, of the factors contributing to the undesirable operations and of the reasons for selecting the proposed treatment. The engineer being interviewed was not asked to justify his reasons for identifying specific problems by supplying numerical data for problem versus non-problem interchanges. He was merely asked to generally describe the conditions that contribute to the problem and to generally describe how the proposed treatment would alleviate these conditions.

Table 3 contains a synopsis of the results of the interviews conducted with engineers from each of the ten states included in the survey. Appendix C contains a more detailed summary of the contents of each interview. The results of the interviews indicated that the majority of the full cloverleaf interchanges without C-D roadways are currently operating in a tolerable fashion. The operational experts would not classify the cloverleaf as a consistent "bottleneck" problem, but did feel that such a problem would exist as the turning volumes became excessive. No state felt that it might be necessary to alter all cloverleafs on a systematic basis and all states contacted, except Texas, still build cloverleaf interchanges without C-D roadways.

However, there are two general situations which will cause a given interchange to operate in an intolerable fashion. The first situation is encountered when the turning volumes conflict with the through volumes in a manner that leads to an intolerable restriction of flow on the mainline. This condition most often occurs in the weaving section where two closely spaced turning movements conflict with each other as well as the through movement. This result was to be expected and no engineer felt that their problem locations were "under performing" but rather that the interchanges were operating under conditions different from those for which they were designed. Another situation that occurs somewhat frequently in the weaving section is the dominance of the high-speed, off-movement over the low-speed, on-movement which results in the on-ramp backing up onto the crossroad. Two states recognized a need to solve this type of problem.

TABLE 3. Summary of Interviews Held With Selected State Representatives

STATE	PERSON INTERVIEWED	INTERVIEW SYNOPSIS
Maryland	Thomas Hicks Assn't Chief Engineer for Traffic Operations	Operation is fair to poor and varies directly with mainline and weaving volume. Consideration is being given to provision of escape taper.
	Irwin Hughes Assn't Chief Engineer for Design	Problems that arise do so with the terminals on crossroad that have no accel or decel lanes. Still use cloverleafs.
Indiana	Clinton A. Venable Chief, Division of Traffic	Operation is bad at those interchanges with tight loop geometrics and high percentage of truck traffic. Tight geometrics do not permit adequate accel and decel performance.
Illinois	Robert E. Craven Engineer of Traffic Operations	Some accident problems on older interchanges with tight loop geometrics, but in the main, operation is not a problem.
Massachusetts	K. Krekorian Deputy Chief Engineer for Traffic Operations	Operation is fairly efficient except in extreme volume conditions.
	Peter J. Hunt Highway Design Engineer	Some problems are experienced on crossroad where access is uncontrolled.
Michigan	Donald Orne Director, Traffic Operations	Operation in weaving section is not satisfactory even on C-D roadway with moderate volumes.

TABLE 3. Summary of Interviews Held With Selected State Representatives (cont.)

STATE	PERSON INTERVIEWED	INTERVIEW SYNOPSIS
Virginia	J. P. Mills Engineer, Bureau of Traffic & Safety	Operation is satisfactory until design volumes are reached.
	Robert Mannell Bureau of Design	Cloverleafs are still used. C-D roadways are added to existing interchanges when mainline is upgraded from 2-lane to 3-lane.
Pennsylvania	Robert J. Doughty Director, Bureau of Traffic Engineering	Short weave sections and high volumes cause temporary problems which are not intolerable.
New York	Robert Millspaugh Division of Traffic and Safety	Operational problems are experienced when weaving volumes become excessive, but no interchange improvements are planned.
California	Parker Hall Assn't Engineer of Design	Problems experienced with high volumes and accidents on short weaving sections on freeways. Adding a C-D roadway or converting to a directional is the desired solution. When the crossroad is not a freeway, problems are usually experienced on the crossroad in the vicinity of the ramp terminals. Conversion of the interchange to a PARCLO A-4 is the desired solution.

TABLE 3. Summary of Interviews Held With Selected State Representatives (cont.)

STATE	PERSON INTERVIEWED	INTERVIEW SYNOPSIS
Texas	Harold D. Cooner Senior Design Engineer	Have some problems with short weave and high volumes. All weaving sections on freeways have C-D roadways.
	Richard Oliver Traffic Engineer	No known problems.

The second situation is encountered when the crossroad is not a controlled access roadway but rather a multi-lane facility with at-grade intersections and operating with varying forms of traffic control such as signalization and median turning lanes in close proximity to the interchange. In this case, the free-flow characteristics of the ramp terminals on the crossroad hamper the effectiveness of the traffic control. Those engineers in the states with cloverleaf interchanges in suburban areas that have experienced considerable population build up and the resulting commercial development along the crossroads felt that the interchange and freeway in this situation could no longer be considered as serving the long distance traveler. The interchange user in this case is a short trip traveler with the freeway serving as an arterial. They felt that the cloverleaf design with its free-flow characteristics was not compatible with this use.

The results of the survey did indicate those situations which resulted in operational problems. While one engineer felt that the weave caused problems regardless of the volume (even with a C-D roadway), the majority of the operational engineers felt the interchanges were operating as expected and that no plans were being contemplated which would result in a systematic upgrading of the operation of cloverleaf interchanges.

Problem Identification

The examination of the accident data base collected for the Interstate System Accident Research - Study II provided a general indication of the factors associated with high numbers of accidents on cloverleaf interchanges. The origional study by Cirillo et al (1969) which utilized this data base concluded that the cloverleaf interchange accident frequency (average number per year) varied directly with the mainline traffic volume entering the interchange. The reexamination of that data base in this study demonstrated that the majority of those accidents that occurred with the increased traffic volume were occurring along the mainline, not on the ramp or on the crossroad. That result merely confirmed the well-known, general relationship between traffic volume and traffic accidents.

The use of the HCM procedures to describe the operation of the various elements within the interchange produced level of service estimates for varying combinations of traffic volume and interchange geometrics. These estimates were used to define those conditions which would cause specific elements within the interchange to restrict flow on the mainline and thereby represent a bottleneck. All volume and geometric variable combinations causing the through traffic flow to become unstable were noted for use in the evaluation of improvements.

The results of the survey were then used to narrow this list of potential areas of conflict within the interchange to those which

historically have consistently led to the breakdown of flow or an intolerable increase in accidents within cloverleaf interchanges. The two principal areas of conflict identified by the survey were the crossroad terminals and the mainline weave section. The effects of conflicts in the two areas on overall interchange performance were different in each case.

The conflicts generated in the vicinity of the crossroad terminals occur with interchanges located in suburban-to-urban areas when the crossroad is a non-access controlled facility with heavy strip development in the vicinity of the interchange. The problem is generally considered to be a safety problem resulting from lane-changing by vehicles entering the crossroad and attempting to get into position to turn left from the crossroad into an establishment near the interchange. Operations away from the interchange rather than through the interchange tend to be thought of as a problem because the free-flow operation of the terminals onto the crossroad tend to disrupt the controlled flow on the crossroad which will be signalized away from the interchange. Also, as the volume on the crossroad increases, the probability of a queue build up on the ramp extending back onto the freeway also increases. However, the basic problem seems to be the fact that the free-flow characteristics of the cloverleaf design prevents control into and through the interchange.

The conflicts generated in the vicinity of the weave section occur with interchanges located in suburban or rural areas but are better characterized as occurring on interchanges involving two major freeways. In this situation, the free-flow characteristics of the cloverleaf interchange are desireable but the capability of the weaving section to efficiently handle the turning movements is inadequate. This situation can be reached with balanced on/off movements but is also likely to occur with a predominate on movement being controlled by a small, but high-speed, off-movement. This creates both a safety problem in the mainline weave section and a congestion problem on the crossroad as the ramp queue build up occurs.

CHAPTER III

The efforts described in the previous chapter were designed to first describe the operational and safety characteristics expected of the full cloverleaf interchange and then to indicate those situations most likely to occur which would necessitate remedial action. With that accomplished, the efforts described in this chapter were designed to evaluate the potential worth of one or more improvements for each situation identified. The improvements were generated from a list specified in the RFP for this project and from the survey of operational and design experts described in the previous chapter.

The improvement types that were mandated for consideration by the RFP were the following:

1) Complete reconstruction of the interchange,

2) Partial reconstruction of the interchanges,

3) Ramp realignment,

4) Traffic control including signalization, ramp closure, etc.,

5) Installation of C-D roadways.

This combination of improvement types and methods of accomplishing improvement types was restructured into three categories:

1) Those improvements which eliminate the standard flow pattern by using temporary loop ramp closure or by converting to a full directional, a partial cloverleaf, or a diamond interchange.

2) Those improvements which modify the standard flow pattern by separating the weaving lanes from the through traffic lanes such as with the addition of a C-D roadway, and

3) Those improvements which retain the standard flow pattern but make it operate more efficiently such as with the use of traffic control measures or by adding length to the weaving section.

The two problem types described in the previous chapter as the "weaving problem" and the "crossroad problem" can be analyzed with respect to each of these three classes of improvement.

Weaving Problem

The "weaving problem" results from conflicts generated in the vicinity of the weave section. In this situation, the capability of the weaving section to efficiently handle the volume of traffic passing through the section or the relative speed of the vehicles using the section is not adequate. The former situation is a capacity problem, reached in the high volume/low speed condition preceeding complete breakdown. The latter situation is one of less volume and more speed in which the operation through the weave section is relatively unsafe due to the speed differential between exiting and entering vehicles.

With respect to those improvements that retain the operation of an existing weave section in these two situations, there is little evidence available to indicate that improvements in the traffic control measures will improve the weaving section performance beyond that theoretically predicted by the manual. In the high volume situation (i.e., at capacity), operation can no longer be improved if one accepts the relationships between driver capability, volume, speed, and space that are used in the HCM to define capacity. (As mentioned earlier, enhancing driver weaving capability is outside the scope of this study). In the less volume/more speed situation, attempts have been made to enhance the weaving section performance through the use of traffic control devices not normally applied in the weaving section. Several states surveyed used YIELD signs at the loop on-ramp terminal, basically to alert the driver as to his responsibilities to use caution in first finding and then accepting a safe gap. While the desired result behind the use of this concept is increased safety in the weaving lanes, there is no data available to determine its actual effect. Theoretically, the use of the YIELD sign at the ramp terminal could induce the ramp vehicles to decelerate, thereby increasing their speed differential with the exiting vehicles and simultaneously decreasing the capacity of the ramp. Ultimately, the sign could serve as a metering device. However, placement of the sign at the ramp terminal maximizes the storage capabilities of the ramp but minimizes the opportunity of the ramp to serve as an acceleration lane prior to the weaving section. Therefore, if speed differential is the characteristic to be altered, the use of any flow restriction device on the ramp should not represent an improvement.

The concept of using some form of ramp control to improve weaving section operation is untested at this time. However, several problems would have to be overcome before it could be used on a cloverleaf interchange. First, and foremost, is the need to "process" ramp vehicles which would require warning, decelerating, and storing vehicles free-flowing onto the ramp from the crossroad. Theoretical

studies by Fenton et al (1972) demonstrated that such action could be accomplished through the construction of a storage area adjacent to the ramp. However, the application of this concept to the loop ramp configuration is not technically feasible with respect to the ramp storage required.

Another state surveyed attempted to improve the operation of the weave section through the application of lane control techniques on the mainline. It was hypothesized that the weaving section operation could be enhanced by removing the through traffic from lane one, leaving only the exiting (i.e., decelerating) traffic. The EXIT only signing series was used to accomplish this task and was successful initially. However, after a short period of time, repeat users realized that lane one was a through lane and started ignoring the signing. This confirms the results of Johnson and Newman (1968) that drivers will use the available pavement to their best advantage. It is also another verification that problem-solving through driver deception will not work and should be discouraged.

The last possibility for improving the weaving operation without modifying or eliminating the flow pattern is to control the mainline speed. However, attempts to restrict the freeway free-flow speed limit to 55 mph have not proven successful. Attempts in California to use differential lane speed controls were unsuccessful. Therefore, it appears that there is no proven method of using traffic control to improve the weaving section operation beyond that predicted by theory.

Increasing the length of the weaving section is a frequently-mentioned technique of improving the weaving operation. However, as pointed out in the discussion of operating characteristics of the weaving section, the effect of added length can be offset by the magnitude of non-weaving traffic. Recall that Figure 10 was used to demonstrate that increasing the length of weaving section ceased to have an effect once operation on the mainline reached level of service 'C' (2,000 vph to 3,000 vph). So, unless the weaving section is very short (300' or less), there appears to be little operational benefit to be gained with the improvement. The cost of the improvement is likely to be reasonably high since it is probable that the addition of 200' or more length would also require the relocation of one or both of the loop ramps. Those states interviewed felt that a project specifically designed to lengthen the weave section was unreasonable. However, if other major work was planned for the interchange, it might then be cost-feasible to have this type of improvement included in the overall project.

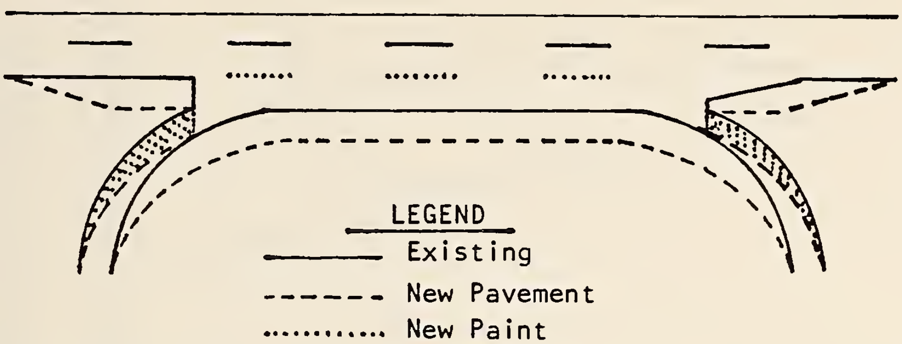
Modifying the standard cloverleaf pattern in order to improve the weaving section operation can be accomplished by separating the weaving traffic from the through traffic. There are two known methods of accomplishing this task. The first is the addition of a C-D roadway,

which is nothing more than separating the weaving lanes from the through lanes and inserting a physical barrier between them. The second technique accomplishes the same thing but without providing a physical barrier. Figure 13 describes the improvement schematically.

The figure includes a description of the hypothesized effect of each portion of the improvement. The paving of the shoulder to provide a deceleration lane in advance of the entrance nose is designed to induce an early separation of weaving traffic from through traffic and to encourage deceleration of the exiting vehicles, thereby reducing the speed differential between entering and exiting traffic. The increased weaving width provides a path for vehicles entering from the loop ramp that is not in direct conflict with those vehicles occupying the deceleration lane. The net effect is the creation of an additional lane through the weaving area, which should improve the overall operation. The added acceleration length or escape taper past the exit loop nose should relieve the pressure on the merging vehicle by allowing more room for acceleration and a longer time for gap selection. Although this improvement has been applied several times, there is no data available to indicate the degree to which each of the hypothesized effects actually take place.

One state surveyed reported using this technique whenever funds were unavailable to alter an existing cloverleaf by creating a different operational pattern or to modify it by adding a C-D roadway. This state reported modifying eight interchanges in this manner, but had not collected any before/after data for evaluation. However, based on observation, a paucity of public comment and no apparent increase in traffic accidents, the state is satisfied with the overall effect and will not hesitate to use the improvement. Of course, this improvement is virtually limited to the case where the mainline passes under the crossroad and there is sufficient width available to add the lane (and retain some shoulder if possible) without affecting the structure. If the structure is affected, then the cost of this improvement versus that of adding a C-D roadway eliminates this improvement from consideration.

Collector-distributor roadways, the other method identified for modifying the standard cloverleaf, are accepted in new construction as a standard element in a full cloverleaf interchange. Some states mandate its use on freeways, some states plan for its inclusion in subsequent upgrading of the freeway through the interchange. In the early sixties, Moskowitz and Newman (1963) concluded "Because of the length required between entrance and exit ramps, a collector road should be used on all cloverleaf interchanges whenever the weaving volumes exceed 1,200 vph. The principle of a cloverleaf with two loops on one side of the freeway is basically incompatible with the principle sometimes expressed as adequate spacing between interchanges". Pinnell and Buhr (1966) stated "a restriction of about 1,000 vph is placed on



Overall Purpose: Improve thru-lane operation (minimize lane changing and speed change) by removing the deceleration action, the weaving action and the acceleration action from the through lanes. This is accomplished by applying the below-listed treatments, each with its own theoretical effect.

TREATMENT	THEORETICAL EFFECT
Add deceleration lane prior to entrance nose by paving shoulder	Benefit flow on the mainline by removing decelerating vehicles at the point of probable deceleration; Benefit flow in the weave section by reducing the speed differential between exiting and entering vehicles.
Add lane in weaving section by paving shoulder	Benefit flow on the mainline by removing the weaving vehicles from the thru set of lanes; Benefit flow in the weave section by separating the weaving action from the thru movement.
Realignment ramp using revise ramp alignment ramp shoulder and striping out existing pavement	Benefit flow in the weave section by realigning ramp vehicles with new (added) auxillary lane.
Add acceleration lane beyond exit gore by paving shoulder	Benefit flow on the mainline by providing entering vehicles the opportunity to increase their speed to that of the through vehicles prior to merging.

FIGURE 13. Description of a Treatment for Improving the Traffic Flow and Safety in the Weaving Section of a Cloverleaf Interchange

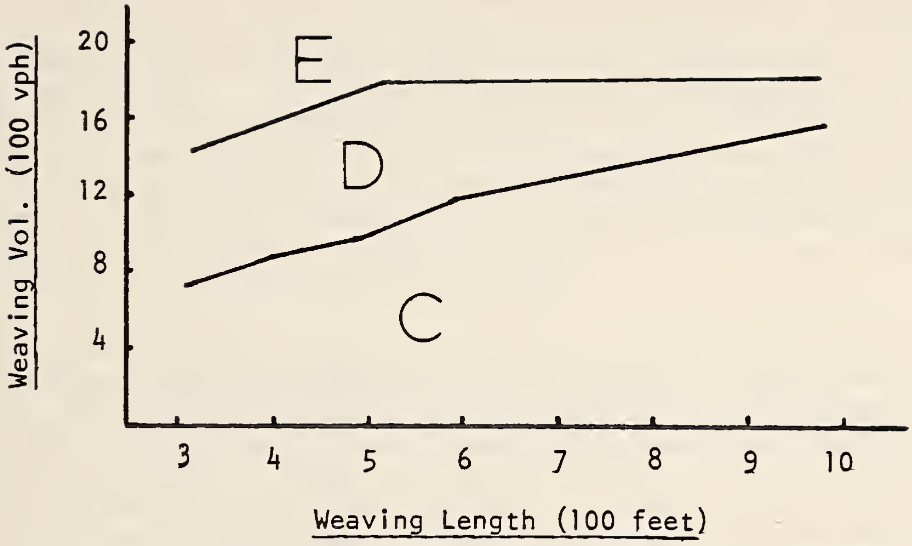


FIGURE 14. Effect of Weaving Length and Weaving Volume on the Level of Service on a C-D Roadway

the capacity of two adjacent left-turn movements due to the weaving maneuver. When collector-distributor roads are used, however, the weaving capacity increases to about 1,500 vph due to the lack of interference by freeway vehicles". Mulinazzi (1973) after in-depth interviews with the roadway design engineers of seven major state transportation departments concluded "collector-distributor roads should become a basic design element of a cloverleaf interchange". The theoretical analyses performed in this study also demonstrated the improvement that can be expected with the addition of the C-D roadway. Figure 10 related level of service to weaving volume and through volume for a standard three-lane section consisting of two through lanes and one auxiliary lane. Figure 14 indicates that 1,600 to 1,800 total weaving vehicles per hour can be processed on a C-D roadway of 500' or more before the flow becomes unstable. This represents an improvement in all cases over the capacity of the standard three-lane section, both with respect to the weaving traffic and the through traffic. Using the data included in Appendix B, a similar demonstration can be provided for a four-lane section.

Irrespective of the actual calculations used, those used by Pinnell and Buhr or those produced in this study, it is easy to demonstrate that the provision of a C-D roadway will improve the capacity of both the weave section and the through lanes. However, recent studies by Mulinazzi (1973) and Taylor et al (1973) on major interchange design, both recommend minimizing (eliminating, if possible) the number of weaving sections in major interchanges due to the speed and capacity restrictions imposed by the loop ramps as well as the

weaving section. Therefore, if the existing cloverleaf is not a freeway-to-freeway interchange and the weaving volumes are not expected to exceed 1,800 vph, the modification of a C-D addition can be expected to provide increased capacity and a better level of service to the through traffic. The actual degree of improvement, of course, depends on the before condition. The cost of the improvement is largely site specific, but is almost sure to involve reconstruction of the structure, thereby making the modification expensive. Each case must be individually considered, therefore, as to whether the addition of a C-D roadway would represent a sufficient improvement in operation to justify its specific cost.

In those situations where the weaving volumes are so large that the interchange modification of the C-D addition is inadequate or if the loop ramps impose a capacity restriction and safety hazard to high speed turning traffic on a freeway-to-freeway interchange, then it will be necessary to alter the basic cloverleaf configuration by eliminating the weave sections and loop ramps entirely. Partial or full directional interchanges will be required to provide the free-flow characteristics necessary on a system interchange serving two freeways. The cost of converting a cloverleaf to some form of directional interchange would be extremely high because of the requirement to maintain traffic and may be prohibitive or impossible when the right-of-way requirements and costs are taken into consideration. A cost effectiveness analysis in this case is almost superfluous since it is the total cost involved that will determine whether or not the improvement can be undertaken.

The preceeding discussion of altering the full cloverleaf to form a fully directional interchange is applicable to a freeway-to-freeway situation in the suburban to rural areas. If the weaving problem occurred on a cloverleaf interchange not linking two freeways and in a suburban to urban setting, then closing of one or more ramps during certain periods of the day can be analyzed as a method eliminating the weaving section to improve the interchange. In examining this method of altering the cloverleaf, it is assumed that the remaining freeway and street system will allow the responsible agency to provide a safe and reasonable alternate service to the public by rerouting the traffic.

Given the peak-hour traffic volumes that indicate a high entrance loop volume and low exit loop volume, a potential alternate is the closing of the exit loop ramp during periods of peaked unbalanced flow. Assuming that this can be accomplished, then the analysis depends on an estimate of how many potential exiting vehicles will still be in the traffic stream at the point of the loop ramp merge. For purposes of this analysis it will be assumed that 100% will remain as through traffic. This means that the flow entering the weaving section (V_f) will be the same for the simple merging operation as it was for

the weaving operation. An examination of the merge graphs (Figure 12) and the weaving graphs for unbalanced flow (Figure 11) reveals that in general, the level of service provided for merging operation alone is an improvement only in those cases where the entering flow (V_f) is less than 2,750 vph and the weaving length is 500' or less. In all other situations, the capacity of through lanes is the major problem.

If the peak-hour traffic volumes indicate a high exit loop volume and a low entrance loop volume, then the possibility of closing the entrance loop ramp during periods of peaked unbalanced flow warrants examination. Comparison of the diverging graphs (Figure 9) with the weaving graphs for unbalanced flow indicates that the simple diverge represents an improvement in almost all cases. However, with the capacity of the loop limited to 1,200 vph, the closing of an entrance loop in an attempt to provide better service for a diverge of 1,200 vph or greater would be futile.

While the closing of the entrance ramp would appear to be successful when the entering volume is low, it is not this situation that is most likely to disrupt the flow within the interchange. The former situation of low exit volume and high entrance volume represents the greatest problem because the lower volume (exiting traffic) can dominate the flow through the weaving section due to its high relative speed. In this situation the benefits of closing the exit ramp can be demonstrated. However, the techniques available for the temporary closing of ramps are not well established for this situation. Changeable message signs have been used successfully to communicate positive guidance information to the driver (e.g., use EXIT A for State Fair). There is little evidence available to predict the success of negative signing with respect to driver observance (e.g., EXIT A closed, Use EXIT B). The convenience of the alternate routing would have a direct effect on the success of the temporary ramp closing in the non-urban area. Therefore, while the closing of ramps is conceivable on paper, the situations in which it is feasible and practical are severely limited, if existent at all.

Crossroad Problem

The "crossroad problem" was previously described as a series of conflicts along the crossroad in the vicinity of the terminals and is characterized by the incompatibility of the ramp terminal free-flow characteristics and the controlled flow characteristics of the crossroad. This incompatability results in a safety problem due to lane-changing by vehicles entering the crossroad from the freeway. While it is conceivable that capacity problems would arise as the crossroad and ramp volumes become excessive, the states citing this situation

felt that conditions leading to the safety problems were encountered first (i.e., prior to capacity problems) and need to be corrected.

Since it is the free-flow characteristics of the basic cloverleaf pattern that contribute to the problem, it does not seem logical that any improvement which retained that flow pattern would be responsive to the problem. The concept of modifying the flow pattern by providing a C-D roadway would also not be responsive to the situation since it would not correct the fact that ramp vehicles free flow onto the crossroad. Neither retaining the operation nor modifying the operation with a C-D road would address the fact that the cloverleaf operational characteristics are not compatible with the characteristics of a non-limited access, suburban or urban arterial. The most logical solution is to alter the operational pattern to conform to the needs of the two intersecting roadways.

Recognizing the nature of the crossroad in this situation to be that of a signalized, suburban arterial, it is desirable to control the flow from the ramps onto the crossroad. This could be accomplished with stop signs at the crossroad terminal. This technique is used by one state surveyed in order to offset the lack of acceleration lanes on the crossroad. However, given the volume level of a suburban arterial and probable volume of turning movements needed to justify the cloverleaf in the first place, this action would likely result in a ramp queue buildup back onto the freeway. Therefore, it would be necessary to use signalization at the ramp terminals, thus clearing the ramps and providing the ramp vehicles the opportunity to perform lane-change maneuvers without interfering with the flow on the crossroad. However, signalization can not be employed without altering the interchange configuration to eliminate the weaving section and then to accommodate the resulting left turn onto the crossroad. This can be accomplished by eliminating all loop ramps and converting to a diamond interchange or by eliminating half of the loops (either the entrance loops or the exit loops) to form a partial cloverleaf (parclo B or parclo A respectively). Although Pinnell and Buhr (1966 B) have demonstrated mathematically that the parclo A-4 provides no more capacity than the signalized diamond (4 phase), the parclo A-4 would be the preferred configuration because it would require less physical change to the existing full cloverleaf interchange. Also, retention of the entrance loops eliminates the need to provide left turns from the crossroad since they can take place continuously across the loop. The only left turns that occur at grade are those off of the ramp onto the crossroad. Not to be overlooked is the fact that the parclo A-4 also eliminates the weave section.

The primary deterrent to the conversion to the parclo A-4 would be if the total number of exiting vehicles would be in excess of that which could be satisfactorily processed by the single freeway exit,

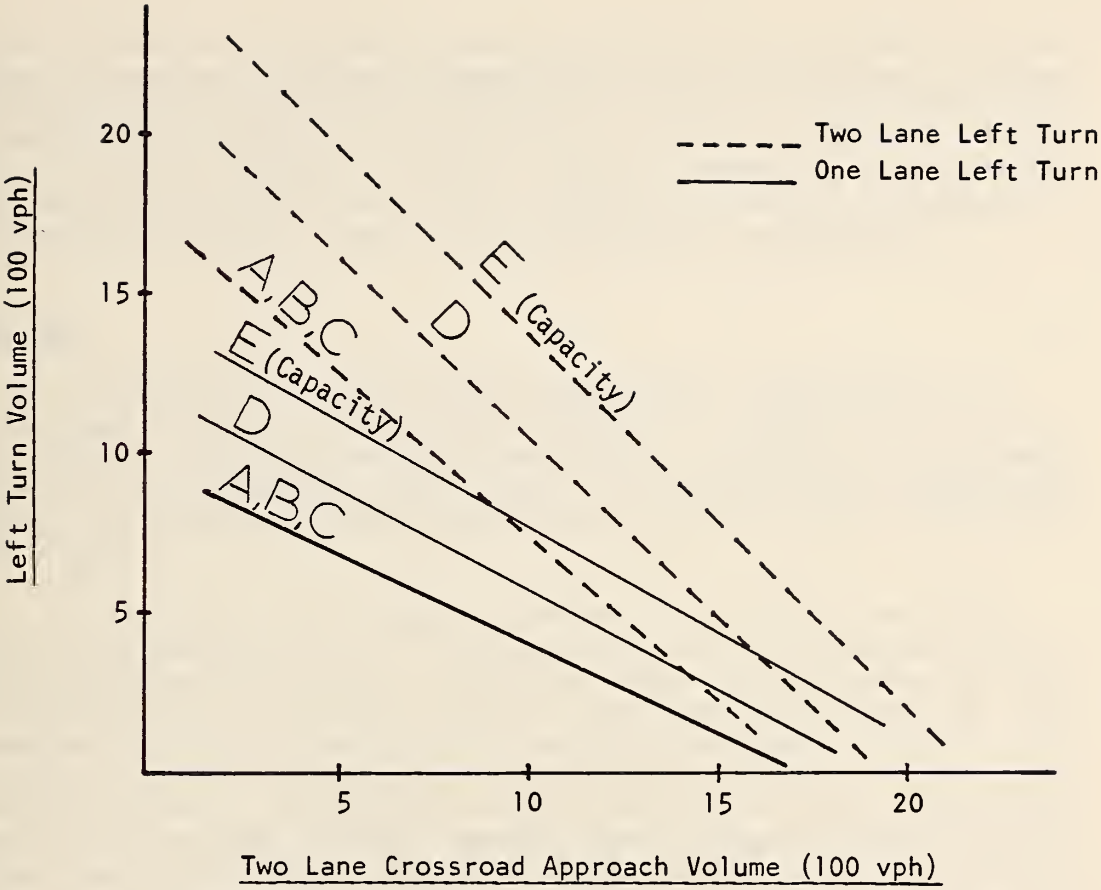


FIGURE 15. Effect of Number of Turning Lanes and Turning Volume on the Crossroad Service Volume

even when expanded to two lanes wide. The two lane exit is more complicated and may even require the dropping of lane one at the exit in order to achieve lane balance. At the crossroad, a double left turn may be needed if it is necessary to process up to 1,200 vph. Pinnell and Buhr (1966 A) demonstrated mathematically that this rate can be achieved with four-phase signalization. They also provided a method for computing the capacity of the interchange (i.e., crossroad with two signalized ramp terminals). The outcome of these calculations are, of course, dependent upon the number of lanes on the crossroad and the limiting factor of distance between the two signalized ramp terminals. Figure 15, derived from the Highway Capacity Manual and indicating the relationship between percent green time (G/C), flow rate (vph), number of left-turn lanes, and intersection level of service, can be used to demonstrate that the second reason for using a double left turn would be to minimize the amount of green time taken from the crossroad through traffic in order to process the ramp vehicles. However, since the principle reason behind the conversion to the parclo is to correct a safety/flow problem and not a capacity/

flow problem, these capacity considerations will be secondary to the need to make the interchange compatible with the operation of the two intersecting roadways (i.e., freeway and arterial). Therefore, it is concluded that altering the full cloverleaf to form a partial cloverleaf of the A-4 design is the only solution responsive to the problem. Cost-effective data is once again superfluous since in the absence of alternate solutions, total cost is the primary consideration.

Summary

Two distinct situations were identified as those which have consistently led to the breakdown of flow or an intolerable increase in accidents within cloverleaf interchanges. A series of improvements were discussed regarding their potential to enhance interchange operations by either retaining, modifying or altering the basic cloverleaf flow pattern.

In the case of the "weaving problem", it was first recognized that the characteristics of the poor operation in the weaving section varied between two extremes. The upper bound of the problem is the situation when the volume of traffic using the weaving lanes and non-weaving lanes approaches capacity and the flow becomes unstable. The lower bound of the problem is the situation when free-flow speeds are being attained by the through traffic with the resulting speed differential for the ramp vehicles impeding the weaving/merging operation. These two situations are not two distinct entities but rather represent the extremes of a continuous scale describing the weaving section operation. It was concluded that the upper bound situation of high volume/low speed conditions (i.e., capacity) could not be improved without modifying or altering the flow pattern. The lower bound is better characterized as a high speed/low volume condition with the high relative speed between mainline and ramp vehicles being the basic problem. Several methods of reducing this differential through speed control and lane control via signing on the mainline were reported to be ineffective while attempts to control the ramp vehicles was shown to be non-responsive to the problem. Lengthening the weaving section was shown to have a beneficial effect in the low volume situation, with this effect diminishing rapidly as the non-weaving volume increases.

Modifying the flow pattern was to be accomplished by separating the weaving lanes from the non-weaving lanes, thereby increasing the width and therefore capacity of the section. Two methods of accomplishing this modification were identified. The first method was the least expensive but also has an undocumented effect. This method consisted of paving the shoulder outside the auxiliary lane, moving the entrance and exit noses to the right, and paving the mainline shoulder leading into the entrance nose and away from the exit nose. The operational

effect is to provide a deceleration lane for the exiting vehicles, weaving lanes separate from the through lanes, and an acceleration lane for the merging vehicles. This improvement has been used several times by one state when the additional pavement can be added without affecting the existing structure. While that state is satisfied with the resulting effect on the weaving section operation, no attempt has been made to document that effect. The other modification was the addition of a C-D roadway. The desired effect on operations of the C-D roadway is identical to that described for the less expensive improvement, but the probability of achieving that effect are improved by the use of the physical barrier to separate the weaving lanes from the non-weaving lanes. The addition of the C-D roadway has a documented effect on the operation in the weaving lanes and the non-weaving lanes but is not readily applied to an isolated interchange. The cost of the improvement is generally quite high due to the need to alter the structures and realign the ramps. Improvements of this magnitude are generally only undertaken as part of major upgrading projects involving several miles of the mainline through the interchange.

Only one method of altering the cloverleaf flow pattern was identified as being responsive to the weaving-at-capacity situation. That was the elimination of the weaving section through the provision of a partial or full directional interchange. This type of interchange has been shown in recent research studies to be the only acceptable type of flow pattern for an interchange involving two major freeways on which it is desirable to maintain a better level of service throughout the interchange, including the turning movements. Availability of funds will be the primary factor affecting the decision to make this type of improvement.

In the case of the "crossroad problem", it was recognized that the very nature of the cloverleaf flow pattern was the reason for the poor operating characteristics on the crossroad. Therefore, those improvements which would retain or modify that flow pattern would not be responsive to the problem. Only those improvements which altered the flow pattern of the ramp vehicles entering the crossroad were considered. The partial cloverleaf with the A-4 design was determined to be the type of flow pattern which would permit the control of the entry rate of ramp vehicles onto the crossroad, not introduce severe capacity limitations, and involve the least expense in converting from a full cloverleaf.

CHAPTER IV

Summary

The purpose of this project was the development of criteria for altering existing full cloverleaf interchanges to improve the traffic operations and safety of this particular configuration. Only the standard cloverleaf configuration with a loop ramp and an outer connection in each quadrant was considered in this study. The data base from the Interstate System Accident Research-Study II project was used to describe the spatial distribution of accidents within the interchange and its relationship to increasing traffic volume. Highway Capacity Manual procedures were used to describe the capacity characteristics of the various junction points within the standard cloverleaf. The results of these two analyses were combined to describe the range of traffic situations that could cause a breakdown in operations on any standard cloverleaf. A survey of ten major states having experience operating full cloverleaf interchanges led to the identification of two problem situations that are the most likely to lead to operational breakdowns on a standard cloverleaf interchange.

The first situation dealt with the operation of the weaving section as it approached capacity. Alternatives that retained, modified or eliminated the weaving section were discussed. Elimination of the weave was shown to be the most effective method of improving capacity but also the most expensive. It was shown that design engineers concur in the opinion that a major interchange between two freeways should not have weaving sections and loop ramps. However, the conversion from a full cloverleaf to a full or partial directional may be cost prohibitive even if land is available (i.e., suburban to rural setting). A three-year-old study in Ohio placed the cost of upgrading an existing cloverleaf to a fully directional interchange at $22 million, and was considered prohibitive then. No change has been made to the interchange since that estimate was made.

Modification of the weaving section to include a C-D roadway was discussed as being less expensive but still operationally restrictive due to the retention of the weaving section. Some states surveyed use this alternate when sections of freeways are widened and an increase in capacity of existing interchanges is desired. Another state surveyed uses a similar modification but does not insert a physical barrier between the weaving lanes and the non-weaving lanes. This alternate is used as a less expensive treatment and is used when no alteration to the structure is required. However, the actual effect on the mainline capacity and the weaving capacity has not been documented.

Retaining the cloverleaf flow pattern but attempting to improve the weaving section operation through the use of traffic control measures were not felt to be effective. Attempts to improve the weaving operation with increased weaving length have not proven effective. The concept of isolated ramp control on the loop ramp of free-flowing, cloverleaf interchanges does not appear feasible or workable. Therefore, interchange modification or redesign appear to be the only proven means of improving the operation of the weaving section, with these two methods being the most expensive to implement.

The second problem situation identified was the incompatibility of the controlled flow characteristics of an arterial-type crossroad and the free-flow characteristics of the ramp terminals at the crossroad. It was concluded that elimination rather than modification or retention of the standard cloverleaf flow pattern was the improvement most responsive to the nature of the problem. Conversion of the interchange to a Parclo A-4 design would provide the opportunity to control the entry rate of ramp vehicles onto the crossroad and thereby improve the operations and safety on the crossroad.

Conclusions and Recommendations

Based primarily on the results of the survey and the theoretical capacity analyses, the following conclusions were drawn:

1) Cloverleaf interchange operations rarely represent capacity "bottlenecks" in the freeway system such that isolated or single purpose projects are undertaken to improve just the interchange.

2) The free-flow characteristics of the cloverleaf ramp terminals are not compatible with the controlled flow characteristics of non-access-controlled crossroads with strip development in the vicinity of the interchange.

3) Cloverleaf interchanges with capacity or crossroad compatibility problems are better served by improvements involving redesign and reconstruction than by improvements involving currently available traffic control techniques.

Although the engineers interviewed rarely felt that the cloverleaf interchange operation was intolerable, they did express some doubt that any major improvements program could be undertaken in the near future to improve them if their operation did become intolerable. They felt that improvements involving reconstruction and land acquisition would be, for the most part, either cost-prohibitive or unacceptable to the public. Therefore, there does appear to be a definite

need to identify solutions to operational problems that do not attempt to improve capacity by using more land. Solutions that improve operations by improving driver skill or capability or solutions that use traffic control to decrease demand need further investigation. Examples of these types of solutions are provided by Wulfinghoff (1975) and his "base-lane" concept which couples a new set of "rules of the road" with a special pavement marking to provide more surface capacity and by May et al (1975) and their priority entry control strategy for freeway ramps in which vehicles with the highest occupancy would be given priority for entering the freeway proper. The base-lane concept attempts to improve capacity by improving the driver's utilization of the available roadway. The priority entry concept attempts to improve capacity by reducing the demand for the available roadway. These concepts appear to provide more long-range benefits than those considered in this study and it is recommended that more effort be directed in that direction in the future.

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APPENDIX A

The purpose of this appendix is to provide additional detail regarding the formation of the data base used in the accident analysis. As described in the body of the report, this data was originally compiled by the Federal Highway Administration for analysis in the project entitled, "Interstate System Accident Research - Study II" and utilized primarily in the report entitled, "Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System".

The data was originally collected in the ISAR study by interchange section which was defined as one-half the distance to the adjacent interchanges ahead and behind of the subject interchange. Each study section was then subdivided into its component study units such as loop off-ramp, acceleration plus mainline unit, deceleration half of weave plus mainline unit, etc. A full cloverleaf has a minimum of 32 study units (e.g., four loop ramps, four O-C ramps, etc.). Data was then collected and recorded in three major categories for each study unit: (a) highway data, including geometrics and design features, (b) traffic data including volumes as distributed over a 24-hour period, commercial traffic and speed data, and (c) accident data if the study unit had one or more accidents for the year being reported. For the purposes of this study, specific bits of data from each of the three categories was identified and requested for all study sections involving full cloverleaf interchanges. Figure 16 contains a description of the record layout for each record supplied by FHWA for each study unit within each interchange.

Data for 224 interchange-years was included on the tape received from FHWA. A FORTRAN program was then written which could sum data within interchanges for future analysis. The program had the capability to create up to ten combinations of study units within each interchange. For example, in combination A, group one totaled the data for the four loop ramps, group two totaled the data for the two O-C on-ramp, etc., up to ten groups, which taken as a whole, always equalled the total number of accidents recorded for the interchange. Seven different combinations were prepared for use in the analyses. Figure 17 is a schematic of a full cloverleaf interchange and shows the FHWA study unit designators as assigned by FHWA. Table 4 shows the various groupings of study units as they were formed for use in the seven combinations utilized in this study. For each group of study units, the FORTRAN program would produce the following data:

1) total number of accidents on all units,

One Summary Record for Each Interchange Unit

Position	Description
1-2	State Code
3-4	Year
5-7	Interchange Number
8-10	Unit Number
11-13	Unit Length
14	Type of Area
15-16	Study Unit
17	Type of Crossroad
18	Crossroad Traffic Control
19-22	7 a.m. - 9 a.m. ADT
23-26	9 a.m. - 4 p.m. ADT
27-30	4 p.m. - 6 p.m. ADT
31-34	24 Hour ADT
35-36	% Commercial, Day
37-38	Total Number of Accidents
39-40	Number of Accidents, 7 a.m. - 9 a.m.
41-42	Number of Accidents, 9 a.m. - 4 p.m.
43-44	Number of Accidents, 4 p.m. - 6 p.m.
45-46	Number of Accidents, All Other
47-48	Number of 1 Vehicle Accidents
49-50	Number of Rear-End Accidents
51-52	Number of All Other Accidents
53-57	Not Used

File Specifications

9 Track, 1600 bpi, IBM Standard Labels
Record Length - 57 bytes
Block Size - 7329 bytes (57x127)
DS Name - FHWA. OHIO. UNITS
Sort - 1 through 10 ascending

FIGURE 16. Record Layout for the ISAR Data Base as Received from FHWA

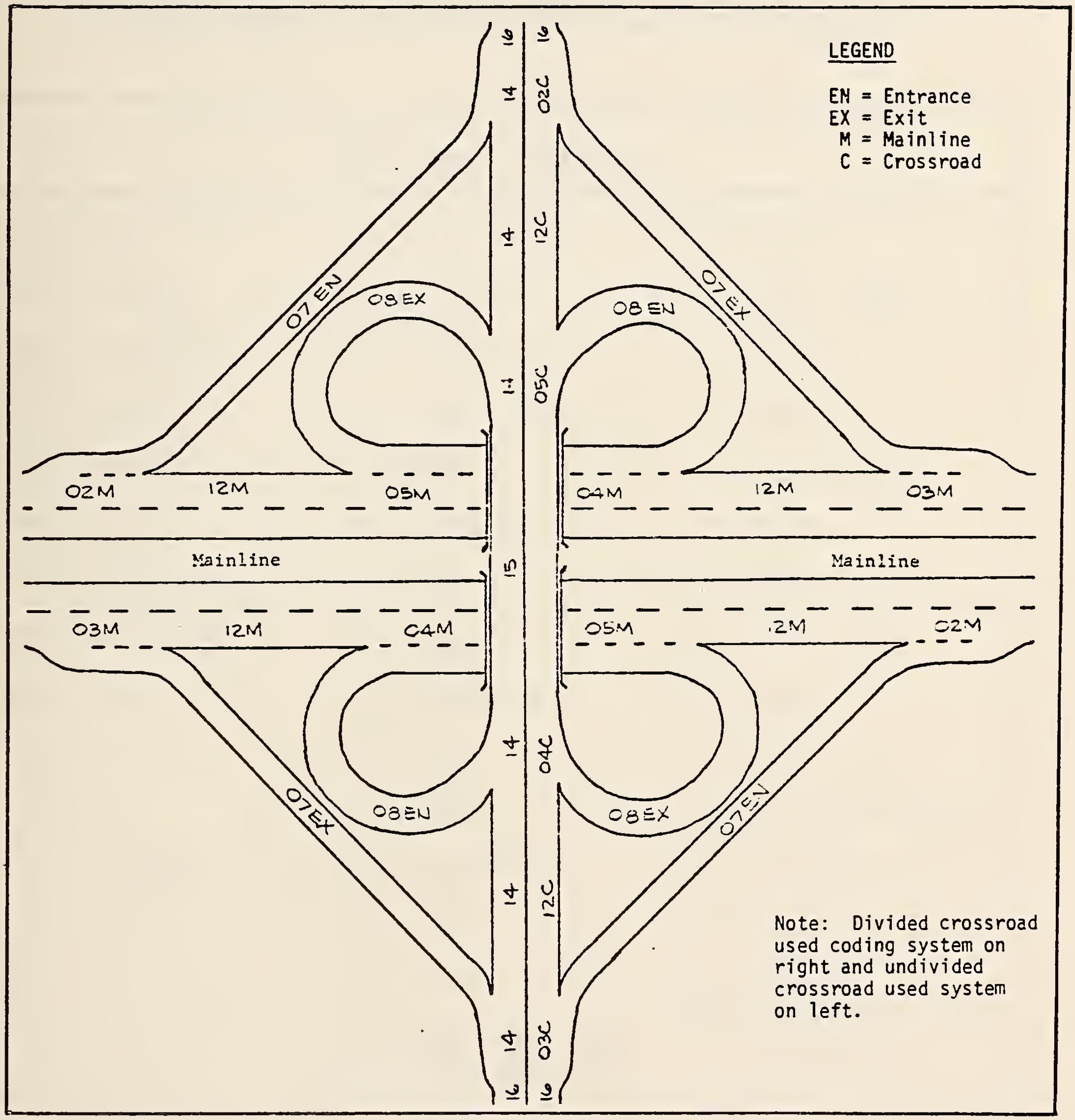


FIGURE 17. Schematic of Full Cloverleaf Interchange Showing the Location Codes Used in the ISAR-Study II

TABLE 4. Equivalency Table for Converting Accident Location from Ohio Code System to FHWA Code System Used in ISAR-Study II

ODOT Code = FHWA Code		
01 = 00.01	18 = 18	51 = 17, 18
02 = 02M, 02C	19 = 14, 40	71 = 07EX, 08EX
03 = 03M, 03C	21 = 02M, 03M	72 = 07EX
04 = 04M, 04C	22 - 02M	73 = 08EX
05 = 05M, 05C	23 = 03M	76 = 07EN, 08EN
06 = 06	26 = 02C, 03C	77 = 07EN
07 = 07EN, 07EX	27 = 02C	78 = 08EN
08 = 08EN, 08EX	28 = 03C	81 = 12M, 15M
09 = 40	31 = 04M, 05M	82 = 12M
10 = 41	32 = 04M	86 = 12C, 15C
11 = 42	33 = 05M	96 = 56,61,40,41,42
12 = 12M, 12EX	36 = 04C, 05C	97 = 17,18,40,41,42
13 = 56	37 = 04C	98 = 14,17,40,41,42, 56,61
14 = 14	38 = 05C	99 = 15M,15C,16,17,18, 41,42,56
15 = 15	40 = 02M, 03M, 04M, 05M, 12M, 15M	
16 = 16	46 = 02C,03C,04C,05C, 12C,14C,15C	
17 = 17		

2) average volume (24 ADT) across all units,

3) peak volume (largest values) on all units, and

4) total number of units in the group.

Using the data described in this fashion, it was possible to edit the data for each interchange. For instance, using the "number of units" figure it was possible to eliminate data for the interchanges that did not have the standard cloverleaf configuration of four loop ramps and four outer-connection ramps. Some interchanges included data for more than eight ramps. Some interchanges had the correct total number of study units, but an illogical combination of unit types within the interchange. For example, one interchange had six off-ramps and two on-ramps. In some cases, it was possible to correct obvious errors, but in many cases this was not possible and the data for that interchange (which could represent up to eight interchange-years worth of data) had to be eliminated. This edit reduced the data base from 224 interchange-years to 169 interchange-years. Table 5 contains a summary for all 224 data points with only the final 169 entries having a code for 'ID'.

The below-listed information was prepared for each interchange from a visual scan of a computer dump of the original geometric and traffic data as collected by FHWA:

A) TYPE -- 1 = undivided crossroad with YIELD sign at ramp terminals,
2 = divided crossroad with YIELD sign at ramp terminals,
3 = undivided crossroad with no TCD at ramp terminals,
4 = divided crossroad with no TCD at ramp terminals.

B) AREA -- 1 = urban as defined in ISAR data base
(AREAN) 0 = rural

C) PASSC -- 1 = crossroad passes under freeway
(PASSN) 0 = crossroad passes over freeway

Table 6 contains a listing of all descriptive data recorded for each interchange. The following pages contain scatter plots of the data demonstrating the distribution of data by interchange. These plots are provided for the sole purpose of describing the data visually and are not intended to represent the results of any analyses performed during the study.

TABLE 5. Statistics for ISAR Data Base as Received from FHWA (N=224) With Annual Accidents (A), Average Length (L), Number of Units (N) and Peak Length Provided for the Mainline Study Units

OBS	TYPE	AREA	INTCH	LO	YR	A22	L22	N22	P22	A23	L33	N33	P23	A32	L32	N32	P32	A33	L33	N33	P33	A72	L72	N72	P72	A77	L77	N77	P77	A73	L33	N33	P38	A78	L77	N77	P78	A82	L42	N82	P92
1	2	1	1	A	2	0	90	2	101	1	61	2	73	0	54	2	58	0	54	2	58	0	128	2	162	0	131	2	163	0	102	2	135	0	104	2	142	0	[illegible]	4	59
2	2	1	1	A	3	1	90	2	101	2	61	2	73	1	54	2	58	0	54	2	58	0	128	2	162	0	131	2	163	0	102	2	135	0	104	2	142	1	[illegible]	4	59
3	2	1	1	A	4	0	90	2	101	1	61	2	73	1	54	2	58	0	54	2	58	1	128	2	162	0	131	2	163	1	102	2	135	0	104	2	142	4	[illegible]	4	58
4	2	1	1	A	5	0	90	2	101	4	61	2	73	2	54	2	58	1	54	2	58	0	128	2	162	0	131	2	163	0	102	2	135	0	104	2	142	1	[illegible]	4	59
5	2	1	1	A	6	0	90	2	101	4	61	2	73	2	54	2	58	6	54	2	58	2	128	2	162	0	131	2	163	2	102	2	135	0	104	2	142	2	[illegible]	4	58
6	1	1	2	B	2	1	101	2	104	0	54	2	55	1	55	2	55	0	54	2	55	1	179	2	186	0	127	2	135	0	[illegible]	2	[illegible]	0	133	2	134	1	[illegible]	4	101
7	1	1	2	B	3	1	101	2	104	5	54	2	55	0	55	2	55	2	54	2	55	1	179	2	186	0	127	2	135	0	86	2	90	0	133	2	134	3	[illegible]	4	101
8	1	1	2	B	4	0	101	2	104	1	54	2	55	1	55	2	55	0	54	2	55	1	179	2	186	0	127	2	135	0	96	2	86	0	133	2	134	2	[illegible]	4	101
9	1	1	2	B	5	0	101	2	104	1	54	2	55	0	55	2	55	1	54	2	55	1	179	2	186	0	127	2	135	0	86	2	86	1	133	2	134	2	[illegible]	4	101
10	1	1	2	B	6	3	101	2	104	2	54	2	55	1	55	2	55	2	54	2	55	0	179	2	186	0	127	2	135	1	[illegible]	2	90	0	133	2	134	0	[illegible]	4	101
11			12		1	1	77	2	78	1	65	2	66	1	30	2	32	0	34	2	34	0	111	3	148	2	70	5	137	1	67	2	70	1	47	2	81	4	57	9	145
12			12		2	4	77	2	78	0	65	2	66	0	30	2	32	0	34	2	34	4	111	3	148	1	70	5	137	0	67	2	76	3	47	2	81	2	57	9	145
13			12		3	2	77	2	78	0	65	2	66	1	30	2	32	0	34	2	34	0	111	3	148	0	70	5	137	0	67	2	76	0	47	2	81	1	57	9	145
14			12		4	0	77	2	78	1	65	2	66	0	30	2	32	1	34	2	34	1	111	3	148	0	70	5	137	3	67	2	75	0	47	2	81	3	57	9	145
15			12		5	3	77	2	78	1	65	2	66	1	30	2	32	3	34	2	34	1	114	2	148	0	70	5	137	0	67	2	76	5	47	2	81	4	57	9	145
16	3	1	24	C	1	2	78	2	79	0	64	2	66	0	46	2	46	1	46	2	46	0	137	2	144	1	322	2	355	0	[illegible]	2	113	0	72	2	74	5	81	7	169
17	3	1	24	C	2	2	78	2	79	1	64	2	66	0	46	2	46	0	46	2	46	0	137	2	144	0	322	2	355	2	[illegible]	2	113	0	72	2	74	0	81	7	169
18	3	1	24	C	3	1	78	2	79	0	64	2	66	0	46	2	46	1	46	2	46	0	137	2	144	1	322	2	355	0	[illegible]	2	113	0	72	2	74	5	81	7	169
19	3	1	24	C	4	2	78	2	79	2	64	2	66	0	46	2	46	0	46	2	46	0	137	2	144	0	322	2	355	0	[illegible]	2	113	0	72	2	74	1	81	7	169
20	3	1	24	C	5	1	78	2	79	1	64	2	66	0	46	2	46	0	46	2	46	0	137	2	144	0	322	2	355	1	[illegible]	2	113	0	72	2	74	2	81	7	169
21	3	1	24	C	6	1	78	2	79	0	64	2	66	0	46	2	46	0	46	2	46	0	137	2	144	0	322	2	355	3	105	2	113	1	72	2	74	3	81	7	169
22	3	1	24	C	7	0	78	2	79	1	64	2	66	0	46	2	46	0	46	2	46	0	137	2	144	0	322	2	355	0	105	2	113	0	72	2	74	2	81	7	169
23	2	1	60	D	5	0	65	2	78	0	43	2	48	0	34	2	34	0	34	2	34	0	121	2	128	0	159	2	166	0	113	2	138	1	92	2	84	0	79	4	84
24	2	1	60	D	8	1	65	2	78	2	43	2	48	0	34	2	34	0	34	2	34	0	121	2	128	0	159	2	166	0	113	2	138	0	92	2	84	0	79	4	94
25	3	1	62	E	1	2	84	2	90	0	81	2	82	0	30	2	30	1	30	2	30	4	129	2	133	0	139	2	144	0	79	2	84	0	84	2	86	2	51	6	77
26	3	1	62	E	2	1	84	2	90	2	81	2	82	0	30	2	30	1	30	2	30	2	129	2	133	1	139	2	144	0	79	2	84	1	84	2	86	1	51	6	77
27	3	1	62	E	3	0	84	2	90	0	81	2	82	1	30	2	30	0	30	2	30	1	129	2	133	1	139	2	144	1	79	2	84	1	84	2	86	0	51	6	77
28	3	1	62	E	4	0	84	2	90	0	81	2	82	0	30	2	30	0	30	2	30	1	129	2	133	0	139	2	144	0	79	2	84	1	84	2	86	0	51	6	77
29	3	1	62	E	5	2	84	2	90	1	81	2	82	0	30	2	30	1	30	2	30	0	129	2	133	0	139	2	144	0	79	2	84	1	84	2	86	0	51	6	77
30	3	1	62	E	6	0	84	2	90	3	81	2	82	1	30	2	30	0	30	2	30	5	129	2	133	0	139	2	144	0	79	2	84	1	84	2	86	0	51	6	77
31	3	1	62	E	7	1	84	2	90	1	81	2	82	1	30	2	30	0	30	2	30	2	129	2	133	4	139	2	144	0	79	2	84	2	84	2	86	0	51	6	77
32	3	1	72	F	1	1	79	2	81	1	65	2	67	0	29	2	30	0	29	2	30	1	161	2	163	2	164	2	173	2	78	2	79	1	75	2	75	2	62	6	97
33	3	1	72	F	2	0	79	2	81	2	65	2	67	0	29	2	30	0	29	2	30	1	161	2	163	2	164	2	173	0	78	2	79	5	75	2	75	0	62	6	97
34	3	1	72	F	3	1	79	2	81	2	65	2	67	0	29	2	30	0	29	2	30	1	161	2	163	0	164	2	173	3	78	2	79	2	75	2	75	1	62	6	97
35	3	1	72	F	4	0	79	2	81	2	65	2	67	0	29	2	30	0	29	2	30	2	161	2	163	0	164	2	173	0	78	2	79	[illegible]	75	2	75	2	62	6	97
36	3	1	72	F	5	1	79	2	81	1	65	2	67	0	29	2	30	0	29	2	30	0	161	2	163	5	164	2	173	3	78	2	79	2	75	2	75	4	62	6	97
37	3	1	72	F	6	6	79	2	81	2	65	2	67	0	29	2	30	0	29	2	30	1	161	2	163	0	164	2	173	1	78	2	79	4	75	2	75	2	62	6	97
38			101		1	2	37	2	44	1	40	3	52	2	25	2	33	3	43	2	55	2	107	2	110	0	55	4	103	0	72	2	83	1	80	2	86	1	65	4	85
39			101		3	0	37	2	44	2	40	3	52	0	25	2	33	1	43	2	55	1	107	2	110	0	55	4	103	0	72	2	83	0	80	2	86	1	65	4	85
40			101		5	1	37	2	44	2	40	3	52	1	25	2	33	1	43	2	55	4	107	2	110	0	55	4	103	3	72	2	83	1	80	2	86	1	65	4	85
41			101		6	3	37	2	44	4	40	3	52	1	25	2	33	10	43	2	55	2	104	1	104	4	55	4	103	7	72	2	83	2	80	2	86	4	65	4	85
42			101		7	1	37	2	44	10	40	3	52	1	25	2	33	1	43	2	55	1	107	2	110	1	55	4	103	4	72	2	83	1	80	2	86	3	65	4	85
43			101		8	3	37	2	44	4	40	3	52	3	25	2	33	3	43	2	55	3	107	2	110	0	55	4	103	4	72	2	83	2	80	2	86	7	65	4	85
44			111		1	11	78	2	79	8	22	2	24	6	35	2	37	6	35	2	37	28	77	2	90	8	109	2	110	3	88	2	90	3	53	2	58	9	52	4	59
45			111		2	7	78	2	79	7	22	2	24	8	35	2	37	8	35	2	37	18	77	2	90	4	109	2	110	5	88	2	90	3	53	2	58	10	52	4	59
46			111		3	10	78	2	79	12	22	2	24	16	35	2	37	11	35	2	37	10	77	2	90	9	109	2	110	8	88	2	90	6	53	2	58	16	52	4	59
47			111		4	7	78	2	79	6	22	2	24	14	35	2	37	7	35	2	37	11	77	2	90	0	109	2	110	7	88	2	90	3	53	2	58	15	52	4	59
48			111		5	9	78	2	79	4	22	2	24	12	35	2	37	9	35	2	37	5	77	2	90	13	109	2	110	7	88	2	90	0	53	2	58	19	52	4	59
49			111		6	17	78	2	79	5	22	2	24	18	35	2	37	[illegible]	35	2	37	7	77	2	90	4	109	2	110	14	88	2	90	2	53	2	58	9	52	4	59
50			111		7	10	78	2	79	2	22	2	24	12	35	2	37	4	35	2	37	3	77	2	90	6	109	2	110	11	88	2	90	4	53	2	58	9	52	4	59
51			[illegible]		1	9	79	2	[illegible]	4	27	2	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	37	2	[illegible]	7	[illegible]	2	[illegible]	2	[illegible]	2	[illegible]	7	[illegible]	[illegible]	[illegible]	4	85	2	93	4	[illegible]	4	67

TABLE 5. Continued

OBS	TYPE	AREA	INTCH	IO	YR	A22	L22	N22	P22	A23	L23	N23	P23	A32	L32	N32	P32	A33	L33	N33	P33	A72	L72	N72	P72	A77	L77	N77	P77	A73	L73	N73	P73	A78	L78	N78	P78	A82	L92	N82	P82
52			112		2	7	79	2	80	6	27	2	30	5	37	2	39	2	37	2	38	14	115	2	120	3	83	2	84	5	64	2	75	3	87	2	93	4	47	4	67
53			112		3	10	79	2	80	4	27	2	30	11	37	2	39	8	37	2	38	7	115	2	120	2	83	2	84	7	69	2	79	2	89	2	93	16	47	4	67
54			112		4	9	79	2	80	2	27	2	30	8	37	2	38	10	37	2	38	7	115	2	120	5	83	2	84	7	64	2	74	3	89	2	93	7	47	4	67
55			112		5	10	79	2	80	7	27	2	30	8	37	2	39	10	37	2	38	11	115	2	120	1	83	2	84	10	69	2	78	0	89	2	93	4	47	4	67
56			112		6	10	79	2	80	4	27	2	30	10	37	2	39	9	37	2	38	8	115	2	120	7	83	2	84	11	69	2	73	2	89	2	93	12	47	4	67
57			112		7	17	79	2	80	3	27	2	30	18	37	2	39	6	37	2	38	7	115	2	120	2	83	2	84	11	69	2	74	4	89	2	93	8	47	4	67
58	2	1	129	G	5	0	103	2	107	0	36	2	41	0	32	2	32	0	32	2	32	2	103	2	106	0	117	2	117	0	65	2	69	0	74	2	74	0	76	4	85
59	2	1	129	G	6	1	103	2	107	2	36	2	41	0	32	2	32	0	32	2	32	0	103	2	106	0	117	2	117	0	64	2	[illegible]	0	74	2	74	0	75	4	95
60	2	1	129	G	8	1	103	2	107	0	36	2	41	0	32	2	32	0	32	2	32	0	103	2	106	2	117	2	117	2	53	2	69	0	74	2	74	0	76	4	85
61	2	1	129	G	9	0	103	2	107	1	36	2	41	0	32	2	32	0	32	2	32	1	103	2	106	3	117	2	117	0	69	2	69	0	74	2	74	0	76	4	85
62	3	1	130	H	1	0	65	1	65	5	53	3	61	0	35	2	35	4	35	2	35	0	75	2	77	1	166	2	184	0	107	2	115	0	61	2	62	1	42	4	52
63	3	1	130	H	2	0	65	1	65	0	53	3	61	1	35	2	35	2	35	2	35	1	75	2	77	0	166	2	184	0	107	2	115	0	61	2	62	5	42	4	52
64	3	1	130	H	3	2	65	1	65	10	53	3	61	7	35	2	35	7	35	2	35	2	75	2	77	2	166	2	184	0	107	2	115	1	61	2	62	9	42	4	52
65	3	1	130	H	4	6	65	1	65	8	53	3	61	1	35	2	35	4	35	2	35	3	75	2	77	0	166	2	184	1	107	2	115	2	61	2	62	4	42	4	52
66	3	1	130	H	5	5	65	1	65	9	53	3	61	5	35	2	35	3	35	2	35	1	75	2	77	4	166	2	184	1	107	2	115	2	61	2	62	7	42	4	52
67	3	1	130	H	6	1	65	1	65	10	53	3	61	5	35	2	35	3	35	2	35	2	75	2	77	1	166	2	184	0	107	2	115	2	61	2	62	3	42	4	52
68	3	1	130	H	7	3	65	1	65	5	53	3	61	3	35	2	35	7	35	2	35	1	75	2	77	0	166	2	184	3	107	2	115	1	61	2	62	3	42	4	52
69	1	1	133	I	1	2	95	2	110	0	43	2	58	2	26	2	29	2	26	2	29	0	99	2	107	0	81	2	89	1	73	2	76	0	81	2	83	2	56	4	100
70	1	1	133	I	2	6	95	2	110	8	43	2	58	2	26	2	29	3	26	2	29	0	99	2	107	0	81	2	89	0	73	2	76	0	91	2	63	7	56	4	100
71	1	1	133	I	3	4	95	2	110	1	43	2	58	5	26	2	29	2	26	2	29	3	99	2	107	1	81	2	89	0	73	2	76	1	81	2	83	4	56	4	100
72	1	1	133	I	4	12	95	2	110	7	43	2	58	5	26	2	29	5	26	2	29	1	99	2	107	1	81	2	88	1	73	2	76	2	81	2	83	7	56	4	100
73	1	1	133	I	5	5	95	2	110	2	43	2	58	4	26	2	29	3	26	2	29	4	99	2	107	1	81	2	89	2	73	2	76	3	81	2	83	8	56	4	100
74	1	1	133	I	6	8	95	2	110	3	43	2	58	8	26	2	29	2	26	2	29	3	99	2	107	0	81	2	88	1	73	2	76	2	81	2	83	11	56	4	100
75	1	1	133	I	7	7	95	2	110	8	43	2	58	8	26	2	29	5	26	2	29	4	99	2	107	1	81	2	88	2	73	2	75	1	81	2	83	4	56	4	100
76	1	1	134	J	1	0	67	2	98	1	22	2	23	1	29	2	30	2	29	2	30	0	121	2	129	0	138	2	144	0	99	2	100	0	91	2	93	4	73	4	90
77	1	1	134	J	2	2	67	2	98	0	22	2	23	1	29	2	30	2	29	2	30	0	121	2	128	1	138	2	144	0	99	2	100	0	91	2	93	2	73	4	99
78	1	1	134	J	3	2	67	2	98	1	22	2	23	1	29	2	30	8	29	2	30	2	121	2	128	1	138	2	144	1	99	2	100	1	91	2	93	4	73	4	90
79	1	1	134	J	4	4	67	2	98	1	22	2	23	5	29	2	30	2	29	2	30	0	121	2	128	0	138	2	144	0	99	2	100	2	91	2	93	7	73	4	90
80	1	1	134	J	5	4	67	2	98	3	22	2	23	6	29	2	30	4	29	2	30	2	121	2	128	0	138	2	144	2	99	2	100	2	91	2	93	11	73	4	90
81	1	1	134	J	6	5	67	2	98	2	22	2	23	3	29	2	30	3	29	2	30	1	121	2	128	0	138	2	144	1	99	2	100	1	91	2	93	7	73	4	90
82	1	1	134	J	7	3	67	2	98	1	22	2	23	6	29	2	30	6	29	2	30	0	121	2	128	0	138	2	144	1	99	2	100	2	91	2	93	14	73	4	90
83	4	0	135	K	2	0	73	2	82	0	45	2	47	0	37	2	41	1	36	2	38	1	165	2	176	0	115	2	122	0	95	2	100	0	130	2	136	0	69	4	81
84	4	0	135	K	3	0	73	2	82	0	45	2	47	0	37	2	41	1	36	2	38	0	165	2	176	0	115	2	122	0	95	2	100	0	130	2	136	1	69	4	81
85			151		6	13	65	2	80	9	31	2	42	11	28	2	29	8	28	2	29	17	63	2	87	8	67	2	93	4	69	2	70	1	62	2	62	19	66	4	88
86			151		7	18	65	2	80	1	31	2	42	24	28	2	29	5	28	2	29	5	63	2	87	2	67	2	93	7	69	2	70	4	62	2	62	13	66	4	88
87			169		7	0	80	2	80	0	58	2	58	0	30	2	30	0	30	2	30	2	184	1	188	0	160	1	160	0	109	1	109	0	134	1	134	0	91	4	105
88			175		0	0	49	2	50	0	35	2	38	0	30	2	31	0	31	2	32	0	157	2	164	0	162	2	175	0	119	2	120	0	121	2	123	0	86	4	95
89			175		1	0	49	2	50	0	35	2	38	0	30	2	31	0	31	2	32	0	157	2	164	0	162	2	175	0	119	2	120	0	121	2	123	0	86	4	95
90			175		2	0	49	2	50	0	35	2	38	1	30	2	31	0	31	2	32	1	157	2	164	0	162	2	175	1	119	2	120	0	121	2	123	0	86	4	95
91			175		3	0	49	2	50	0	35	2	38	1	30	2	31	1	31	2	32	0	157	2	164	0	162	2	175	1	114	2	113	0	121	2	123	0	96	4	95
92			185		0	0	49	2	51	1	44	2	44	0	31	2	32	0	31	2	32	2	186	2	208	0	115	2	116	0	95	2	95	0	135	2	136	0	78	4	93
93			185		1	1	49	2	51	0	44	2	44	0	31	2	32	0	31	2	32	0	186	2	206	0	115	2	116	0	95	2	95	0	135	2	136	1	78	4	93
94			185		2	0	49	2	51	0	44	2	44	0	31	2	32	0	31	2	32	0	186	2	208	0	115	2	116	0	95	2	95	0	135	2	136	0	78	4	93
95			185		3	0	49	2	51	0	44	2	44	0	31	2	32	0	31	2	32	1	181	2	198	0	115	2	116	0	95	2	95	0	135	2	136	0	78	4	93
96	1	1	203	L	2	2	83	2	87	1	52	2	59	0	20	2	22	2	24	2	25	1	73	2	77	1	96	2	111	2	62	2	71	1	55	2	65	0	41	4	70
97	1	1	203	L	3	1	83	2	87	0	52	2	59	0	20	2	22	0	24	2	25	0	73	2	77	0	96	2	111	3	62	2	71	0	55	2	65	1	41	4	70
98	1	1	203	L	5	0	83	2	87	0	52	2	59	0	20	2	22	0	24	2	25	0	73	2	77	0	96	2	111	0	62	2	71	0	55	2	65	0	41	4	70
99	1	1	203	L	6	4	83	2	87	0	52	2	59	1	20	2	22	1	24	2	25	0	70	1	70	4	96	2	111	1	62	2	71	1	55	2	65	1	41	4	70
100	1	1	203	L	7	1	83	2	87	1	52	2	59	7	20	2	22	3	24	2	25	4	73	2	77	6	96	2	111	5	62	2	71	5	55	2	65	1	41	4	70
101			233		3	0	37	2	40	1	40	2	40	2	52	2	55	0	42	2	45	1	120	2	120	1	115	2	[illegible]	0	62	2	65	0	70	2	70	0	61	4	70
102			233		4	0	37	2	40	2	40	2	40	1	52	2	55	2	42	2	45	0	120	2	120	0	115	2	[illegible]	0	62	2	65	0	70	2	70	1	61	4	70

TABLE 5. Continued

CBS	TYPE	AREA	INTCH	IO	YR	A22	L22	N22	P22	A23	L23	N23	P23	A32	L32	N32	P32	A33	L33	N33	P33	A72	L72	N72	P72	A77	L77	N77	P77	A73	L73	N73	P73	A78	L78	N78	P78	A82	L82	N82	P82
103			243		5	2	37	2	40	2	40	2	40	0	52	2	55	0	42	2	45	1	120	2	120	0	115	2	120	0	62	2	65	0	70	2	70	1	63	4	70
104			243		8	1	37	2	40	1	40	2	40	2	52	2	55	0	42	2	45	2	120	2	120	2	115	2	120	0	62	2	65	1	70	2	70	0	63	4	70
105			251		1	1	57	2	74	1	35	3	39	0	26	2	30	0	23	1	23	0	92	2	95	0	94	2	100	0	53	2	59	0	53	2	55	0	53	4	57
106			251		2	3	57	2	74	2	35	3	39	0	26	2	30	0	23	1	23	0	52	2	95	1	94	2	100	2	53	2	59	0	53	2	55	0	53	4	57
107			251		3	3	57	2	74	0	35	3	39	0	26	2	30	0	23	1	23	0	92	2	95	0	94	2	100	2	53	2	58	0	53	2	55	0	53	4	57
108			251		4	2	57	2	74	1	35	3	39	0	26	2	30	0	23	1	23	0	92	2	95	0	94	2	100	1	53	2	58	0	53	2	55	0	53	4	57
109			251		5	0	57	2	74	2	35	3	39	0	26	2	30	0	23	1	23	0	92	2	95	1	94	2	100	0	53	2	58	0	53	2	55	1	53	4	57
110			251		6	2	57	2	74	0	35	3	39	1	26	2	30	0	23	1	23	1	92	2	95	0	94	2	100	0	53	2	58	0	53	2	55	2	53	4	57
111			251		7	2	57	2	74	1	35	3	39	0	26	2	30	1	23	1	23	0	92	2	95	0	94	2	100	1	53	2	58	0	53	2	55	0	53	4	57
112	2	1	253	M	1	1	60	2	69	0	42	2	47	0	34	2	34	0	34	2	34	0	112	2	122	2	151	2	175	2	85	2	87	1	70	2	71	0	67	4	94
113	2	1	253	M	2	0	60	2	68	0	42	2	47	0	34	2	34	0	34	2	34	1	112	2	122	0	151	2	175	0	85	2	87	1	70	2	71	0	67	4	94
114	2	1	253	M	3	0	60	2	68	0	42	2	47	0	34	2	34	0	34	2	34	1	112	2	122	0	151	2	175	0	85	2	87	1	70	2	71	1	67	4	94
115	2	1	253	M	4	0	60	2	68	0	42	2	47	2	34	2	34	1	34	2	34	2	112	2	122	0	151	2	175	1	85	2	87	0	70	2	71	0	67	4	94
116	2	1	253	M	5	1	60	2	69	0	42	2	47	0	34	2	34	2	34	2	34	1	112	2	122	0	151	2	175	5	85	2	87	0	70	2	71	0	67	4	94
117	2	1	253	M	6	2	60	2	68	0	42	2	47	1	34	2	34	2	34	2	34	2	112	2	122	1	151	2	175	6	85	2	87	0	70	2	71	3	67	4	94
118	2	1	253	M	7	2	60	2	68	0	42	2	47	1	34	2	34	6	34	2	34	1	112	2	122	2	151	2	175	4	85	2	87	1	70	2	71	2	67	4	94
119	3	0	274	N	2	0	60	2	60	0	40	2	40	0	30	2	30	0	30	2	30	0	82	2	82	0	154	2	159	0	95	2	95	0	53	2	53	0	59	4	63
120	3	0	274	N	3	0	60	2	60	0	40	2	40	0	30	2	30	0	30	2	30	0	62	2	82	0	154	2	159	0	95	2	95	0	53	2	53	0	59	4	63
121	3	0	274	N	4	2	60	2	60	0	40	2	40	2	30	2	30	0	30	2	30	0	82	2	92	0	154	2	159	1	95	2	95	0	53	2	53	1	59	4	64
122	3	0	274	N	5	1	60	2	60	0	40	2	40	0	30	2	30	0	30	2	30	0	82	2	82	0	154	2	159	0	95	2	95	0	53	2	53	1	59	4	63
123	3	0	274	N	6	1	60	2	60	1	40	2	40	0	30	2	30	0	30	2	30	1	92	2	82	2	154	2	159	0	95	2	95	0	53	2	53	1	59	4	63
124	3	0	274	N	7	1	60	2	60	0	40	2	40	0	30	2	30	0	30	2	30	1	82	2	82	0	154	2	159	1	95	2	95	0	53	2	53	0	59	4	59
125	3	0	320	O	1	0	60	2	60	0	43	2	44	0	29	2	30	0	29	2	30	0	101	2	102	0	160	2	161	0	107	2	111	0	57	2	57	2	64	4	73
126	3	0	320	O	2	1	60	2	60	3	43	2	44	0	29	2	30	0	29	2	30	1	101	2	102	0	160	2	161	0	107	2	111	0	57	2	57	1	61	4	72
127	3	0	320	O	3	0	60	2	60	0	43	2	44	0	29	2	30	1	25	2	30	0	101	2	102	0	160	2	161	0	107	2	111	0	57	2	57	0	61	4	72
128	3	0	320	O	4	1	60	2	60	2	43	2	44	2	29	2	30	1	29	2	30	0	101	2	102	0	160	2	161	0	107	2	111	0	57	2	57	4	61	4	72
129	3	0	320	O	5	1	60	2	60	0	43	2	44	0	29	2	30	0	29	2	30	0	101	2	102	1	160	2	161	0	107	2	111	0	57	2	57	0	61	4	72
130	3	0	320	O	6	0	60	2	60	0	43	2	44	0	29	2	30	0	25	2	30	1	101	2	102	0	160	2	161	0	107	2	111	0	57	2	57	2	61	4	72
131	3	0	320	O	7	0	60	2	60	0	43	2	44	0	29	2	30	0	29	2	30	0	101	2	102	1	160	2	161	0	107	2	111	0	57	2	57	2	61	4	72
132	4	0	333	P	4	0	95	2	95	0	42	2	53	1	34	2	36	1	34	2	36	0	145	2	162	0	187	2	191	0	135	2	135	0	74	2	78	0	69	5	95
133	4	0	333	P	5	0	95	2	95	0	42	2	53	1	34	2	36	0	34	2	36	0	145	2	162	1	187	2	191	0	135	2	135	1	74	2	78	1	69	5	95
134	4	0	333	P	6	0	95	2	95	0	42	2	53	0	34	2	36	0	34	2	36	0	145	2	162	2	187	2	191	0	135	2	135	0	74	2	78	0	69	5	95
135	4	0	333	P	7	0	95	2	95	0	42	2	53	0	34	2	36	2	34	2	36	1	145	2	162	0	187	2	191	0	135	2	135	1	74	2	78	1	69	5	95
136	4	0	334	Q	4	1	95	2	96	0	57	2	61	0	28	2	23	1	28	2	28	0	170	2	173	0	154	2	155	1	88	2	88	0	113	2	113	1	60	6	106
137	4	0	334	Q	5	1	95	2	96	1	57	2	61	0	28	2	29	0	28	2	28	1	170	2	173	1	154	2	155	0	88	2	88	0	113	2	113	0	60	6	106
138	4	0	334	Q	6	0	95	2	96	0	57	2	61	1	28	2	28	0	28	2	29	0	170	2	173	1	154	2	155	0	88	2	88	1	113	2	113	0	60	6	106
139	4	0	334	Q	7	1	95	2	96	0	57	2	61	0	28	2	29	0	28	2	29	2	170	2	173	0	154	2	155	1	93	2	88	0	113	2	113	2	60	6	106
140	4	0	335	R	4	1	95	2	95	0	53	2	54	0	33	2	33	0	33	2	33	1	137	2	141	0	165	2	189	0	104	2	139	0	89	2	90	1	66	5	94
141	4	0	335	R	5	0	95	2	95	4	53	2	54	1	33	2	33	0	33	2	33	0	137	2	141	0	165	2	189	0	104	2	139	0	89	2	90	0	66	5	94
142	4	0	335	R	6	0	95	2	95	1	53	2	54	0	33	2	33	0	33	2	33	0	137	2	141	0	165	2	189	0	104	2	139	0	89	2	90	0	66	5	84
143	4	0	335	R	7	0	95	2	95	1	53	2	54	2	33	2	33	0	33	2	33	1	137	2	141	0	165	2	189	0	103	2	139	1	89	2	90	1	66	5	94
144	3	0	376	S	2	4	52	4	80	3	53	4	80	0	0	0	0	0	0	0	0	0	114	2	116	1	189	2	194	0	142	2	144	0	69	2	70	2	63	4	72
145	3	0	376	S	3	4	52	4	80	0	53	4	80	0	0	0	0	0	0	0	0	1	114	2	116	0	189	2	194	0	142	2	144	0	69	2	70	2	63	4	72
146	3	0	376	S	4	3	52	4	80	3	53	4	80	0	0	0	0	0	0	0	0	0	114	2	116	2	189	2	194	0	142	2	144	0	69	2	70	2	63	4	72
147	3	0	376	S	5	4	52	4	80	2	53	4	80	0	0	0	0	0	0	0	0	1	114	2	116	2	189	2	194	0	142	2	144	0	69	2	70	1	63	4	72
148	3	0	376	S	6	1	52	4	80	4	53	4	80	0	0	0	0	0	0	0	0	0	114	2	116	0	189	2	194	1	142	2	144	0	69	2	70	0	63	4	72
149	3	0	376	S	7	5	52	4	80	0	53	4	80	0	0	0	0	0	0	0	0	0	114	2	116	0	187	2	194	0	142	2	144	0	69	2	70	4	63	4	72
150	3	0	377	T	2	1	59	4	80	0	44	4	50	0	0	0	0	0	0	0	0	0	147	2	149	0	173	2	173	0	122	2	122	0	93	2	88	0	69	4	72
151	3	0	377	T	3	0	59	4	80	3	44	4	50	0	0	0	0	0	0	0	0	0	147	2	149	0	173	2	173	0	122	2	122	0	88	2	88	0	69	4	72
152	3	0	377	T	4	1	59	4	80	2	44	4	50	0	0	0	0	0	0	0	0	0	147	2	148	0	173	2	173	0	122	2	122	0	88	2	88	2	69	4	72
153	3	0	377	T	5	0	59	4	80	2	44	4	50	0	0	0	0	0	0	0	0	0	147	2	149	0	173	2	173	0	[illegible]	2	122	0	88	2	88	1	69	4	72

TABLE 5. Continued

CHS	TYPE	AREA	INTCH	ID	YR	A22	L22	N22	P223	A223	L233	N233	P232	A232	L322	N322	P323	A323	L333	N333	P372	A372	L722	N722	P727	A727	L777	N777	P773	A773	L733	N733	P738	A738	L788	N788	P782	A782	L822	N822	P82
154	3	0	377	T	6	0	53	4	80	1	44	4	50	0	0	0	0	0	0	0	0	0	147	2	148	0	173	2	173	1	122	2	122	C	88	2	88	2	69	4	72
155	3	0	377	T	7	3	59	4	80	1	44	4	50	0	0	0	0	0	0	0	0	0	147	2	148	0	173	2	173	0	122	2	122	0	88	2	88	3	69	4	72
156	4	0	379	U	2	1	61	4	80	0	57	4	95	C	0	0	0	0	C	0	0	0	142	2	153	0	173	2	183	0	112	2	134	0	84	2	89	0	75	4	123
157	4	0	379	U	3	1	61	4	80	0	57	4	95	0	0	0	0	0	0	0	0	1	142	2	153	0	173	2	183	0	112	2	134	0	84	2	89	0	75	4	123
158	4	0	379	U	4	1	61	4	80	1	57	4	95	C	0	0	0	0	0	0	0	0	142	2	153	0	173	2	183	0	112	2	134	0	84	2	89	1	75	4	123
159	4	0	379	U	5	2	61	4	80	1	57	4	95	C	0	0	0	0	0	0	0	0	142	2	153	0	173	2	183	0	112	2	134	0	84	2	89	4	75	4	123
160	4	0	379	U	6	1	61	4	80	0	57	4	95	0	0	0	0	0	0	0	0	1	142	2	153	0	173	2	183	1	112	2	134	0	84	2	89	1	75	4	123
161	4	0	379	U	7	4	61	4	80	2	57	4	95	0	0	0	0	0	0	0	0	0	142	2	153	0	173	2	183	0	112	2	134	1	84	2	89	1	75	4	123
162	1	0	402	V	0	0	32	2	32	0	37	2	37	0	19	2	19	0	24	2	24	C	80	2	83	0	93	2	100	0	56	2	58	0	58	2	60	0	49	4	50
163	1	0	402	V	1	0	32	2	32	0	37	2	37	0	19	2	19	0	24	2	24	0	80	2	83	0	93	2	100	0	56	2	58	0	58	2	60	0	49	4	50
164	1	0	402	V	2	0	32	2	32	0	37	2	37	1	19	2	19	0	24	2	24	0	80	2	93	0	93	2	100	1	56	2	58	0	58	2	60	0	49	4	50
165	1	0	402	V	3	0	32	2	32	0	37	2	37	1	19	2	19	0	24	2	24	C	80	2	83	0	93	2	100	0	56	2	58	0	58	2	60	1	49	4	50
166	1	0	402	V	4	0	32	2	32	0	37	2	37	C	19	2	19	0	24	2	24	0	80	2	83	0	93	2	100	0	56	2	58	0	58	2	60	1	49	4	50
167	1	0	402	V	5	0	32	2	32	0	37	2	37	C	19	2	19	0	24	2	24	0	80	2	93	0	93	2	100	0	56	2	58	0	58	2	60	2	49	4	50
168	2	0	415	W	1	0	63	2	67	0	43	2	53	0	48	2	48	0	43	2	43	0	88	2	90	0	190	2	192	0	120	2	120	0	74	2	74	0	41	8	73
169	2	0	415	W	2	0	63	2	67	0	43	2	53	1	48	2	48	0	43	2	43	1	88	2	90	2	190	2	192	0	120	2	120	2	74	2	74	0	41	8	73
170	2	0	415	W	3	1	63	2	67	0	43	2	53	0	48	2	48	0	43	2	43	3	88	2	90	3	190	2	192	3	120	2	120	1	74	2	74	0	41	8	73
171	2	0	415	W	4	1	63	2	67	1	43	2	53	2	48	2	43	0	43	2	43	3	88	2	90	3	190	2	192	6	120	2	120	2	74	2	74	0	41	8	73
172	2	0	415	W	5	0	63	2	67	1	43	2	53	2	48	2	48	1	43	2	43	6	88	2	90	6	190	2	192	1	120	2	120	0	74	2	74	3	41	8	73
173			455		0	0	55	2	56	0	47	2	47	0	30	2	30	0	37	2	37	0	152	2	152	0	162	2	164	0	93	2	83	0	89	2	89	0	76	6	122
174			455		1	C	56	2	56	0	47	2	47	0	30	2	30	0	37	2	37	1	152	2	152	0	162	2	164	0	60	2	83	0	89	2	89	2	76	6	122
175			455		2	0	56	2	56	0	47	2	47	0	30	2	30	0	37	2	37	1	152	2	152	0	162	2	164	0	60	2	83	0	89	2	89	0	76	6	122
176			455		3	0	56	2	56	0	47	2	47	1	30	2	30	0	37	2	37	0	152	2	152	1	162	2	164	0	60	2	83	0	89	2	89	1	76	6	122
177			455		4	0	56	2	56	0	47	2	47	0	30	2	30	1	37	2	37	0	152	2	152	0	162	2	164	0	60	2	83	0	89	2	89	1	76	6	122
178			455		5	0	56	2	56	0	47	2	47	0	30	2	30	0	37	2	37	0	152	2	152	C	162	2	164	0	60	2	83	0	89	2	89	1	76	6	122
179			455		6	0	56	2	56	0	47	2	47	0	30	2	30	0	37	2	37	C	152	2	152	1	162	2	164	C	60	2	83	0	89	2	89	3	76	6	122
180			455		7	C	55	3	56	0	47	2	47	0	30	2	30	0	37	2	37	0	152	2	152	0	162	2	164	0	60	2	83	0	89	2	89	4	76	6	122
181	1	0	496	X	4	0	93	2	106	0	61	2	65	0	32	2	33	0	32	2	33	0	187	2	190	0	179	2	188	0	106	2	112	0	129	2	130	1	96	4	105
182	1	0	496	X	5	0	93	2	106	0	61	2	65	0	32	2	33	0	32	2	33	0	187	2	190	0	179	2	188	0	106	2	112	0	129	2	130	0	96	4	105
183	1	0	496	X	6	0	93	2	106	0	61	2	65	1	32	2	33	C	32	2	33	0	187	2	190	0	179	2	188	1	106	2	112	0	129	2	130	0	96	4	105
184	1	0	496	X	7	0	93	2	106	0	61	2	65	0	32	2	33	0	32	2	33	0	187	2	190	0	179	2	188	1	106	2	112	0	129	2	130	0	96	4	105
185	2	0	576	Y	1	0	51	2	51	0	26	2	26	0	33	2	33	0	33	2	33	0	143	2	147	0	168	2	174	3	93	2	100	0	88	2	94	0	81	4	96
186	2	0	576	Y	2	0	51	2	51	0	26	2	26	0	33	2	33	0	33	2	33	1	143	2	147	0	168	2	174	1	93	2	100	0	88	2	94	1	81	4	96
187	2	0	576	Y	3	2	51	2	51	1	26	2	26	0	33	2	33	0	33	2	33	0	143	2	147	0	168	2	174	0	93	2	100	0	88	2	94	4	81	4	96
188	2	0	576	Y	4	1	51	2	51	0	26	2	26	0	33	2	33	2	33	2	33	0	143	2	147	0	168	2	174	0	93	2	100	0	88	2	94	1	81	4	96
189	2	0	576	Y	5	0	51	2	51	1	26	2	26	0	33	2	33	0	33	2	33	0	143	2	147	0	168	2	174	0	93	2	100	0	88	2	94	0	81	4	96
190	2	0	576	Y	6	4	51	2	51	1	26	2	26	2	33	2	33	0	33	2	33	4	143	2	147	4	168	2	174	0	93	2	100	0	88	2	94	1	81	4	76
191	2	0	576	Y	7	2	51	2	51	1	26	2	26	2	33	2	33	1	33	2	33	6	143	2	147	2	168	2	174	1	93	2	100	0	88	2	94	2	81	4	96
192	2	0	576	Y	8	0	51	2	51	0	26	2	26	1	33	2	33	1	33	2	33	2	143	2	147	1	168	2	174	1	93	2	100	2	88	2	94	4	81	4	96
193	2	0	611	Z	3	0	66	2	70	3	34	2	35	3	50	2	50	0	50	2	50	0	160	2	170	0	143	2	170	1	67	2	71	0	129	2	133	0	39	8	73
194	2	0	611	Z	4	1	66	2	70	0	34	2	35	0	50	2	50	0	50	2	50	1	160	2	170	0	143	2	170	1	67	2	71	0	129	2	133	0	39	8	73
195	2	0	611	Z	5	0	66	2	70	0	34	2	35	1	50	2	50	1	50	2	50	3	160	2	170	0	143	2	170	0	67	2	71	0	129	2	133	1	39	8	73
196	2	0	779	1	3	C	47	2	49	0	43	2	46	0	27	2	31	0	27	2	31	0	94	2	100	0	121	2	122	0	76	2	86	0	81	2	85	0	74	4	82
197	2	0	779	1	4	0	47	2	49	0	43	2	46	0	27	2	31	1	27	2	31	0	94	2	100	0	121	2	122	0	76	2	86	0	81	2	85	1	74	4	92
198	2	0	779	1	5	0	47	2	49	0	43	2	46	0	27	2	31	1	27	2	31	0	94	2	100	0	121	2	122	0	76	2	86	0	81	2	85	0	74	4	92
199	2	0	804	2	3	0	32	2	84	0	49	2	50	2	33	2	36	0	33	2	35	0	132	2	135	1	88	2	90	2	90	2	110	0	103	2	105	0	57	4	68
200	2	0	804	2	4	0	92	2	84	1	49	2	50	2	33	2	36	1	33	2	35	1	132	2	135	0	88	2	90	2	90	2	110	0	103	2	105	1	57	4	68
201	2	0	804	2	5	0	82	2	84	0	49	2	50	0	33	2	36	0	33	2	35	1	132	2	135	0	88	2	90	2	90	2	110	0	103	2	105	0	57	4	68
202	2	0	804	2	6	4	82	2	84	1	49	2	50	2	33	2	35	2	33	2	35	1	132	2	135	2	88	2	90	5	90	2	110	1	103	2	105	0	57	4	68
203	2	1	805	3	2	2	65	2	73	0	47	2	48	2	24	2	24	0	24	2	24	0	125	2	131	0	143	2	[illegible]	[illegible]	53	2	61	0	52	2	59	0	43	5	67
204	2	1	[illegible]	3	[illegible]	[illegible]	[illegible]	2	73	0	47	2	48	0	24	2	24	0	24	2	24	0	125	2	131	1	143	2	[illegible]	1	[illegible]	2	61	0	52	2	59	0	49	4	67

TABLE 5. Continued

CBS	TYPE	AREA	INTCH	IO	YR	A22	L22	N22	P22	A23	L23	N23	P23	A32	L32	N32	P32	A33	L33	N33	P33	A72	L72	N72	P72	A77	L77	N77	P77	A73	L73	N73	P73	A78	L78	N78	P78	A82	L82	N82	P82
205	2	1	805	3	5	1	66	2	73	0	47	2	48	0	24	2	24	1	24	2	24	1	125	2	131	0	143	2	155	2	53	2	61	0	52	2	59	0	44	5	62
206	2	1	805	3	6	0	66	2	73	0	47	2	48	4	24	2	24	0	24	2	24	0	125	2	131	1	143	2	155	1	53	2	61	0	52	2	59	0	44	5	62
207	2	1	805	3	7	0	66	2	73	1	47	2	48	1	24	2	24	0	24	2	24	0	125	2	131	1	143	2	155	2	53	2	61	1	52	2	59	0	44	5	62
208	2	1	805	3	8	2	66	2	73	0	47	2	48	0	24	2	24	0	24	2	24	1	125	2	131	2	143	2	155	1	53	2	61	2	52	2	59	0	44	5	62
209	2	0	807	4	2	0	49	2	58	0	37	2	42	0	41	2	43	1	40	2	42	0	91	2	95	0	169	2	170	0	104	2	105	0	70	2	77	1	62	4	67
210	2	0	807	4	3	0	48	2	58	0	37	2	42	1	41	2	43	0	40	2	42	0	91	2	95	1	168	2	170	1	104	2	105	2	70	2	77	0	62	4	67
211	2	0	807	4	4	2	41	2	58	2	37	2	42	1	41	2	43	0	40	2	42	1	91	2	95	1	168	2	170	0	104	2	105	0	70	2	77	0	62	4	67
212	2	0	807	4	5	2	49	2	58	2	37	2	42	2	41	2	43	0	40	2	42	0	91	2	95	0	168	2	170	0	104	2	105	2	70	2	77	1	62	4	67
213	2	0	807	4	6	0	44	2	54	1	37	2	42	0	41	2	43	0	40	2	42	0	91	2	95	0	168	2	170	0	104	2	105	1	70	2	77	0	62	4	67
214	2	0	823	5	1	0	28	2	31	0	41	2	50	0	25	2	27	0	34	2	35	0	114	2	124	0	102	2	109	0	49	2	49	0	52	2	54	0	52	4	65
215	2	0	823	5	2	0	24	2	31	0	41	2	50	0	25	2	27	0	34	2	35	1	114	2	124	0	102	2	109	0	48	2	49	0	52	2	54	0	52	4	65
216	2	0	823	5	3	0	24	2	31	0	41	2	50	1	25	2	27	1	34	2	35	0	114	2	124	0	102	2	107	0	48	2	49	0	52	2	54	0	52	4	65
217	2	0	823	5	4	0	28	2	31	0	41	2	50	0	25	2	27	0	34	2	35	0	114	2	124	0	102	2	109	0	48	2	49	0	52	2	54	0	52	4	65
218	2	0	823	5	5	0	24	2	31	0	41	2	50	0	25	2	27	0	34	2	35	0	114	2	124	0	102	2	109	0	48	2	49	0	52	2	54	1	52	4	65
219	1	0	906	6	1	1	83	2	83	0	46	2	46	3	28	2	30	1	28	2	30	0	157	2	160	0	122	2	125	0	90	2	90	0	110	2	110	3	73	4	94
220	1	0	906	6	2	4	83	2	83	0	46	2	46	2	28	2	30	2	28	2	30	0	157	2	160	0	122	2	125	1	90	2	90	0	110	2	110	2	73	4	94
221	1	0	906	6	3	0	83	2	83	0	46	2	46	2	28	2	30	4	28	2	30	1	157	2	160	0	122	2	125	2	90	2	90	0	110	2	110	0	73	4	94
222	1	0	906	6	4	0	83	2	83	2	46	2	46	2	28	2	30	0	28	2	30	1	157	2	160	2	122	2	125	1	90	2	90	0	110	2	110	1	73	4	94
223	1	0	906	6	5	1	83	2	83	0	46	2	46	1	28	2	30	4	28	2	30	2	157	2	160	0	122	2	125	0	90	2	90	1	110	2	110	1	73	4	94
224	1	0	906	6	6	4	83	2	83	1	46	2	46	1	28	2	30	3	28	2	30	0	157	2	160	1	122	2	125	0	90	2	90	0	110	2	110	2	73	4	94

TABLE 6. Summary Statistics for ODOT Data Base (N=169) With Annual Accidents Distributed Among the Mainline (and Ramps), the Crossroad and Beyond the Interchange

OBS	TYPE	AREA	INTCH	ID	YR	V41	P41	TOTACC	MAINACC	X_RD	BEYOND
1	2	1	1	A	2	717	1123	4	1	1	2
2	2	1	1	A	3	625	1044	13	5	4	4
3	2	1	1	A	4	861	1290	23	8	13	2
4	2	1	1	A	5	953	1380	9	8	0	1
5	2	1	1	A	6	1161	1622	21	18	0	3
6	1	1	2	B	2	914	1123	44	4	24	16
7	1	1	2	B	3	946	1100	46	12	14	20
8	1	1	2	B	4	1169	1356	33	5	15	13
9	1	1	2	B	5	1297	1436	39	6	22	11
10	1	1	2	B	6	1485	1640	53	9	36	8
11	3	1	24	C	1	548	665	15	9	1	5
12	3	1	24	C	2	616	769	9	5	0	4
13	3	1	24	C	3	609	742	12	8	0	4
14	3	1	24	C	4	615	755	9	5	0	4
15	3	1	24	C	5	670	822	9	5	0	4
16	3	1	24	C	6	741	943	15	8	0	7
17	3	1	24	C	7	704	947	13	3	2	8
18	2	1	60	D	5	244	283	1	1	0	0
19	2	1	60	D	8	359	423	3	3	0	0
20	3	1	62	E	1	1229	1308	20	9	0	11
21	3	1	62	E	2	1429	1500	27	9	0	18
22	3	1	62	E	3	1211	1289	15	5	0	10
23	3	1	62	E	4	1219	1297	6	2	0	4
24	3	1	62	E	5	1353	1437	12	5	1	6
25	3	1	62	E	6	1618	1761	15	10	0	5
26	3	1	62	E	7	1874	2010	32	11	2	19
27	3	1	72	F	1	903	1164	16	10	0	6
28	3	1	72	F	2	1094	1500	21	10	0	11
29	3	1	72	F	3	942	1421	23	10	0	13
30	3	1	72	F	4	919	1444	20	8	0	12
31	3	1	72	F	5	1068	1698	38	18	1	19
32	3	1	72	F	6	1219	1775	47	16	0	31
33	2	1	129	G	5	409	513	4	2	2	0
34	2	1	129	G	6	540	733	10	3	3	4
35	2	1	129	G	8	650	820	14	5	4	5
36	2	1	129	G	9	722	948	12	5	[illegible]	7
37	3	1	130	H	1	1875	2020	13	11	1	1
38	3	1	130	H	2	1972	2125	17	9	[illegible]	3
39	3	1	130	H	3	3196	3480	44	40	3	1
40	3	1	130	H	4	3381	3680	33	29	4	0
41	3	1	130	H	5	3677	4000	43	37	6	0
42	3	1	130	H	6	3952	4200	31	27	2	2
43	3	1	130	H	7	4006	4340	31	25	4	1
44	1	1	133	I	1	1584	1755	14	9	1	4
45	1	1	133	I	2	1672	1850	48	26	3	19
46	1	1	133	I	3	2566	2770	34	21	0	13
47	1	1	133	I	4	2729	2940	67	41	0	26
48	1	1	133	I	5	3010	3220	51	32	0	19
49	1	1	133	I	6	3155	3370	54	38	2	14
50	1	1	133	I	7	3266	3480	61	40	1	20
51	1	1	134	J	1	1503	1680	19	8	1	10
52	1	1	134	J	2	1590	1775	20	8	1	11
53	1	1	134	J	3	2336	2530	38	21	0	17
54	1	1	134	J	4	2495	2700	48	21	0	27
55	1	1	134	J	5	2729	2970	66	34	0	32

TABLE 6. Continued

OBS	TYPE	AREA	INTCH	IO	YR	V41	P41	TOTACC	MAINACC	X_RD	BEYOND
56	1	1	134	J	6	2820	3100	53	23	0	30
57	1	1	134	J	7	2901	3200	72	33	4	35
58	4	0	135	K	2	303	318	6	2	1	3
59	4	0	135	K	3	394	448	6	2	0	4
60	1	1	203	L	2	1046	1426	15	10	4	1
61	1	1	203	L	3	1109	1439	10	5	4	1
62	1	1	203	L	5	1579	1899	0	0	0	0
63	1	1	203	L	6	1468	2061	15	13	0	2
64	1	1	203	L	7	1647	2021	41	33	5	3
65	2	1	253	M	1	260	420	17	6	4	7
66	2	1	253	M	2	328	500	10	2	3	5
67	2	1	253	M	3	386	580	16	3	3	10
68	2	1	253	M	4	462	700	27	6	8	13
69	2	1	253	M	5	475	695	14	9	1	4
70	2	1	253	M	6	554	840	21	17	2	2
71	2	1	253	M	7	582	870	30	19	4	7
72	3	0	274	N	2	164	210	3	0	0	3
73	3	0	274	N	3	264	328	14	0	2	12
74	3	0	274	N	4	358	427	25	6	2	17
75	3	0	274	N	5	472	565	19	2	3	14
76	3	0	274	N	6	508	605	26	6	1	19
77	3	0	274	N	7	531	625	21	3	1	17
78	3	0	320	O	1	462	500	9	2	1	6
79	3	0	320	O	2	526	565	11	3	0	8
80	3	0	320	O	3	675	710	5	1	0	4
81	3	0	320	O	4	692	740	18	10	0	8
82	3	0	320	O	5	710	755	18	2	1	15
83	3	0	320	O	6	783	830	24	3	2	19
84	3	0	320	O	7	710	770	17	3	2	12
85	4	0	333	P	4	540	580	5	2	1	2
86	4	0	333	P	5	602	645	11	4	1	6
87	4	0	333	P	6	659	715	7	2	1	4
88	4	0	333	P	7	721	765	13	5	0	8
89	4	0	334	Q	4	517	580	9	4	3	2
90	4	0	334	Q	5	564	645	17	4	11	2
91	4	0	334	Q	6	623	715	10	3	6	1
92	4	0	334	Q	7	650	765	22	6	9	7
93	4	0	335	R	4	426	490	5	3	1	1
94	4	0	335	R	5	470	525	11	5	1	5
95	4	0	335	R	6	500	580	4	1	1	2
96	4	0	335	R	7	508	590	10	6	1	3
97	3	0	376	S	2	892	975	15	10	0	5
98	3	0	376	S	3	988	1078	8	7	0	1
99	3	0	376	S	4	1103	1165	18	10	2	6
100	3	0	376	S	5	1405	1470	18	10	1	7
101	3	0	376	S	6	1490	1560	15	6	0	9
102	3	0	376	S	7	1575	1660	17	9	3	5
103	3	0	377	T	2	937	985	14	1	0	13
104	3	0	377	T	3	1041	1095	8	3	1	4
105	3	0	377	T	4	1150	1180	11	5	0	6
106	3	0	377	T	5	1507	1590	11	3	0	8
107	3	0	377	T	6	1609	1710	13	4	0	9
108	3	0	377	T	7	1726	1840	16	7	0	9
109	4	0	379	U	2	1031	1050	5	1	0	4
110	4	0	379	U	3	1145	1165	3	2	0	1

TABLE 6. Continued

OBS	TYPE	AREA	INTCH	ID	YR	V41	P41	TOTACC	MAINACC	X_RD	BEYOND
111	4	0	379	U	4	1232	1255	7	3	0	4
112	4	0	379	U	5	1840	1900	11	7	0	4
113	4	0	379	U	6	2038	2110	8	4	0	4
114	4	0	379	U	7	2206	2290	17	8	1	8
115	1	0	402	V	0	180	199	1	0	0	1
116	1	0	402	V	1	184	200	2	0	0	2
117	1	0	402	V	2	317	369	2	2	0	0
118	1	0	402	V	3	279	302	13	2	0	11
119	1	0	402	V	4	343	354	6	1	0	5
120	1	0	402	V	5	300	335	5	2	0	3
121	2	0	415	W	1	412	531	11	0	1	10
122	2	0	415	W	2	463	601	9	6	1	2
123	2	0	415	W	3	681	841	17	11	2	4
124	2	0	415	W	4	876	1142	26	18	4	4
125	2	0	415	W	5	761	2070	26	20	5	1
126	1	0	496	X	4	184	213	1	1	0	0
127	1	0	496	X	5	219	255	4	0	3	1
128	1	0	496	X	6	247	285	4	2	1	1
129	1	0	496	X	7	265	315	3	1	2	0
130	2	0	576	Y	1	365	477	14	3	1	10
131	2	0	576	Y	2	405	528	10	3	3	4
132	2	0	576	Y	3	445	581	20	7	7	6
133	2	0	576	Y	4	650	764	23	4	7	12
134	2	0	576	Y	5	650	769	25	1	5	19
135	2	0	576	Y	6	684	810	35	16	4	15
136	2	0	576	Y	7	718	851	51	17	13	21
137	2	0	576	Y	8	800	1042	45	12	12	21
138	2	0	611	Z	3	389	620	14	7	0	7
139	2	0	611	Z	4	496	774	11	3	4	4
140	2	0	611	Z	5	360	582	12	6	2	4
141	2	0	779	1	3	175	219	4	0	0	4
142	2	0	779	1	4	261	334	4	2	0	2
143	2	0	779	1	5	280	313	4	1	0	3
144	2	0	804	2	3	704	960	46	5	2	39
145	2	0	804	2	4	999	1269	42	8	3	31
146	2	0	804	2	5	1076	2000	26	3	4	19
147	2	0	804	2	6	1681	1897	67	18	4	45
148	2	1	805	3	2	343	407	6	4	0	2
149	2	1	805	3	3	397	472	5	5	0	0
150	2	1	805	3	5	473	576	10	5	1	4
151	2	1	805	3	6	473	576	8	6	0	2
152	2	1	805	3	7	575	735	8	6	0	2
153	2	1	805	3	8	549	660	10	8	0	2
154	2	0	807	4	2	337	529	8	2	0	6
155	2	0	807	4	3	711	934	35	5	3	27
156	2	0	807	4	4	914	1140	30	7	5	18
157	2	0	807	4	5	1234	1585	32	9	3	20
158	2	0	807	4	6	1338	1718	39	2	1	36
159	2	0	823	5	1	115	161	3	0	1	2
160	2	0	823	5	2	233	267	2	1	0	1
161	2	0	823	5	3	172	230	2	2	0	0
162	2	0	823	5	4	291	346	2	0	0	2
163	2	0	823	5	5	142	196	1	1	0	0
164	1	0	906	6	1	901	1077	38	8	4	26
165	1	0	906	6	2	927	1109	52	11	3	39

TABLE 6. Continued

OBS	TYPE	AREA	INTCH	ID	YR	V41	P41	TOTACC	MAINACC	X_RD	BEYOND
166	1	0	906	6	3	1068	1446	45	9	1	35
167	1	0	906	6	4	1523	1791	70	9	3	58
168	1	0	906	6	5	2388	2566	66	10	4	52
169	1	0	906	6	6	2665	3016	63	12	3	49

TABLE 7. Identification of 32 Individual Interchanges in ODOT Data Base (N=169)

OBS	TYPE	AREA	INTCH	ID	AREAN	PASSN	PASSC
1	2	1	1	A	1	0	0
2	1	1	2	B	1	0	0
3	3	1	24	C	1	1	1
4	2	1	60	D	1	1	1
5	3	1	62	E	1	1	1
6	3	1	72	F	1	1	1
7	2	1	129	G	1	0	0
8	3	1	130	H	1	1	1
9	1	1	133	I	1	1	1
10	1	1	134	J	1	1	1
11	4	0	135	K	0	0	0
12	1	1	203	L	1	1	1
13	2	1	253	M	1	0	0
14	3	0	274	N	0	1	1
15	3	0	320	O	0	1	1
16	4	0	333	P	0	0	0
17	4	0	334	Q	0	1	1
18	4	0	335	R	0	1	1
19	3	0	376	S	0	0	0
20	3	0	377	T	0	1	1
21	4	0	379	U	0	1	1
22	1	0	402	V	0	1	1
23	2	0	415	W	0	0	0
24	1	0	496	X	0	0	0
25	2	0	576	Y	0	0	0
26	2	0	611	Z	0	0	0
27	2	0	779	1	0	0	0
28	2	0	804	2	0	0	0
29	2	1	805	3	1	1	1
30	2	0	807	4	0	1	1
31	2	0	823	5	0	1	1
32	1	0	906	6	0	1	1

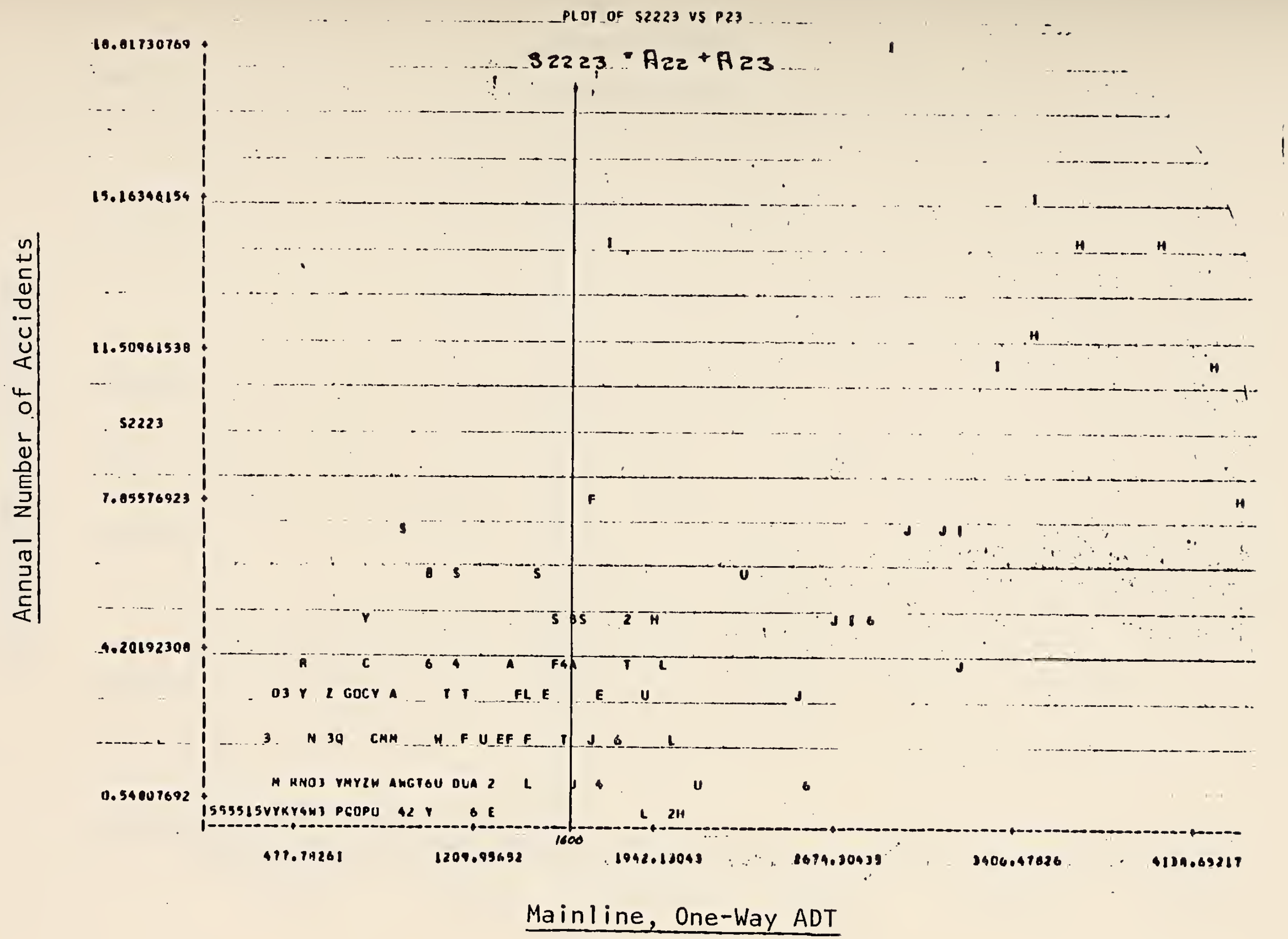


FIGURE 18. Accident Frequency on Accel and Decel Lanes of the Outerconnections Versus Mainline Volume

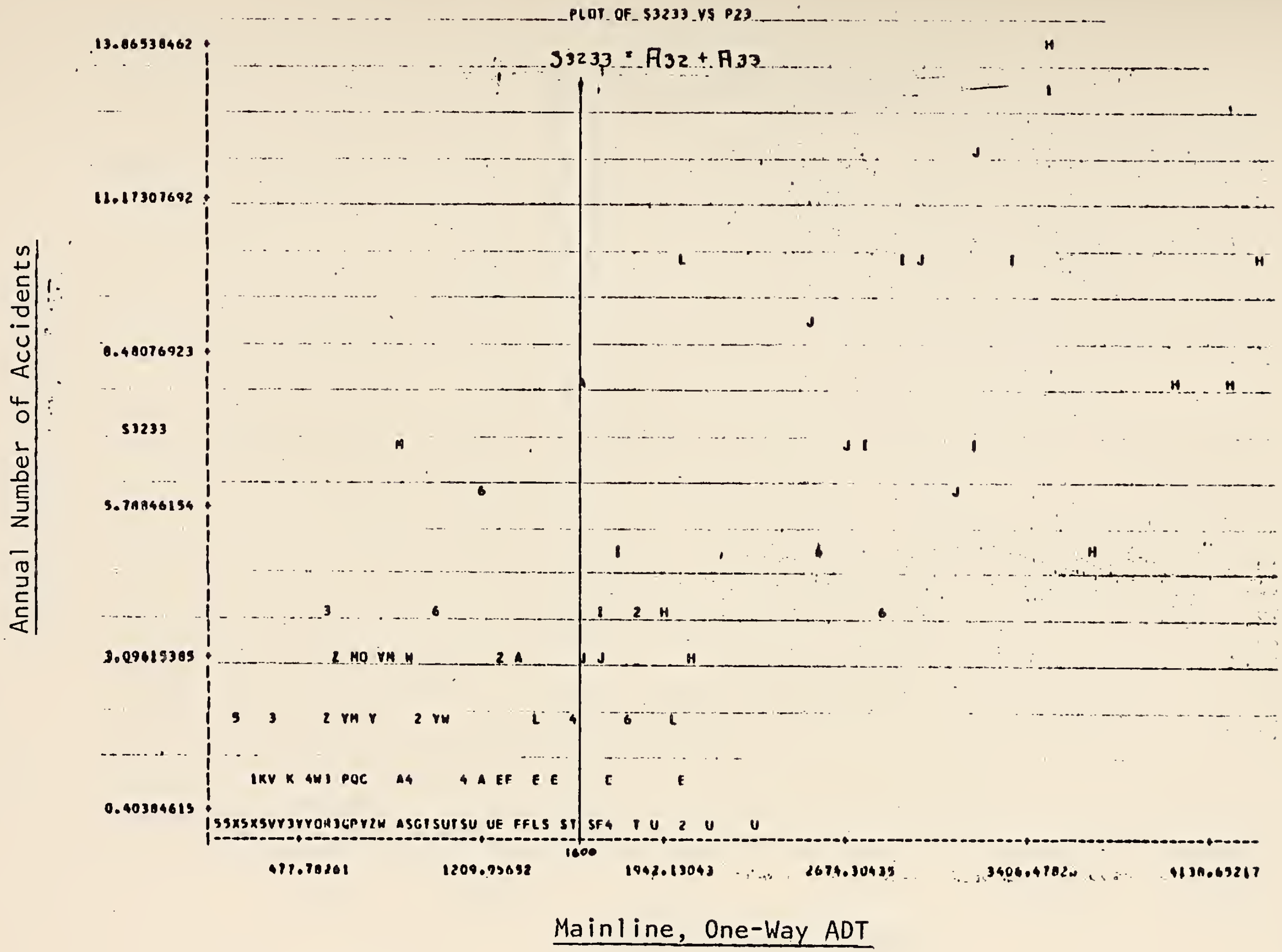


FIGURE 19. Accident Frequency on Weave Section Versus Mainline Volume

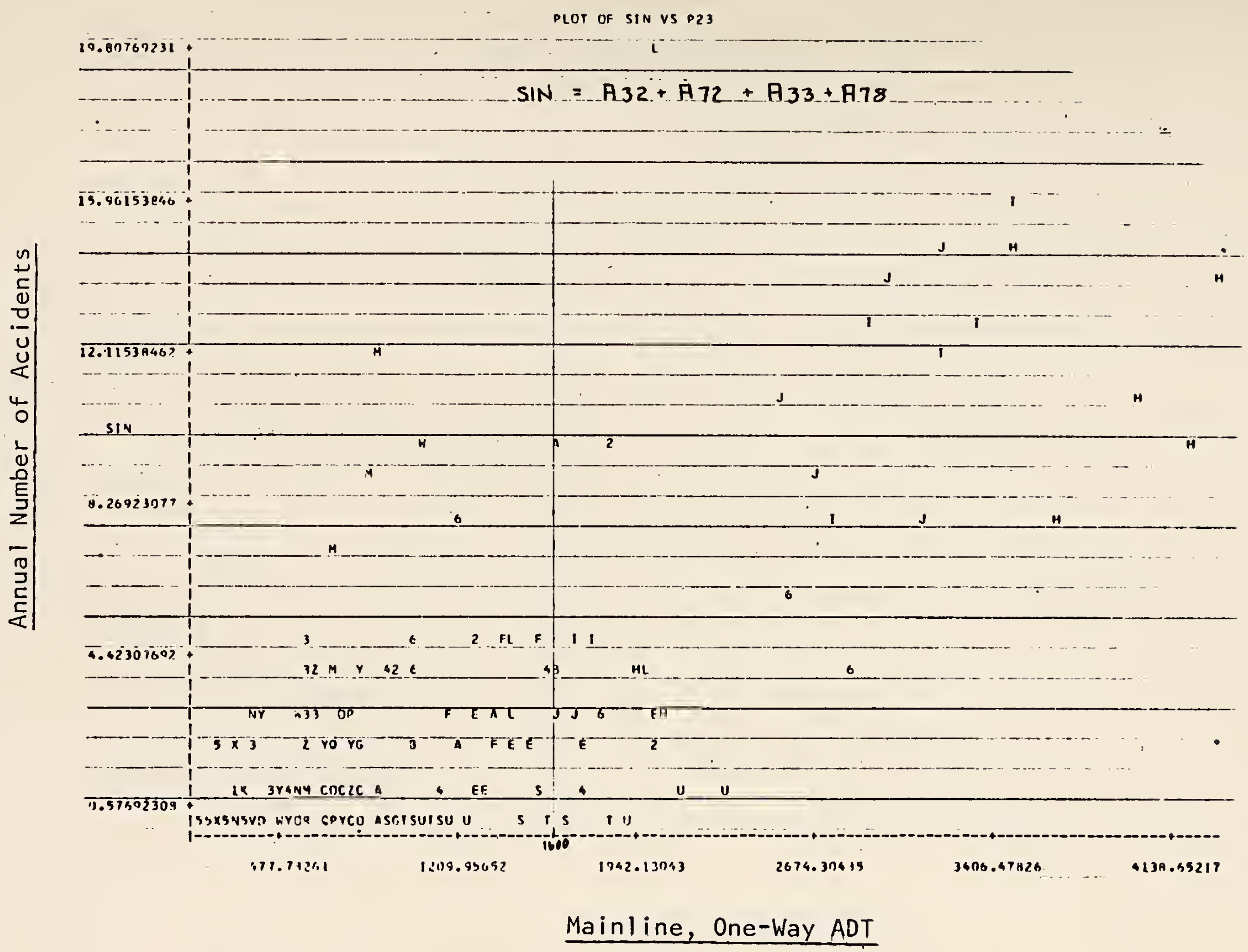


FIGURE 20. Accident Frequency on Weave Section and Loop Ramps Versus Mainline Volume

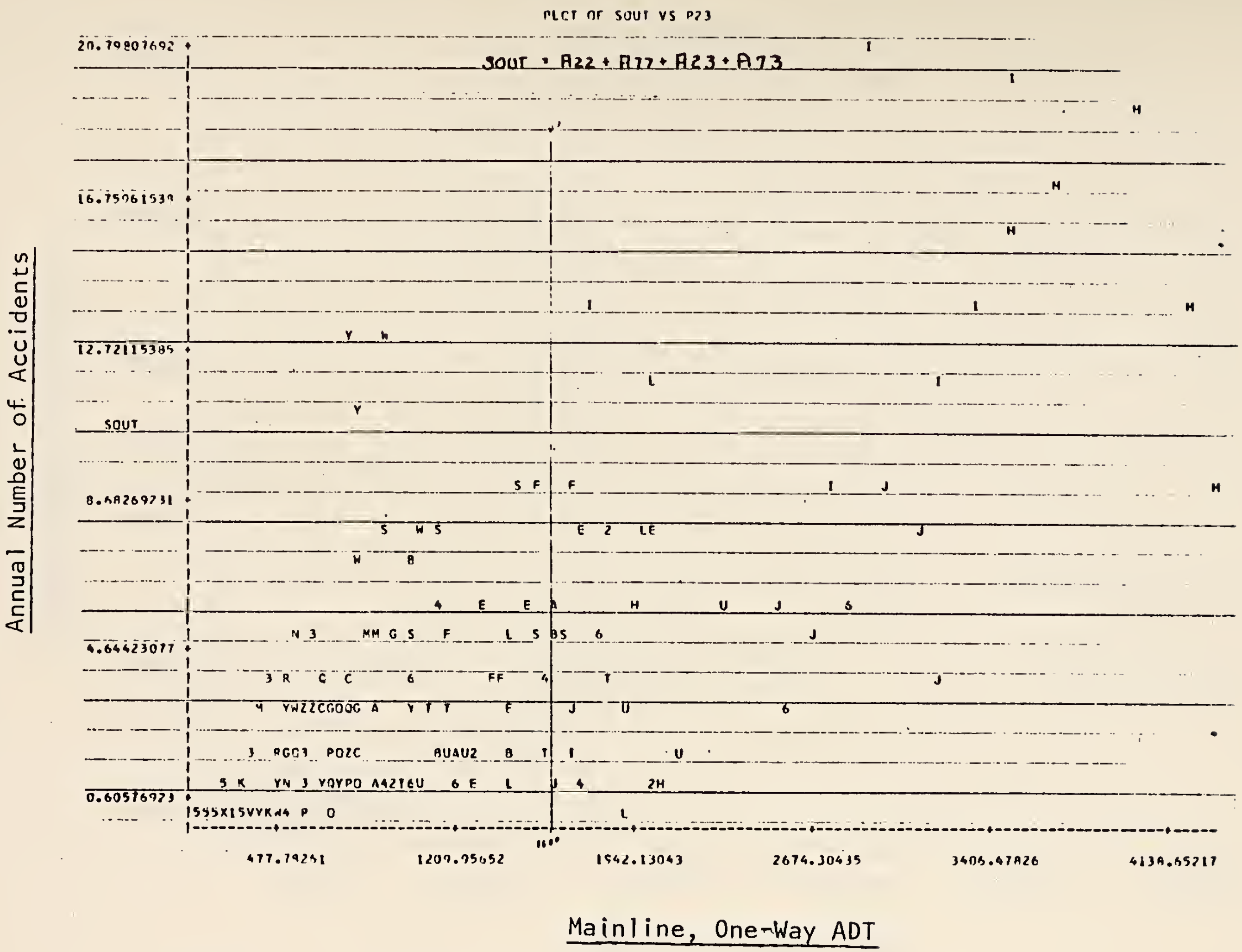


FIGURE 21. Accident Frequency on Accel and Decel Lanes and Outerconnection Ramps Versus Mainline Volume

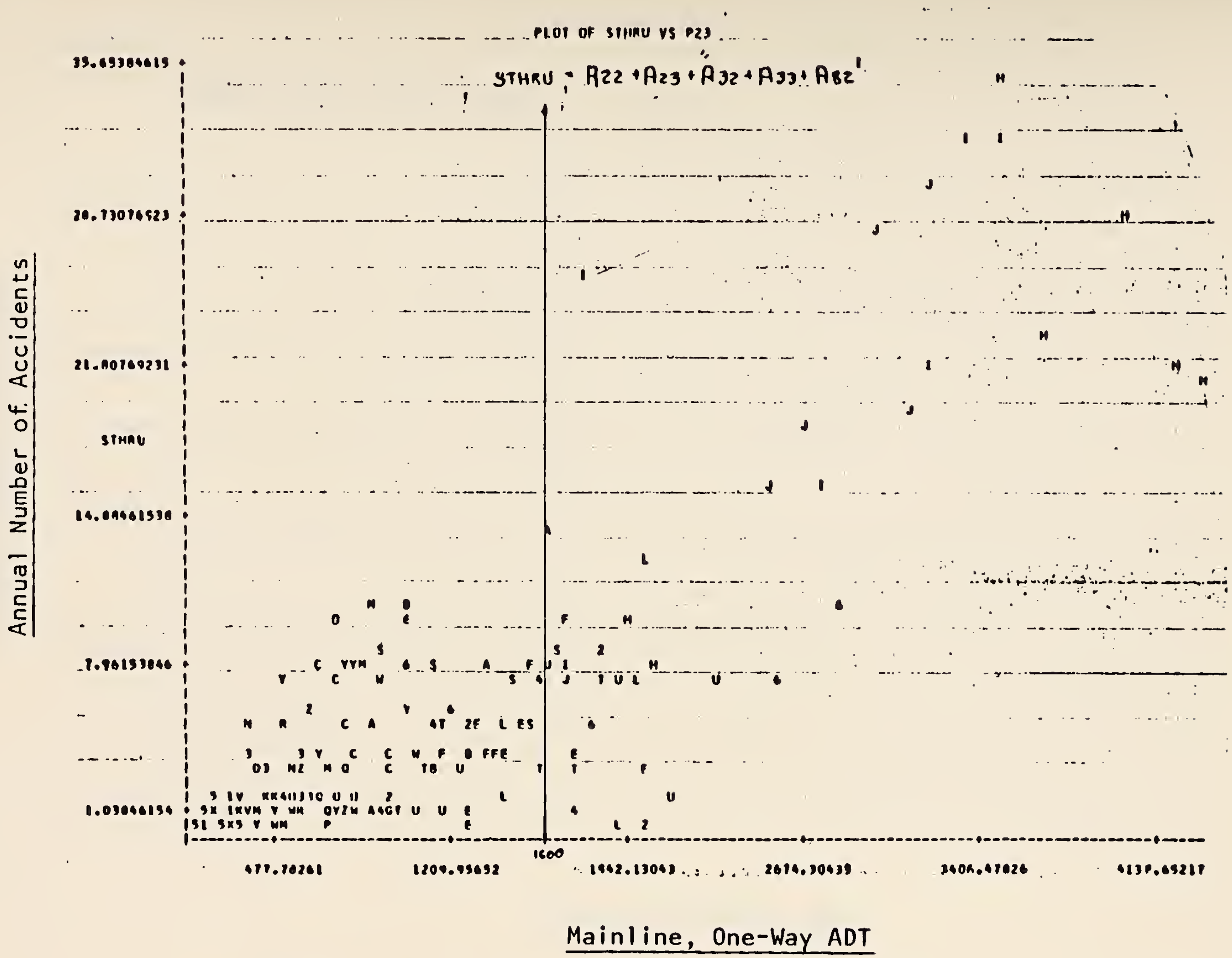


FIGURE 22. Accident Frequency on the Mainline Versus Mainline Volume

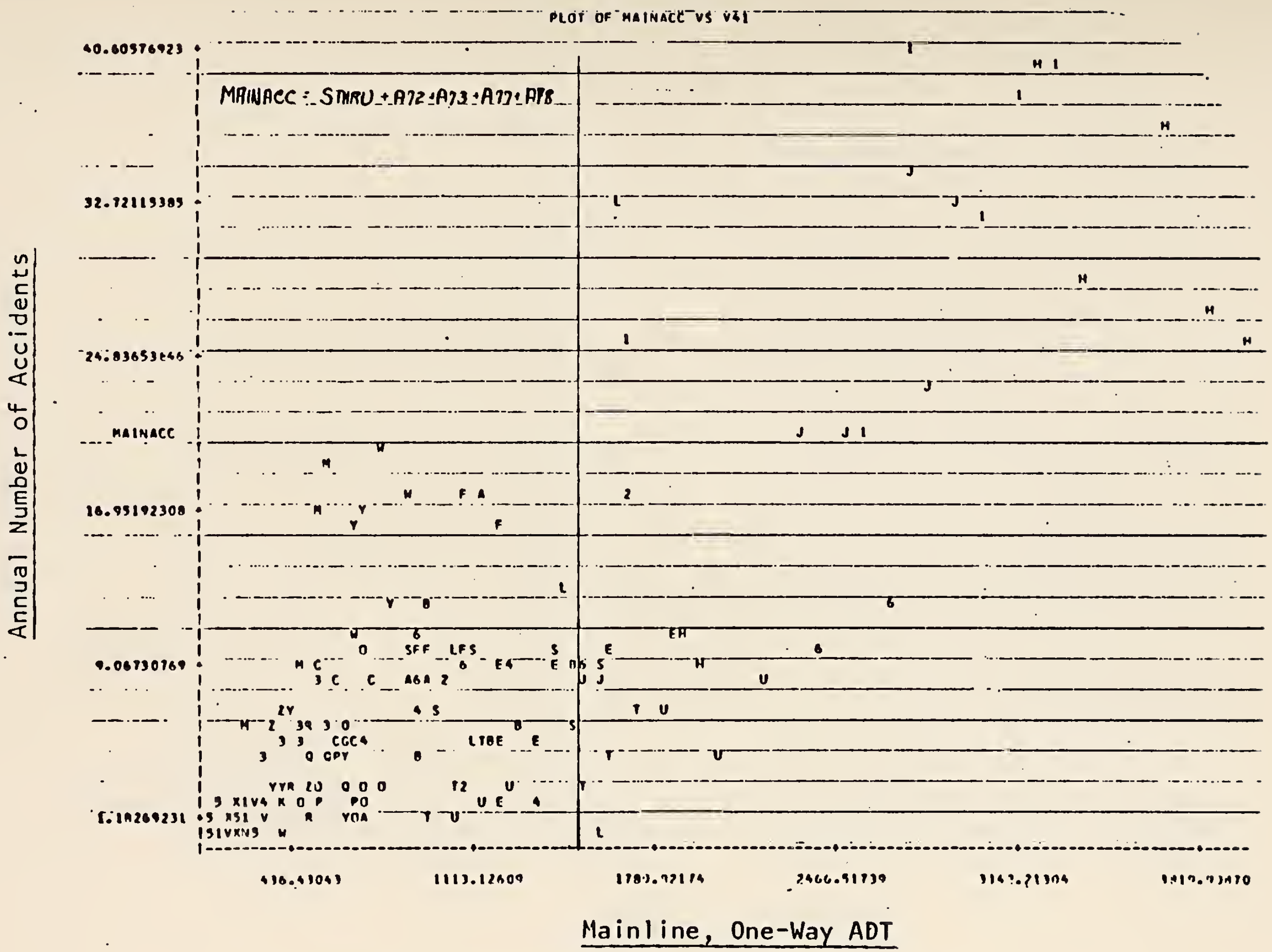


FIGURE 23. Accident Frequency on the Mainline and Ramp Versus the Mainline Volume

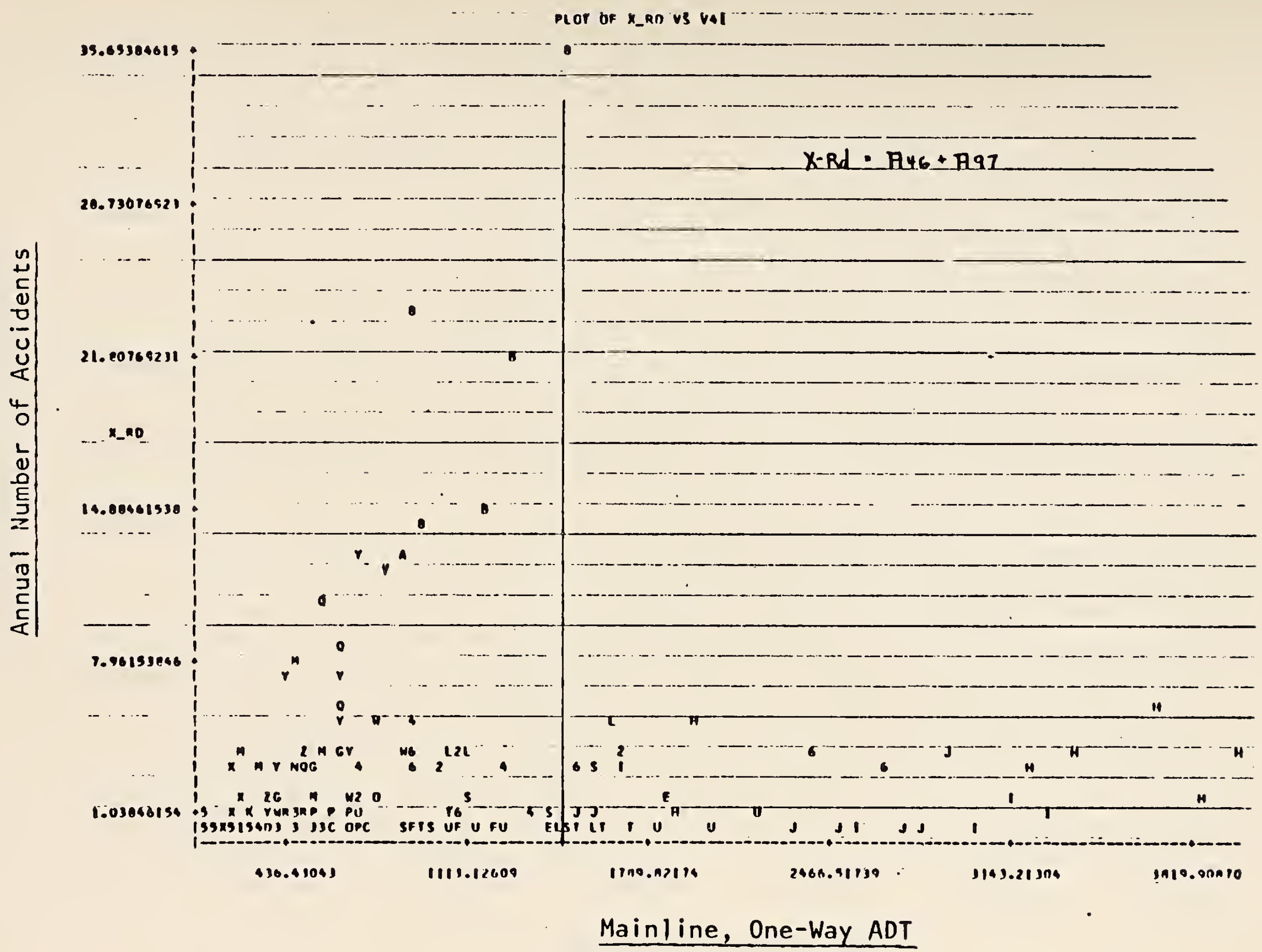


FIGURE 24. Accident Frequency on the Crossroad Versus the Mainline Volume

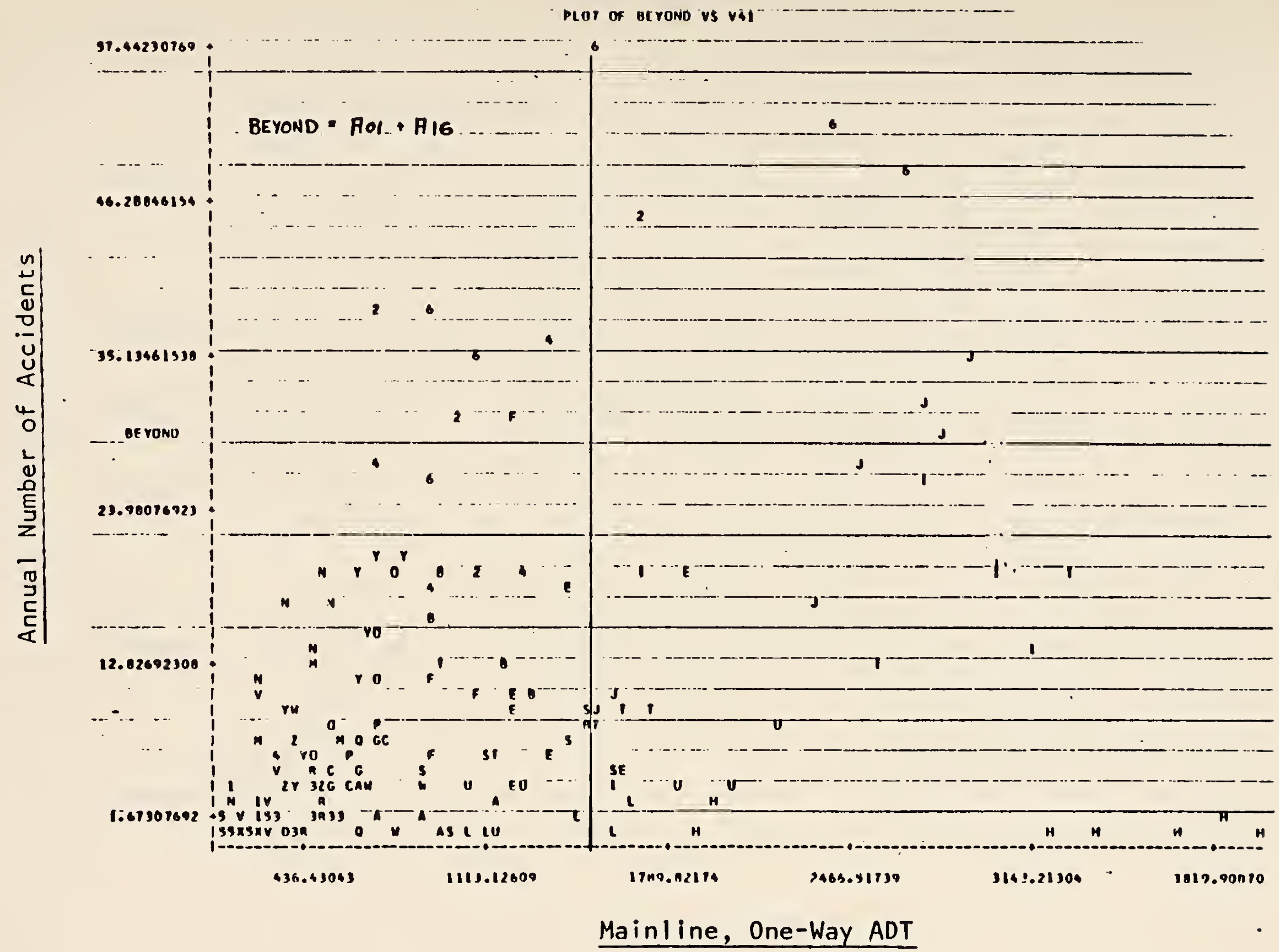


FIGURE 25. Accident Frequency Beyond the Interchange Versus Mainline Volume

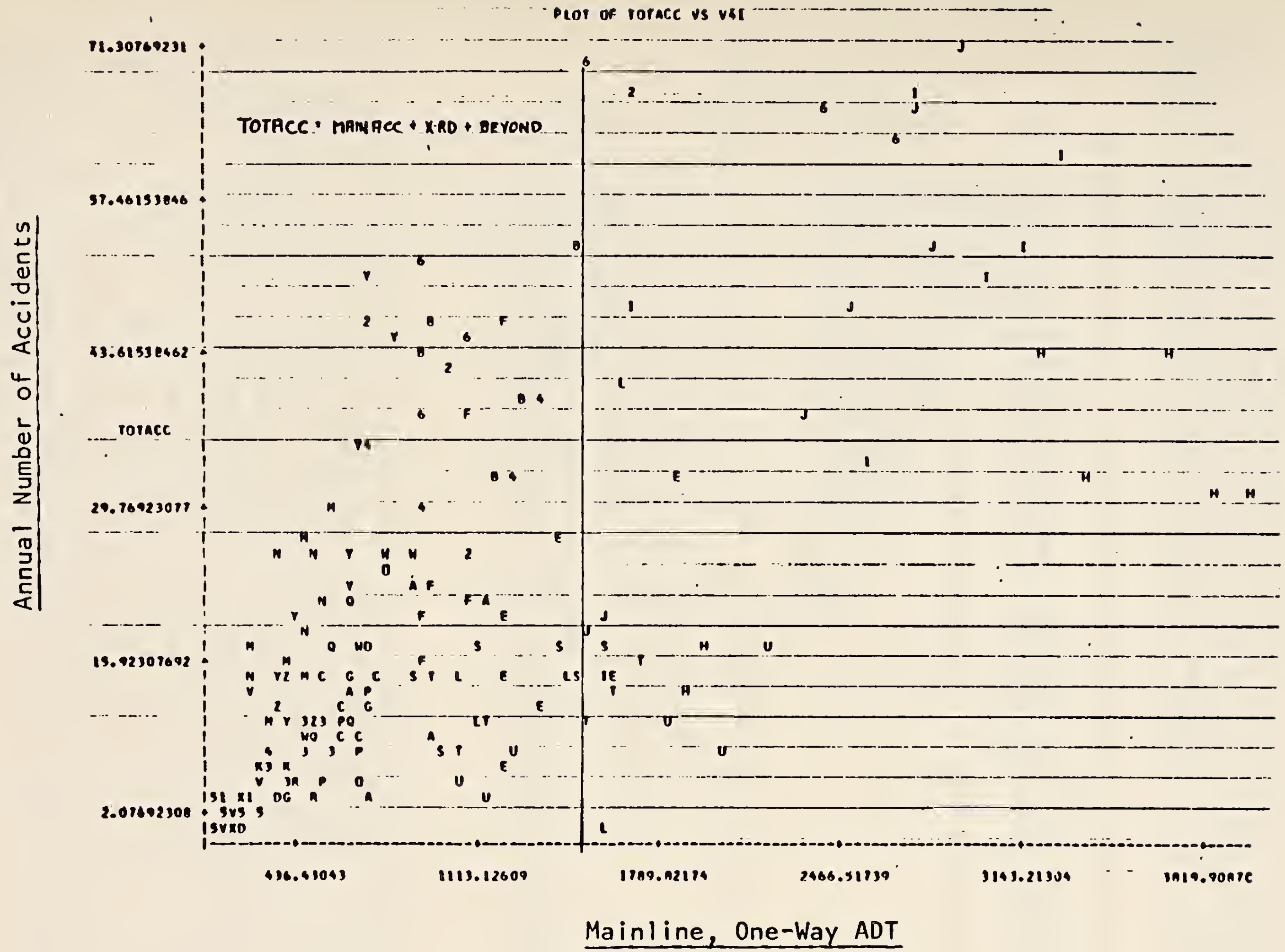


FIGURE 26. Annual Number of Accidents Within and Beyond the Interchange Versus Mainline Volume

APPENDIX B

This appendix contains the output from the level of service calculations for the weaving section. The procedures of Chapter Seven of the Highway Capacity Manual were used in these calculations. Computer adaptations of these procedures contained in the FHWA battery of programs entitled, "Urban Transportation Planning".

The input for each calculation included the following variables:

1) flow (VPH) entering the weave section from the entrance ramp,
2) flow (VPH) entering the weave section from lane one of the mainline,
3) flow (VPH) on the mainline just prior to the weave section,
4) peak-hour factor,
5) length of weaving section,
6) number of lanes on mainline,
7) percent grade on mainline, and
8) degree of curvature on mainline.

The range of values used for each variable was the following:

1) 100 vph to 1,400 vph in 100 vph increments,
2) 100 vph to 1,400 vph in 100 vph,
3) eleven values ranging 1,500 vph to 4,000 vph,
4) 0.77 and 1.00,
5) 400' to 1,000' in 100' increments,
6) two lanes and three lanes which with the auxiliary lane make section widths equal to three lanes and four lanes,
7) 0%, and
8) 0°.

The output from each calculation is the level of service which is defined as "a qualitative measure relating directly to the minimum quality of flow as represented in Table 7.3 of the HCM". The output is displayed in 1,400 vph x 1,400 vph matrices for which all other factors are held constant. Seven matrices, one for each weaving length increment, are presented on a single page, with successive pages representing the increments of mainflow flow (V_f) prior to the weaving section. The results are grouped into four sets of data. The first set of results presented is for the three lane condition (i.e., two through lanes and one auxiliary lane) and the second set is for the four-lane condition (three through lanes and one auxiliary lane) with the peak-hour factor held constant at 0.75 for both sets. The last two sets are for three and four lane widths with the peak-hour factor equal to 1.00.

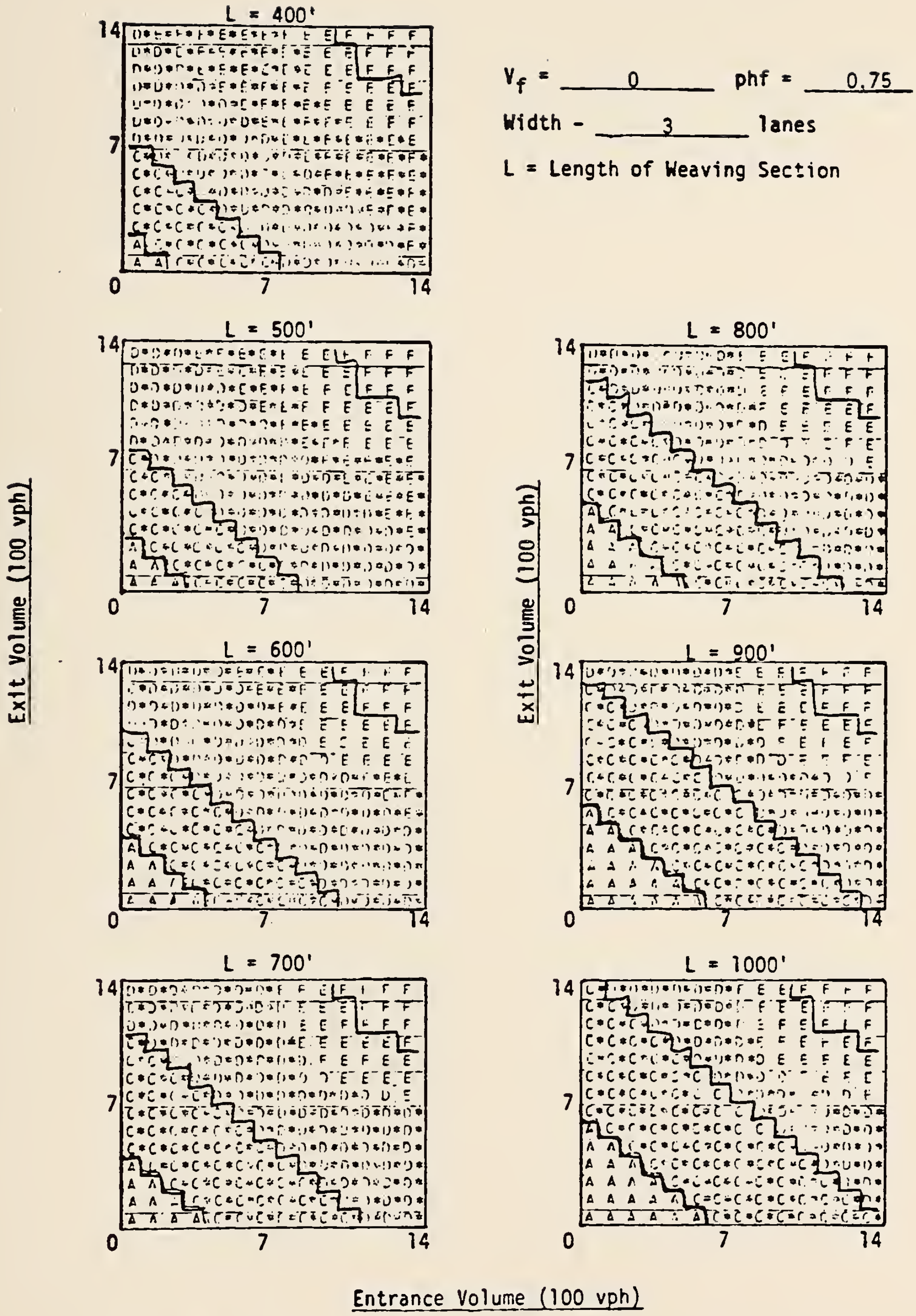
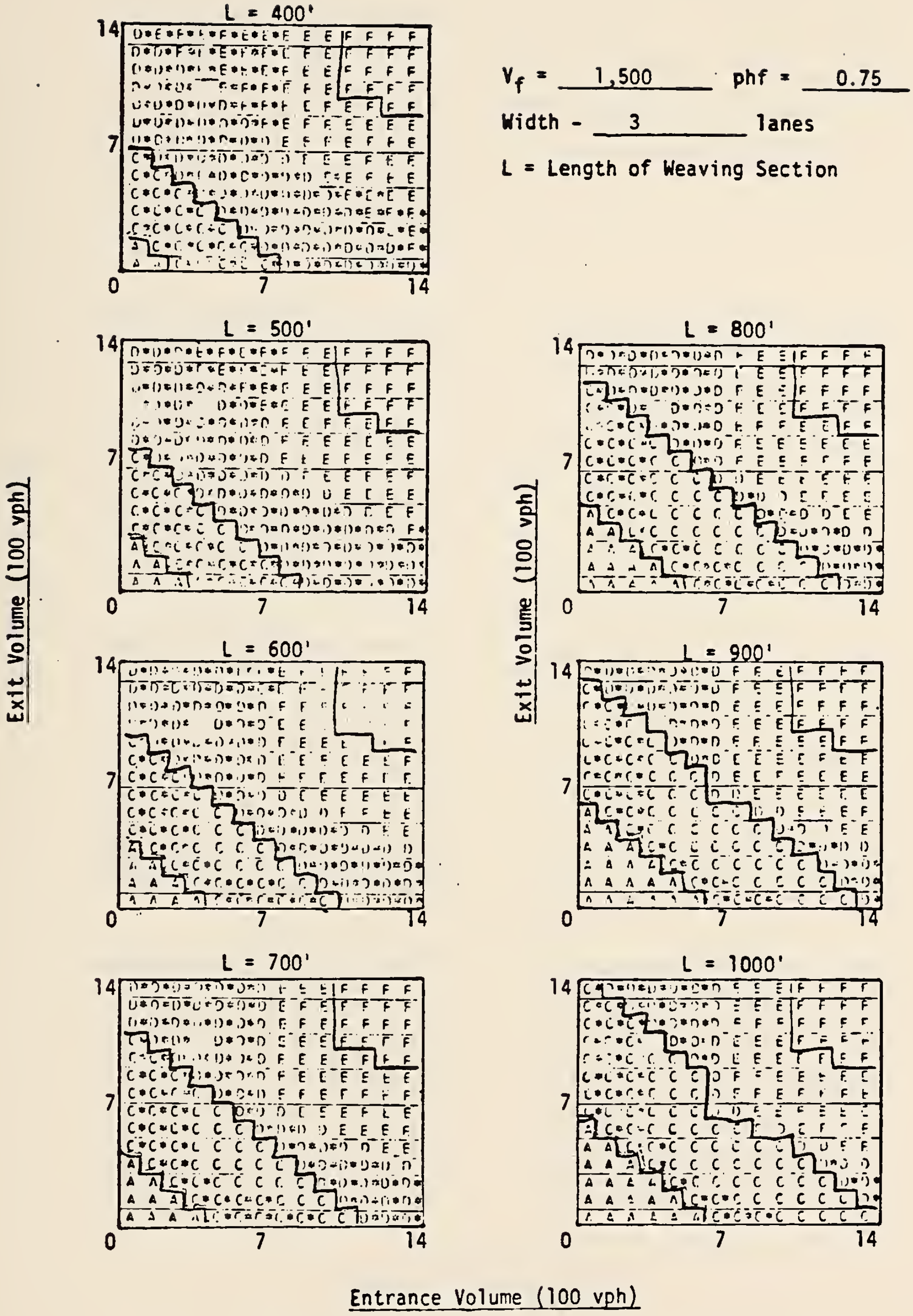


FIGURE 27. Minimum Level of Service Provided by Varying Combinations of Weaving Volume Given Specific Combinations of Upstream Volume (V_f), Peak Hour Factor (phf), Number of Lanes and Weaving Section Length



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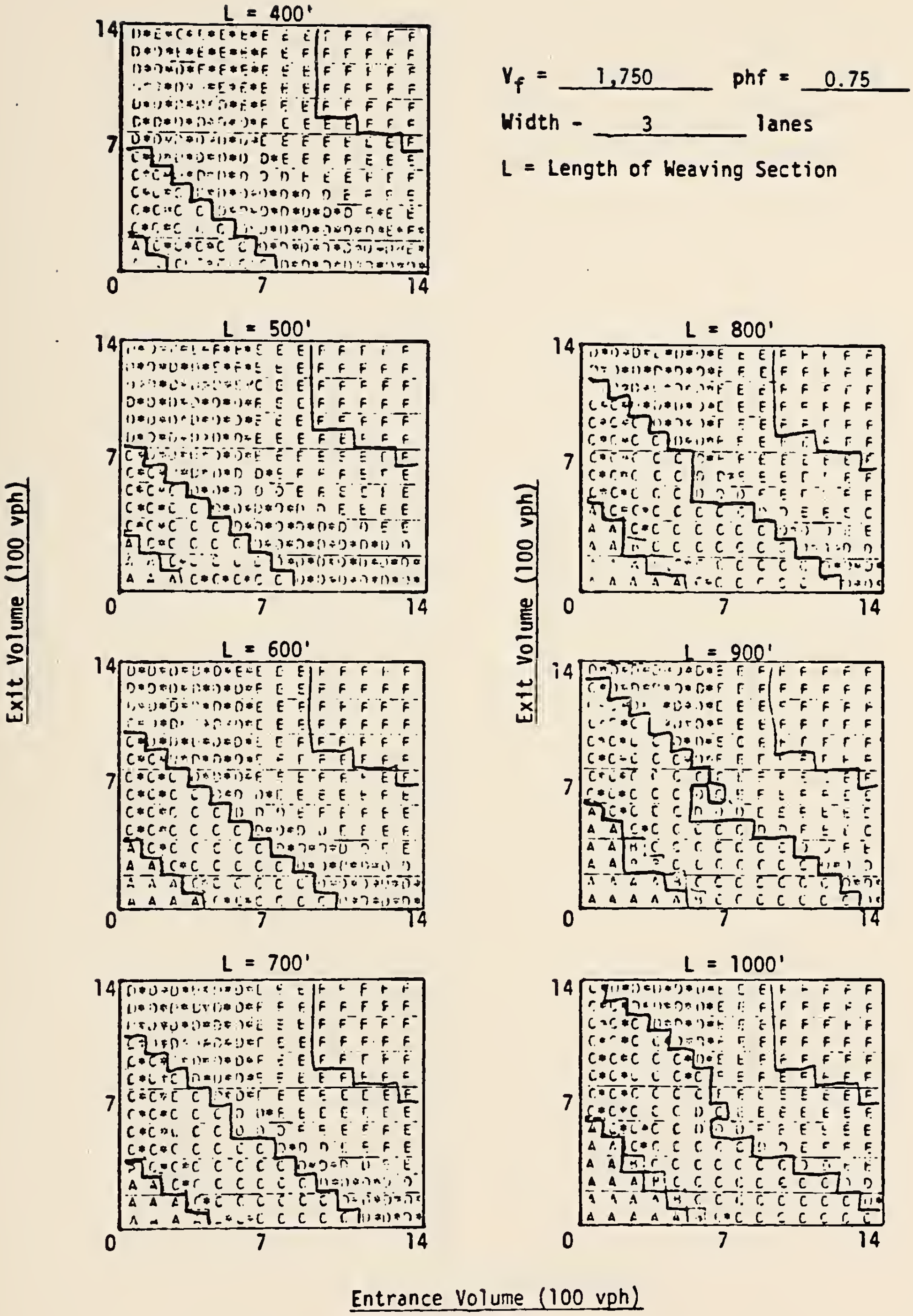

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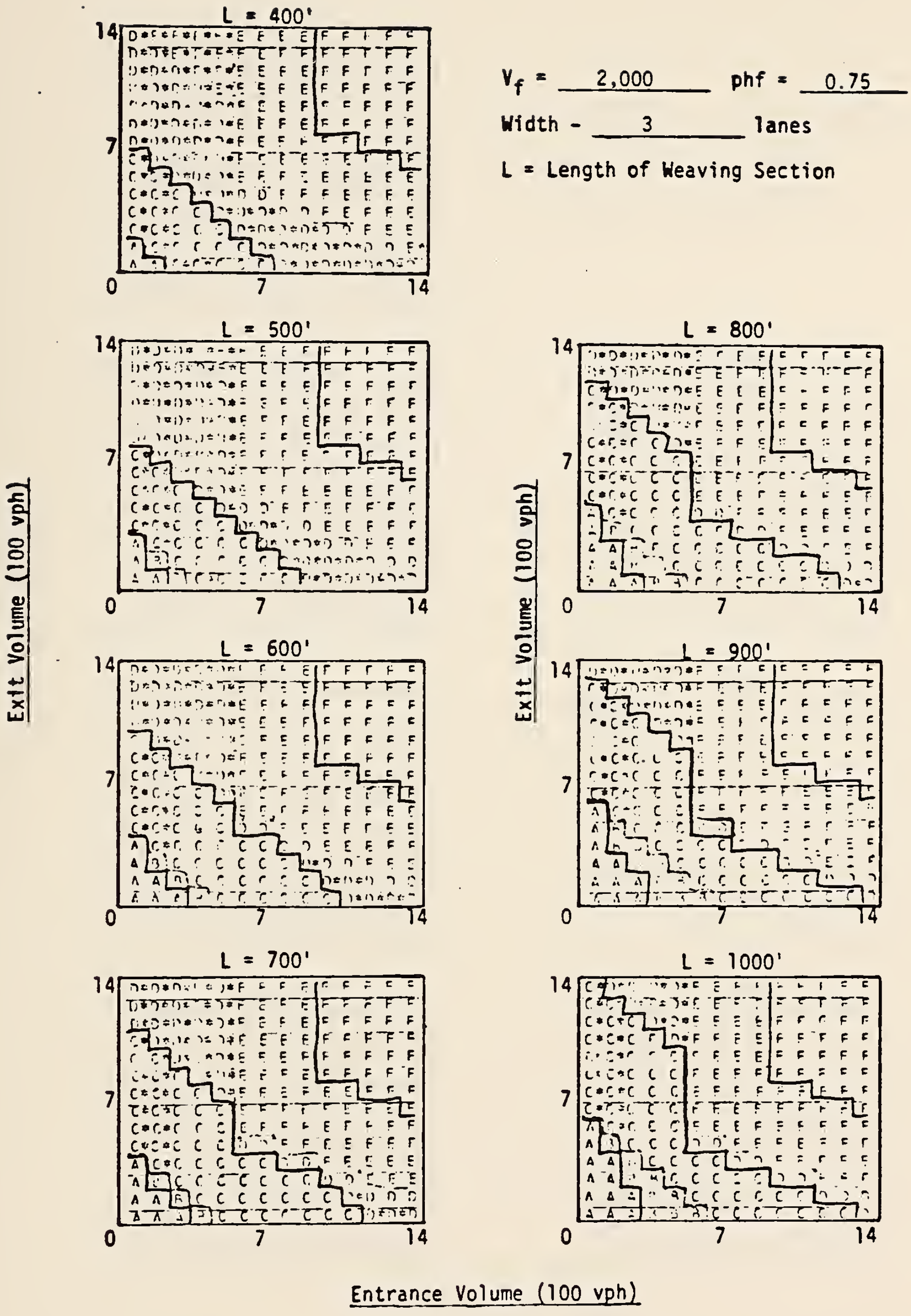

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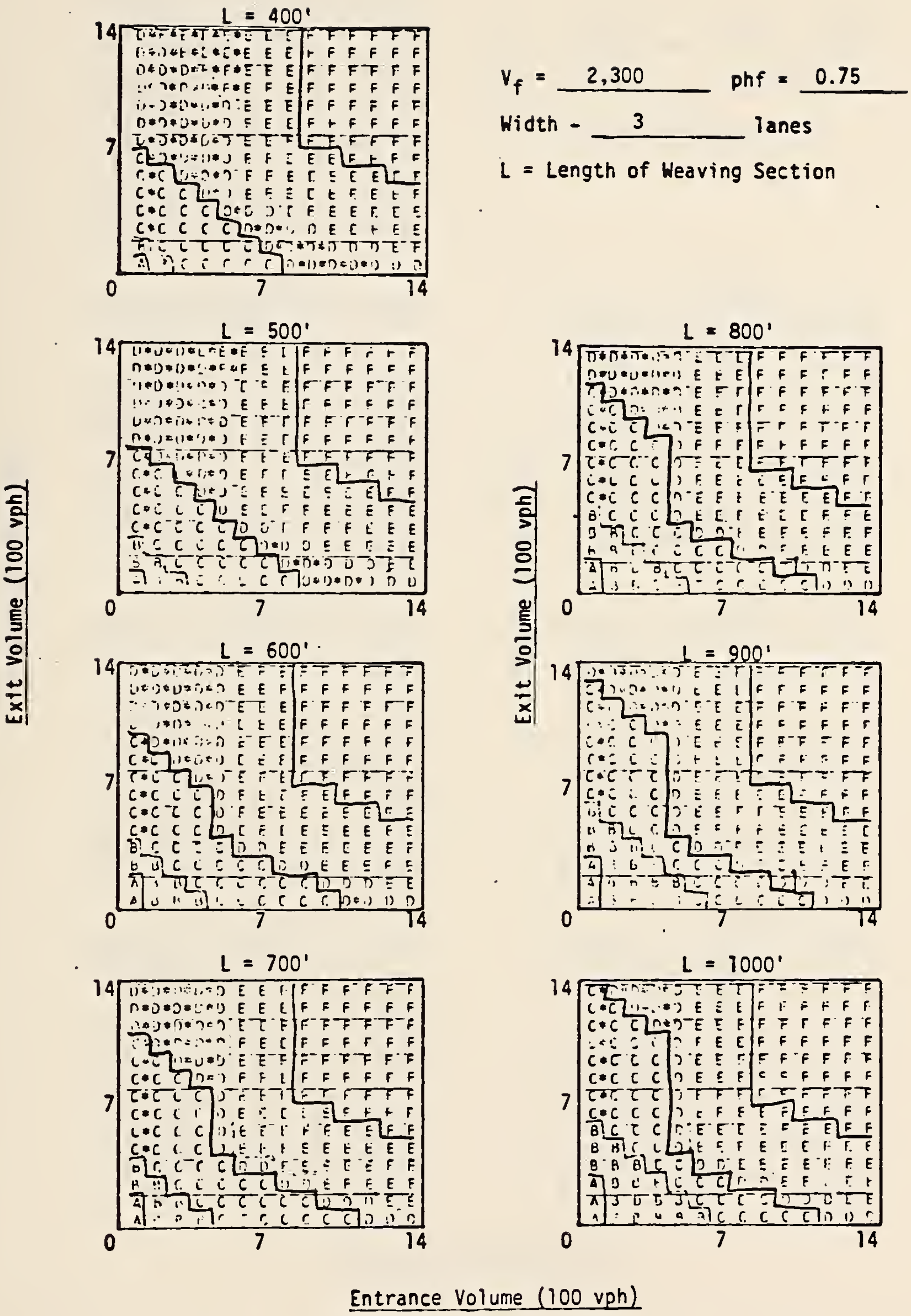

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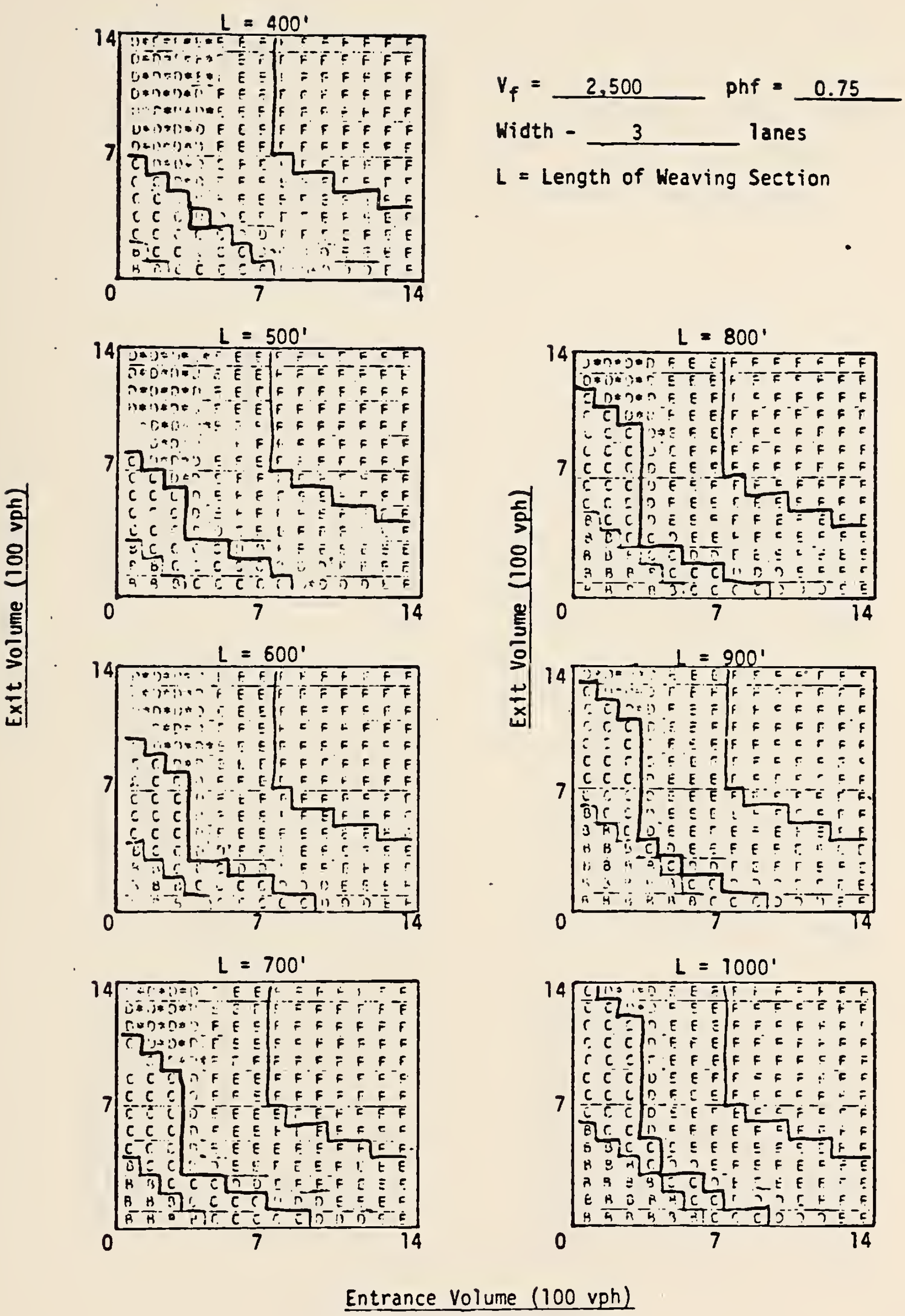

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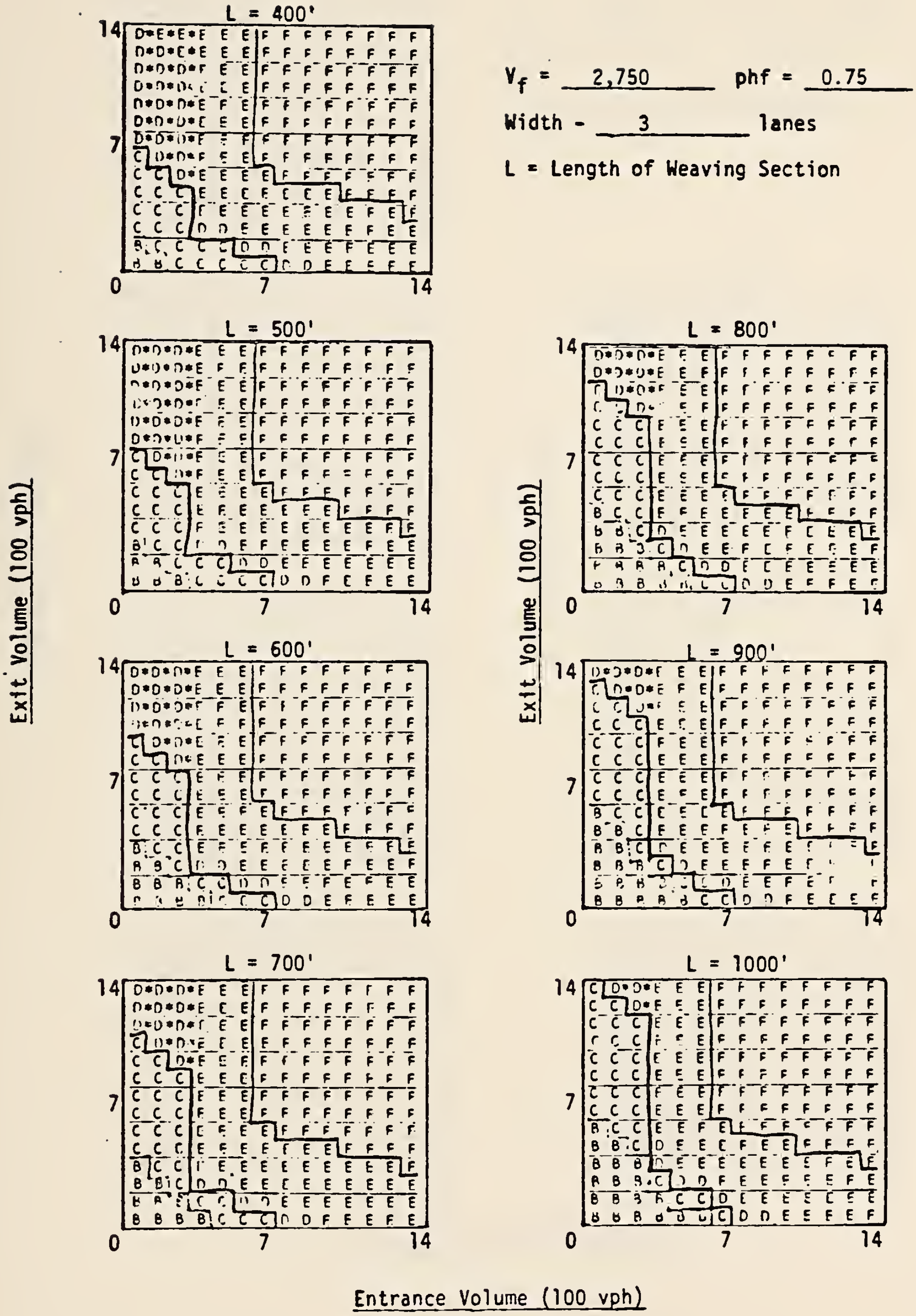

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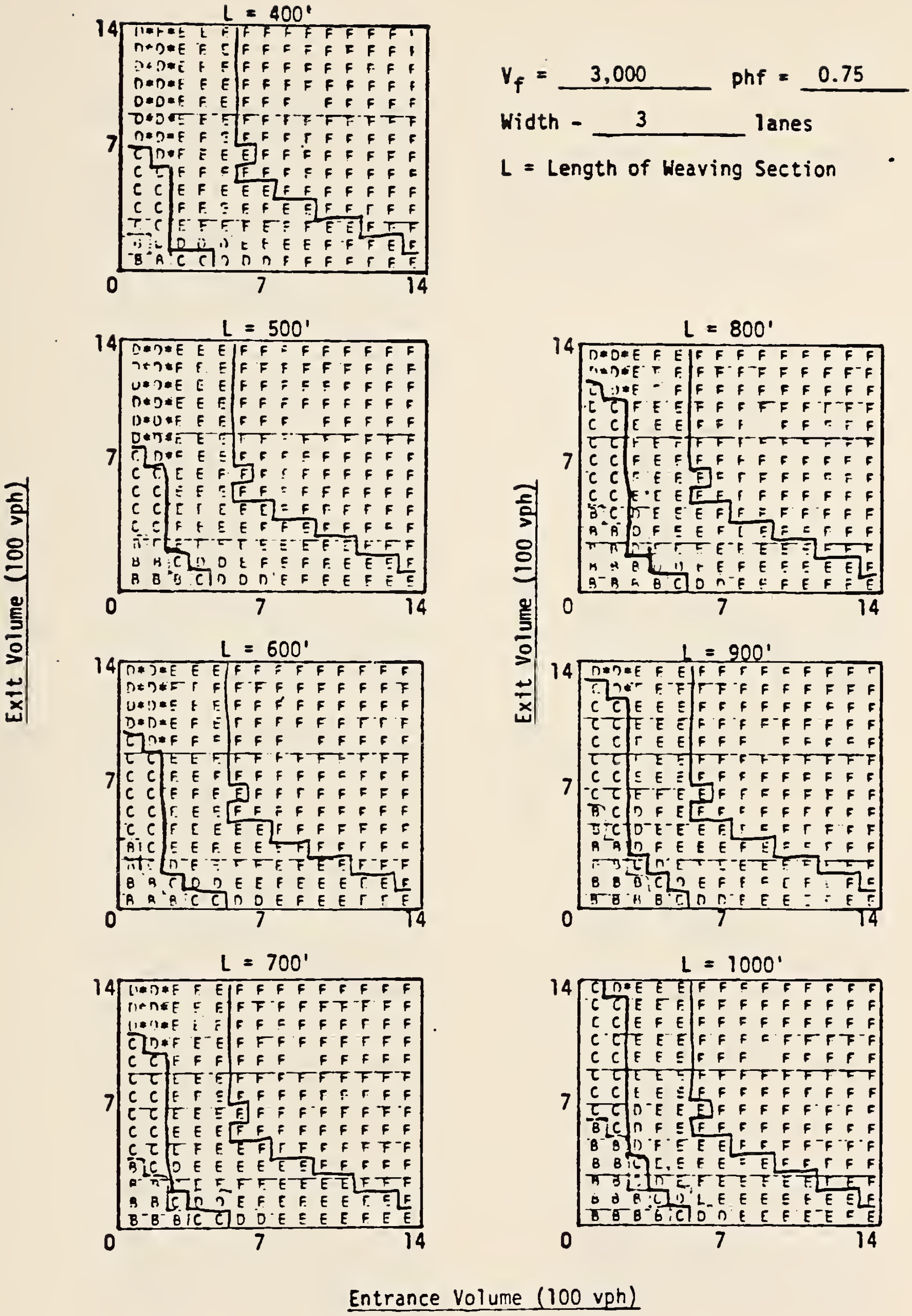

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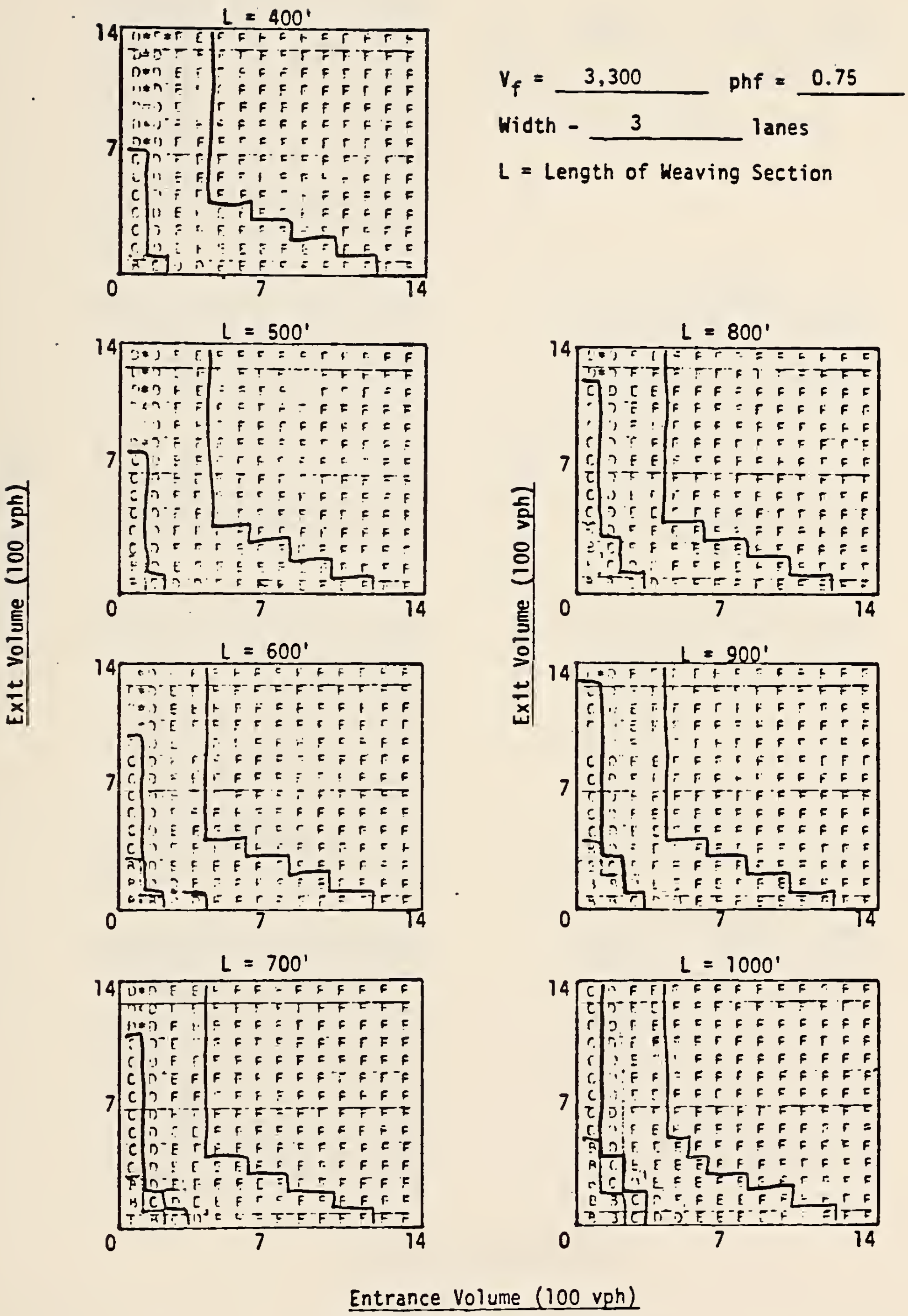

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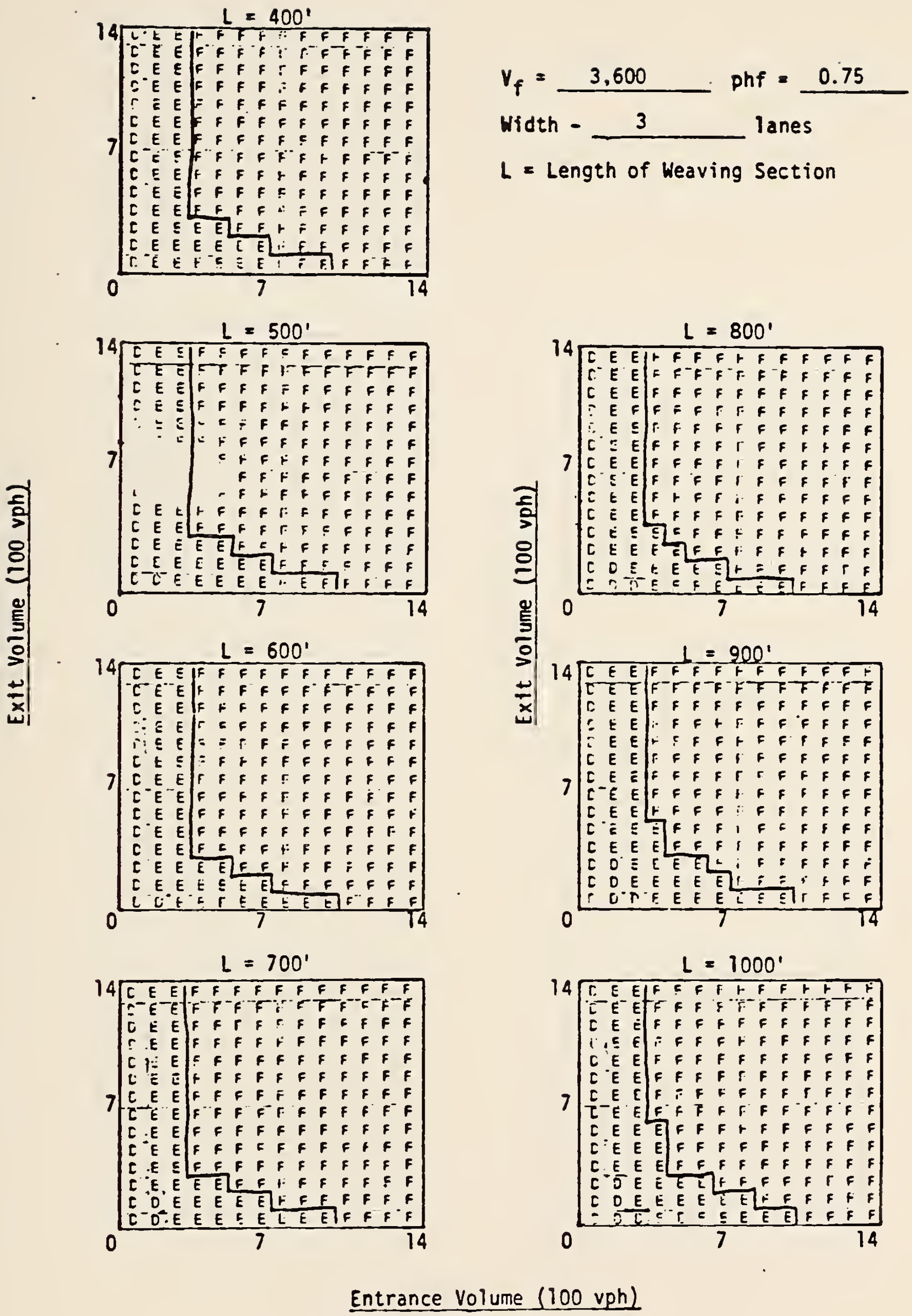

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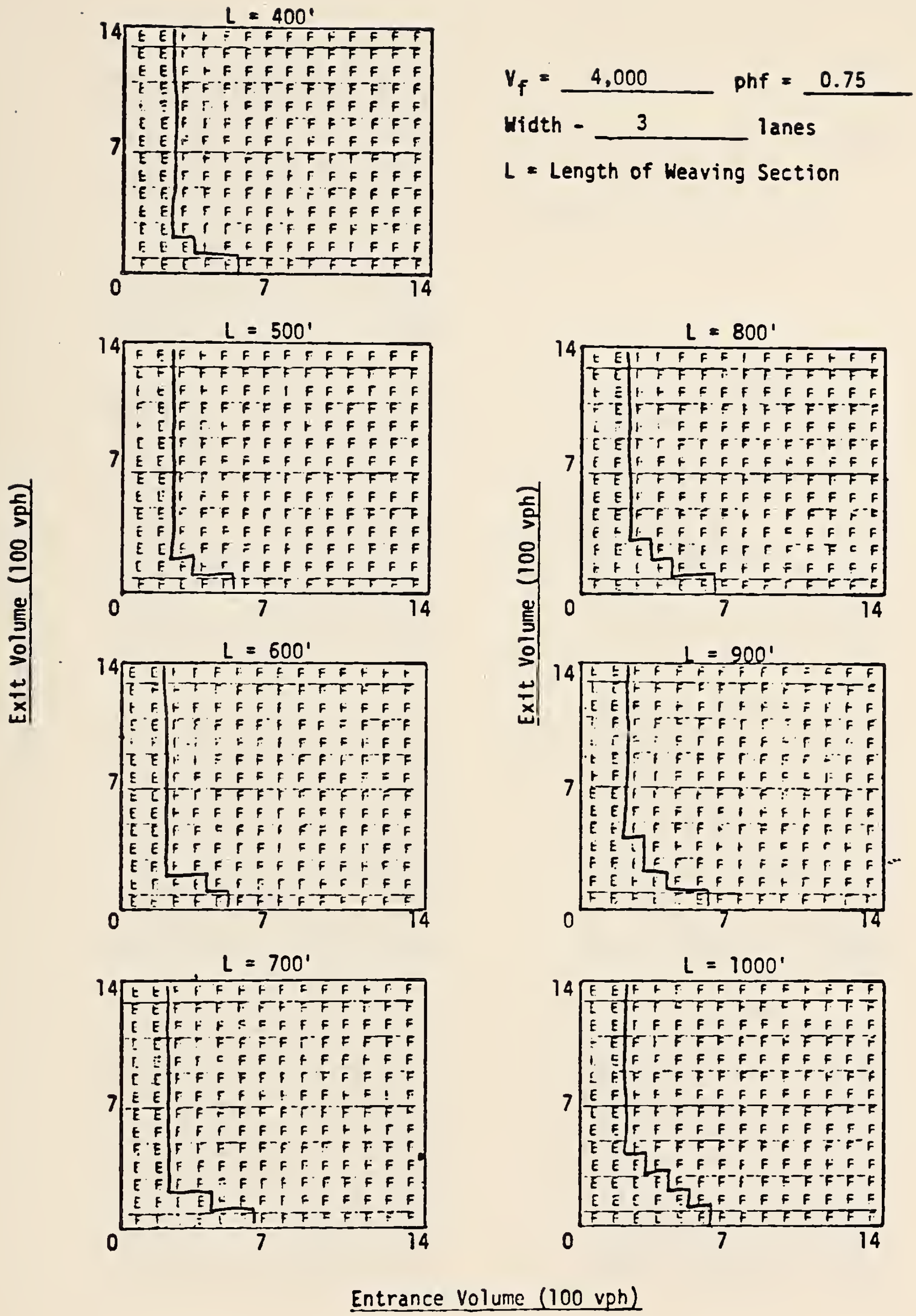

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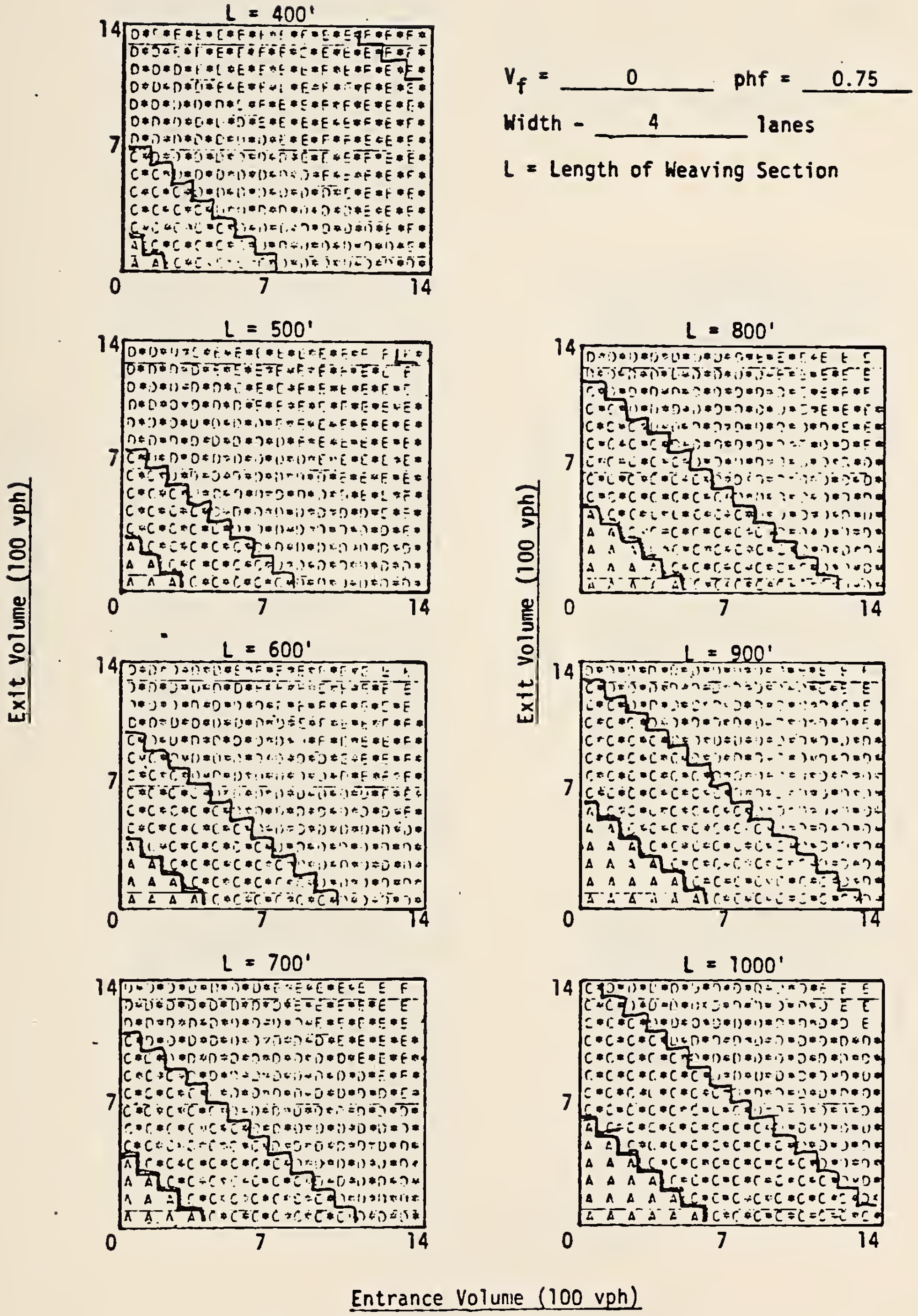


FIGURE 27. Continued

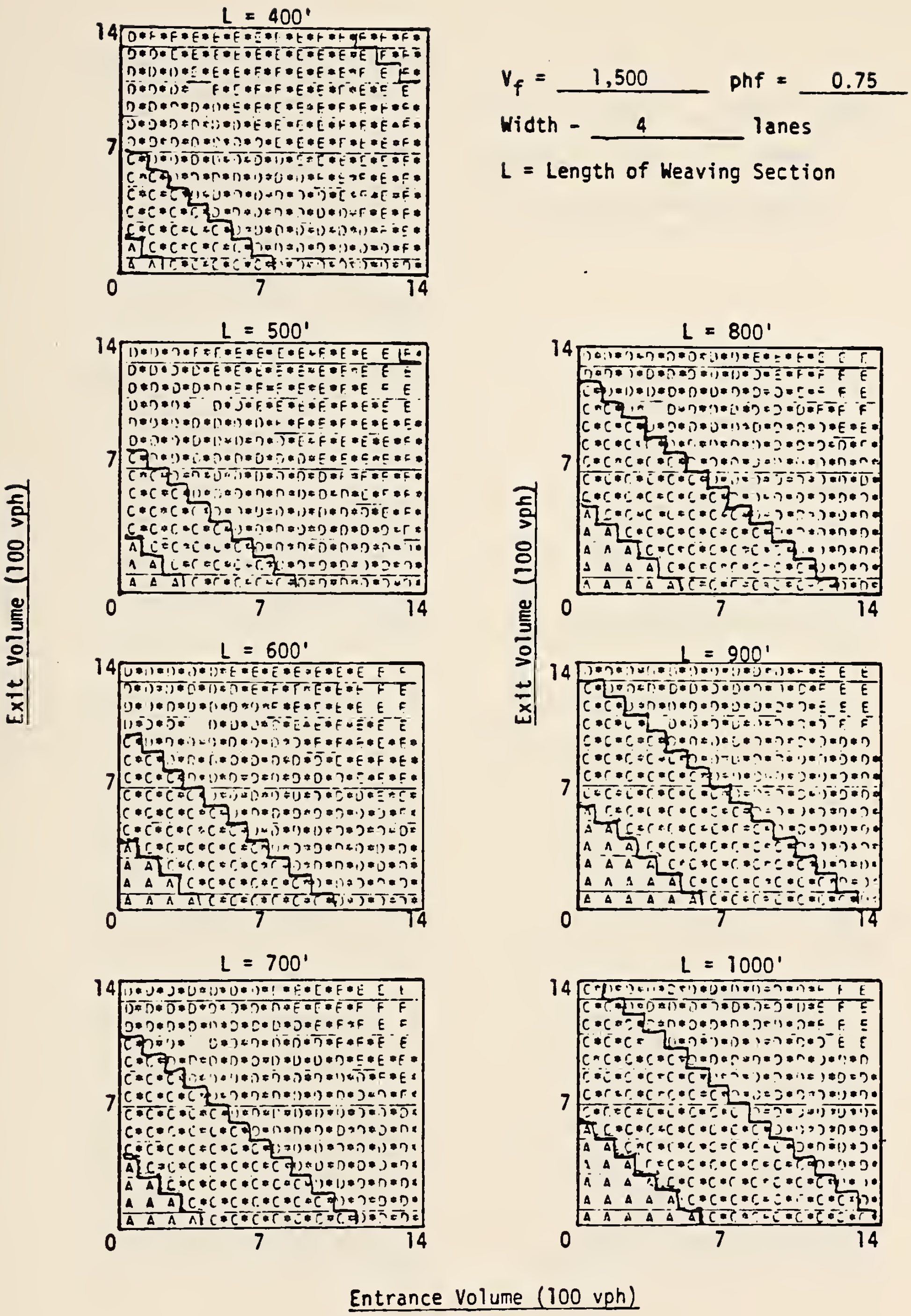


FIGURE 27. Continued

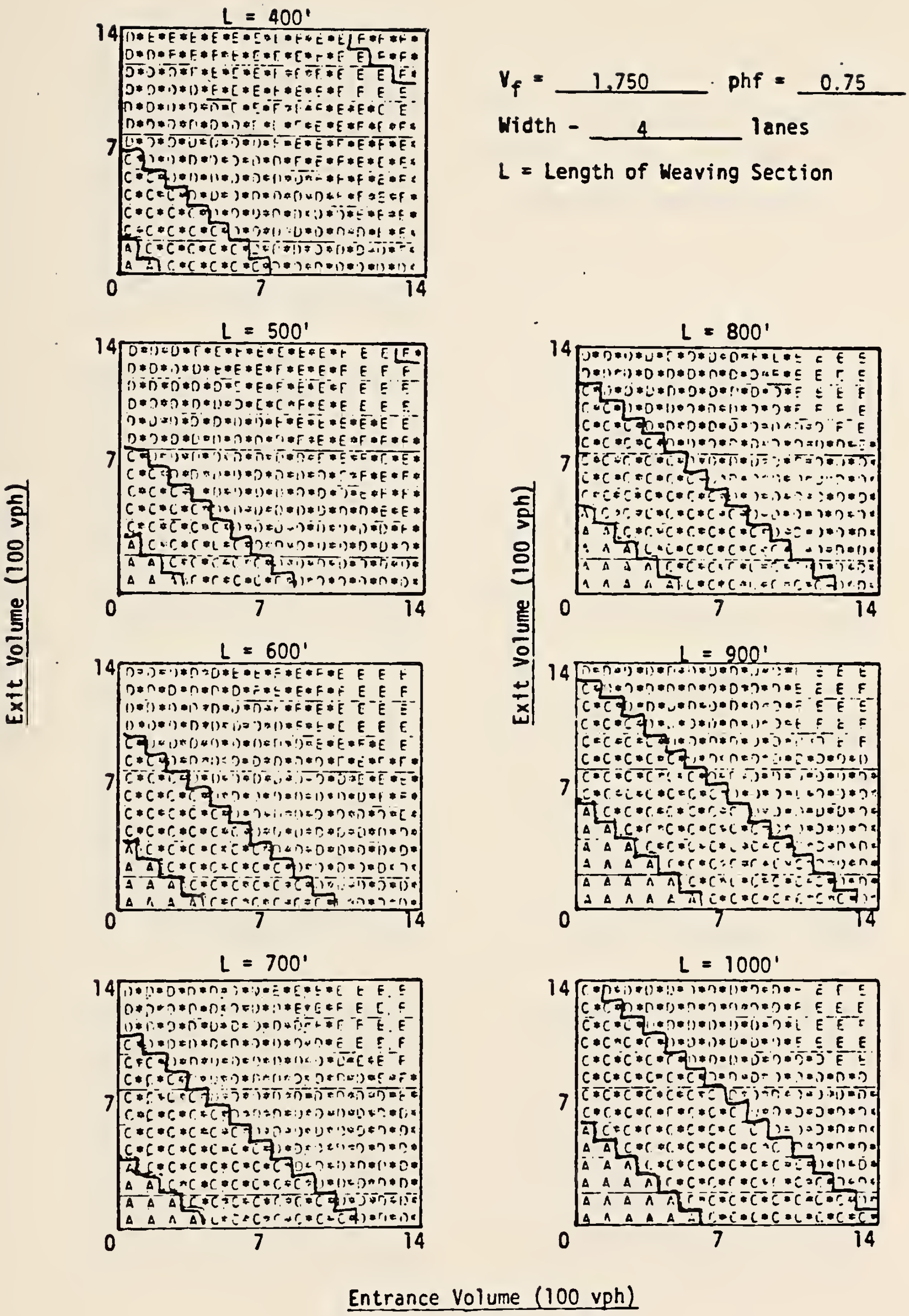
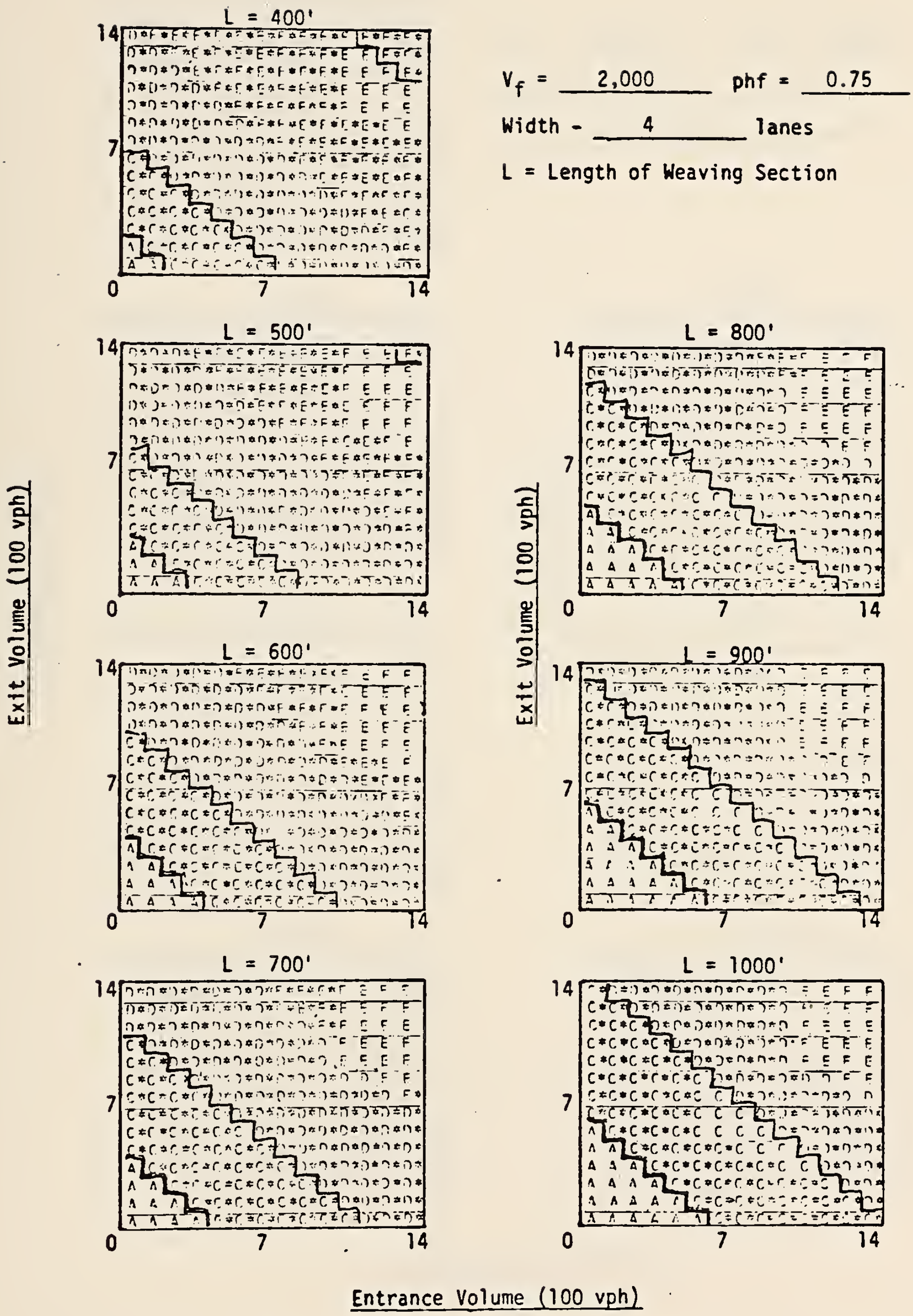


FIGURE 27. Continued



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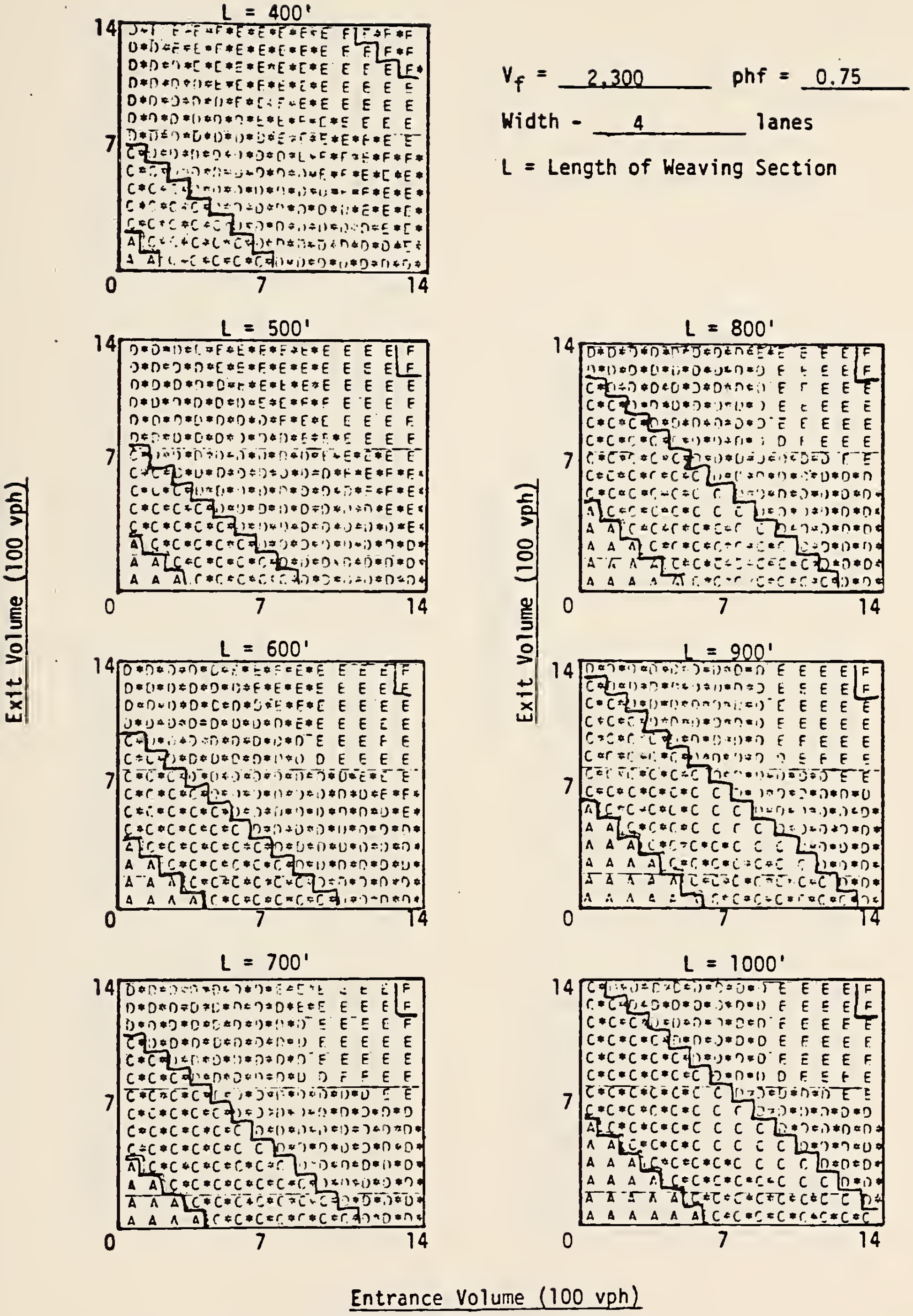

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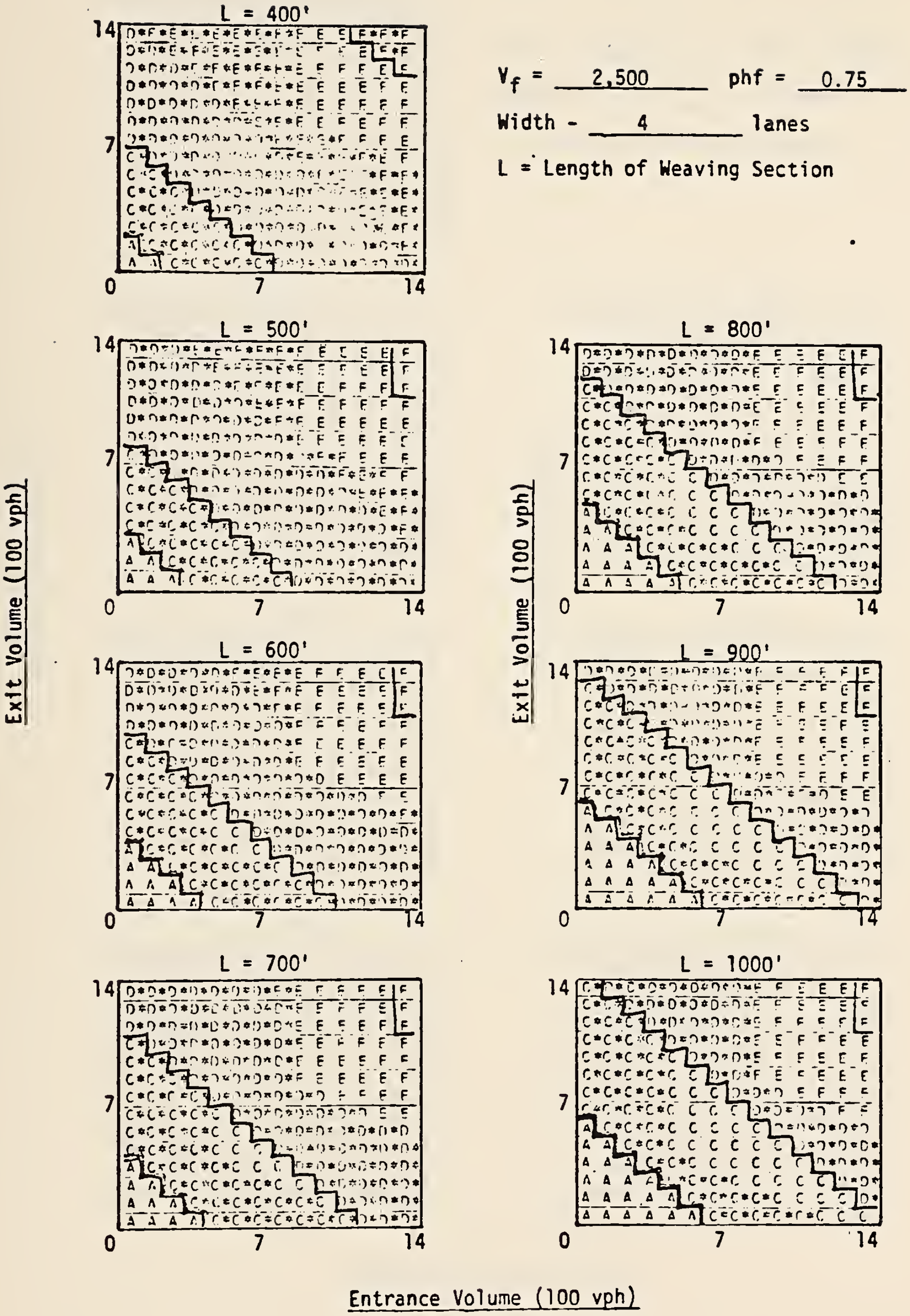

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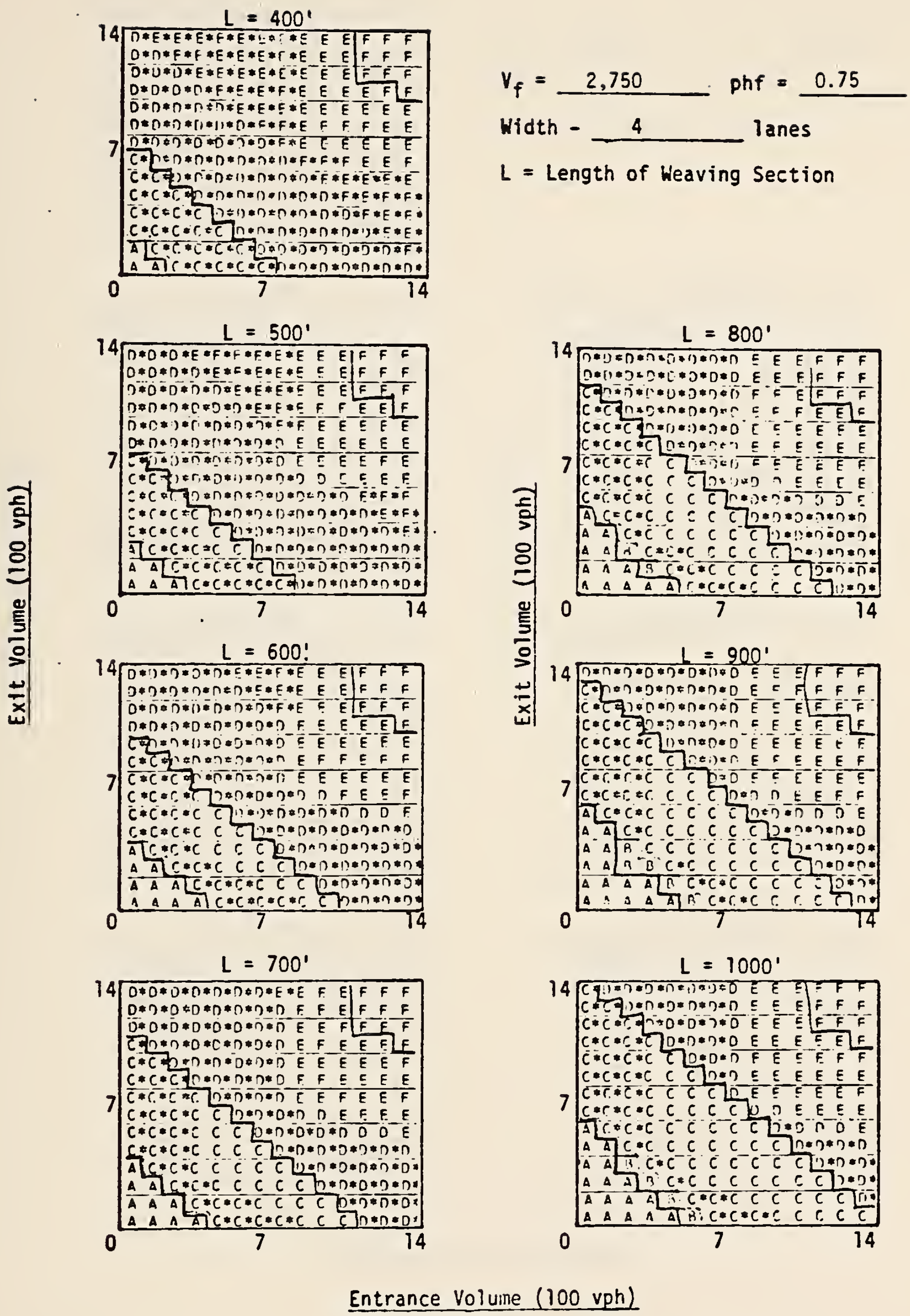

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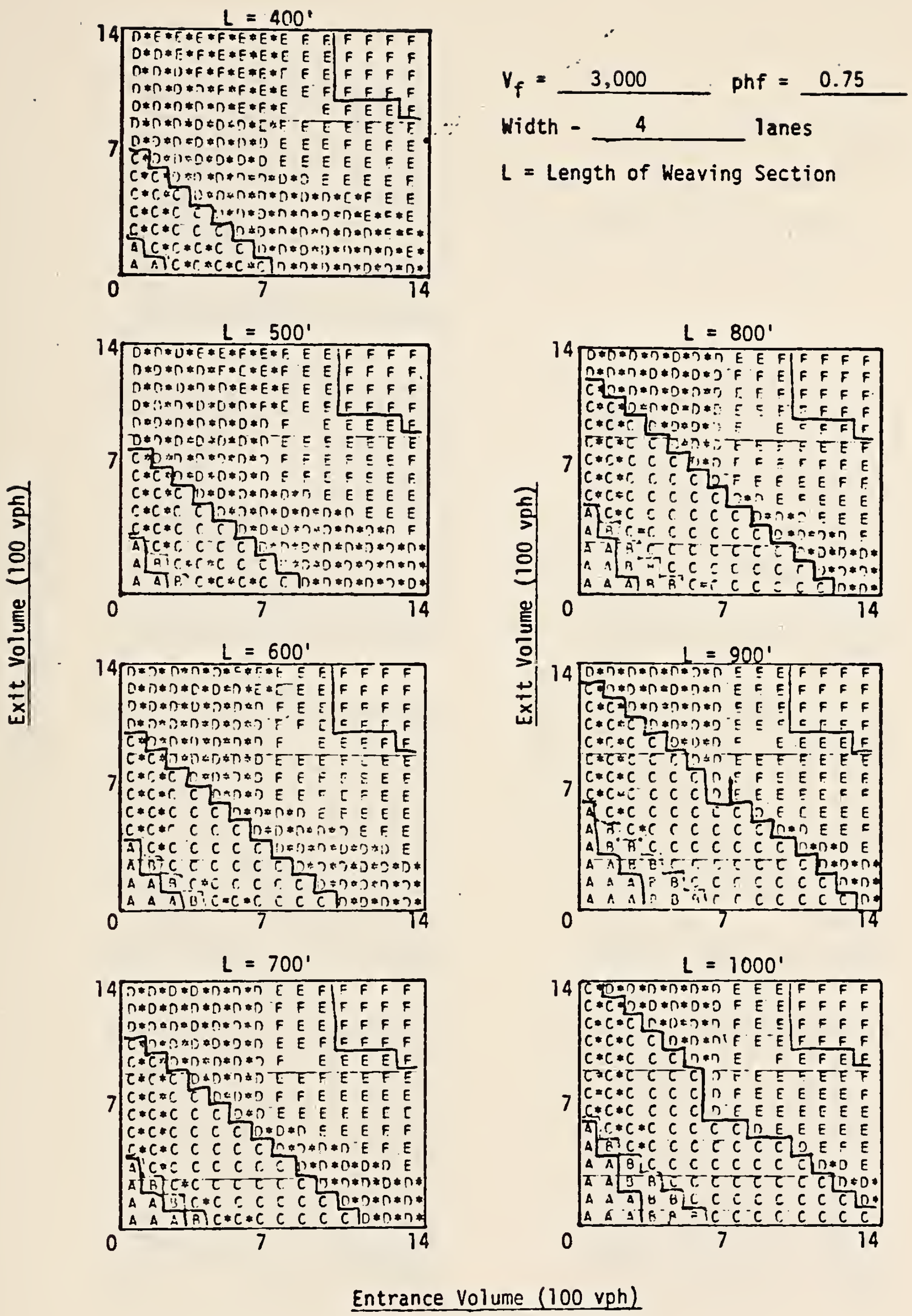

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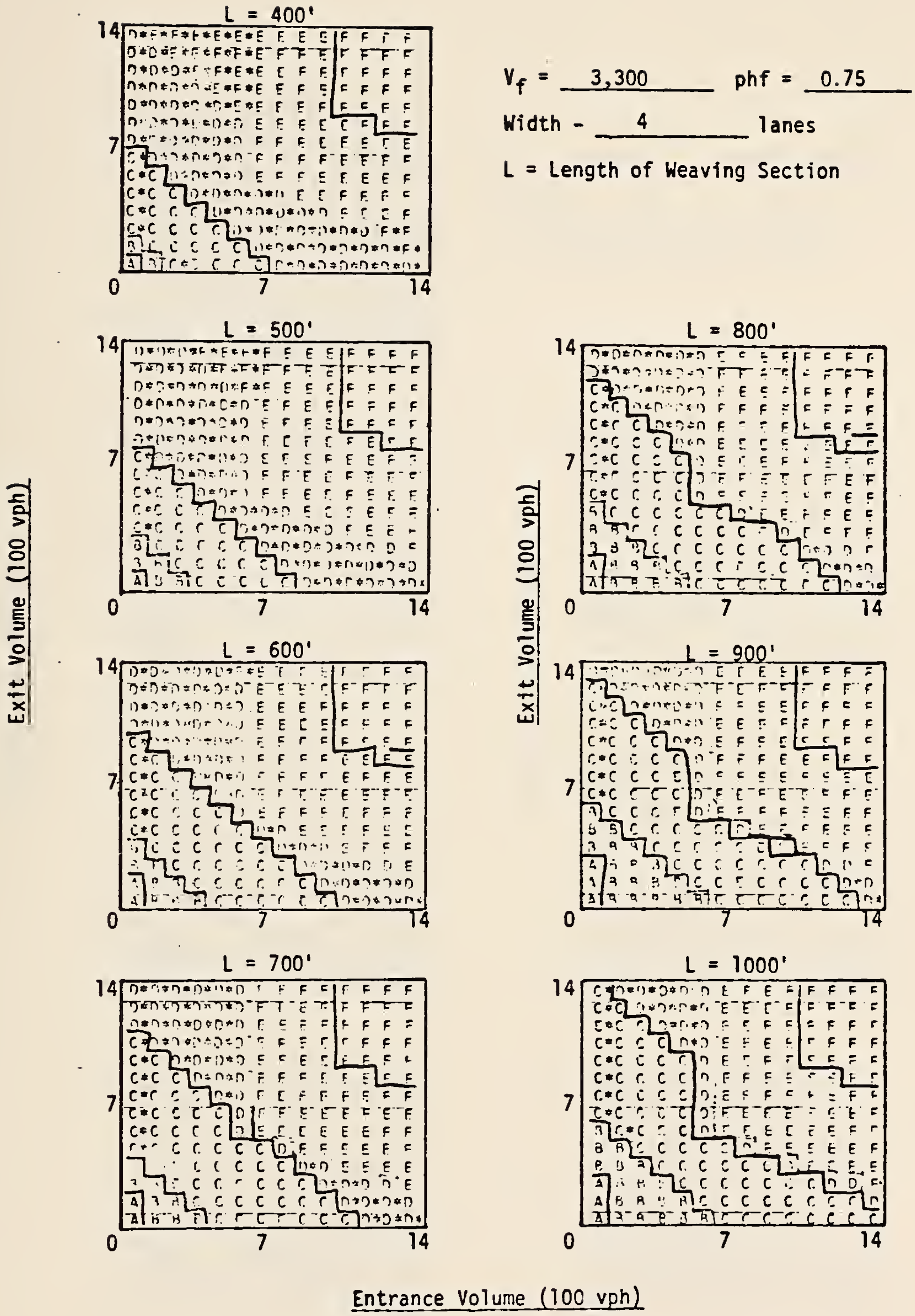

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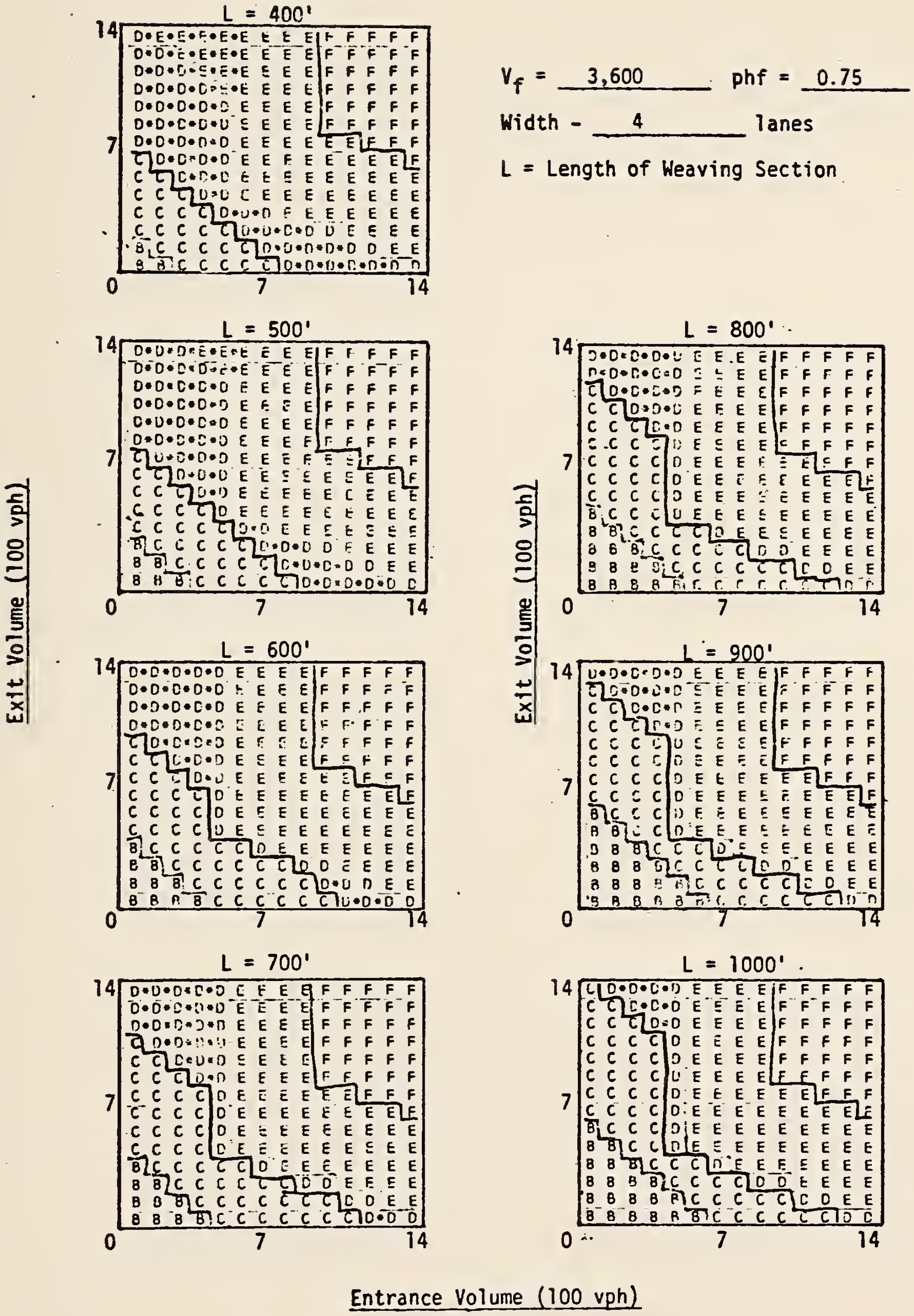

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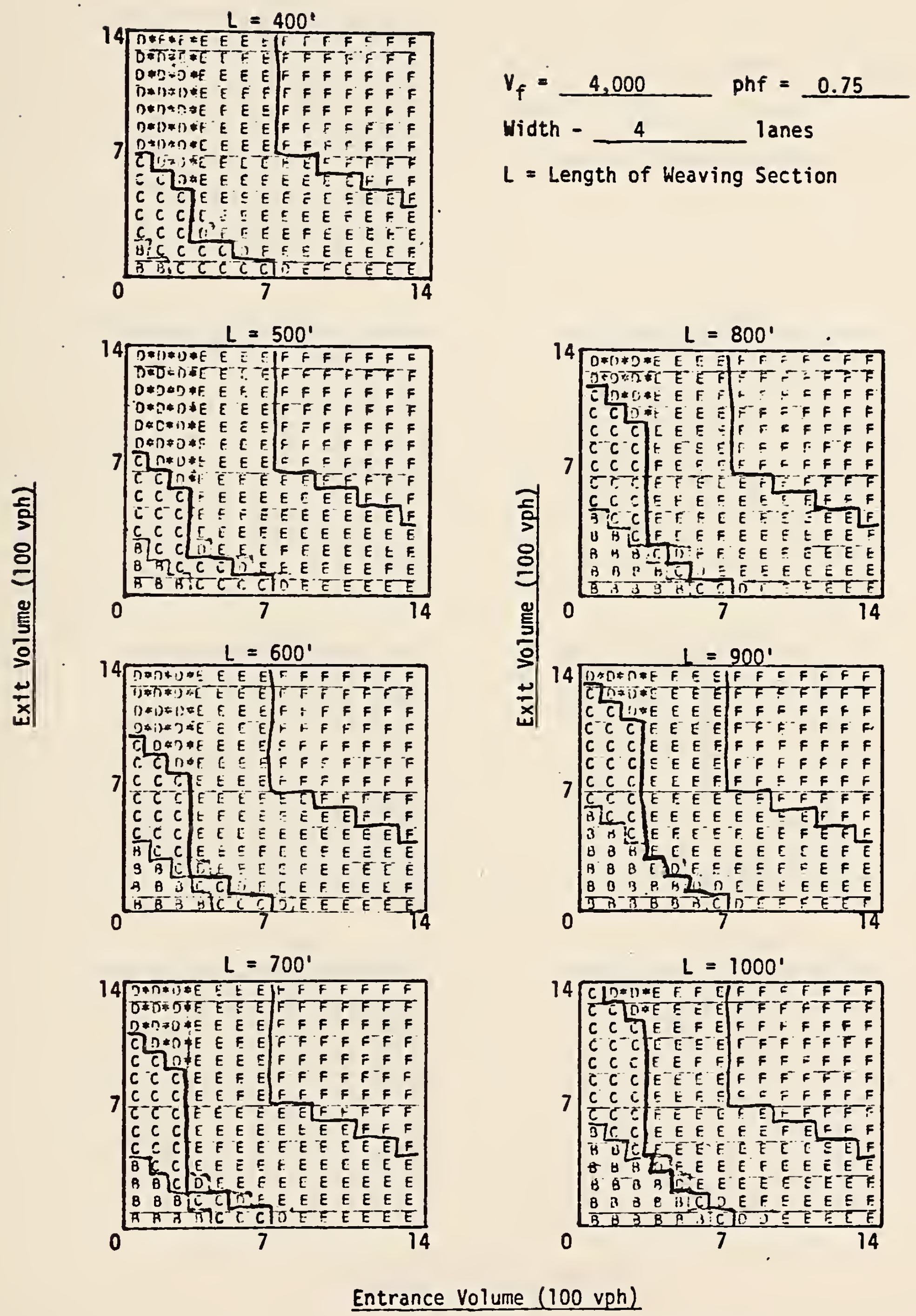

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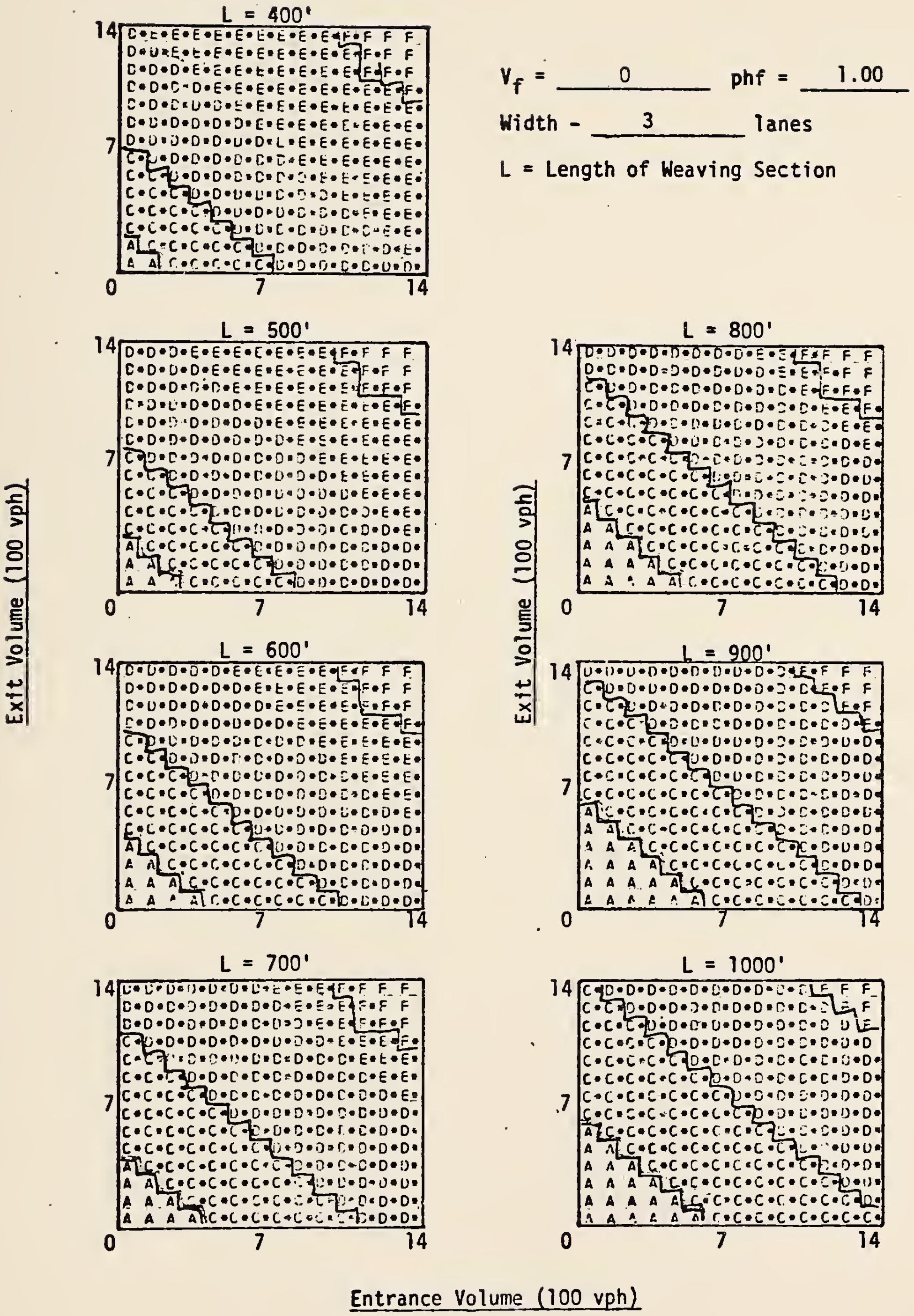

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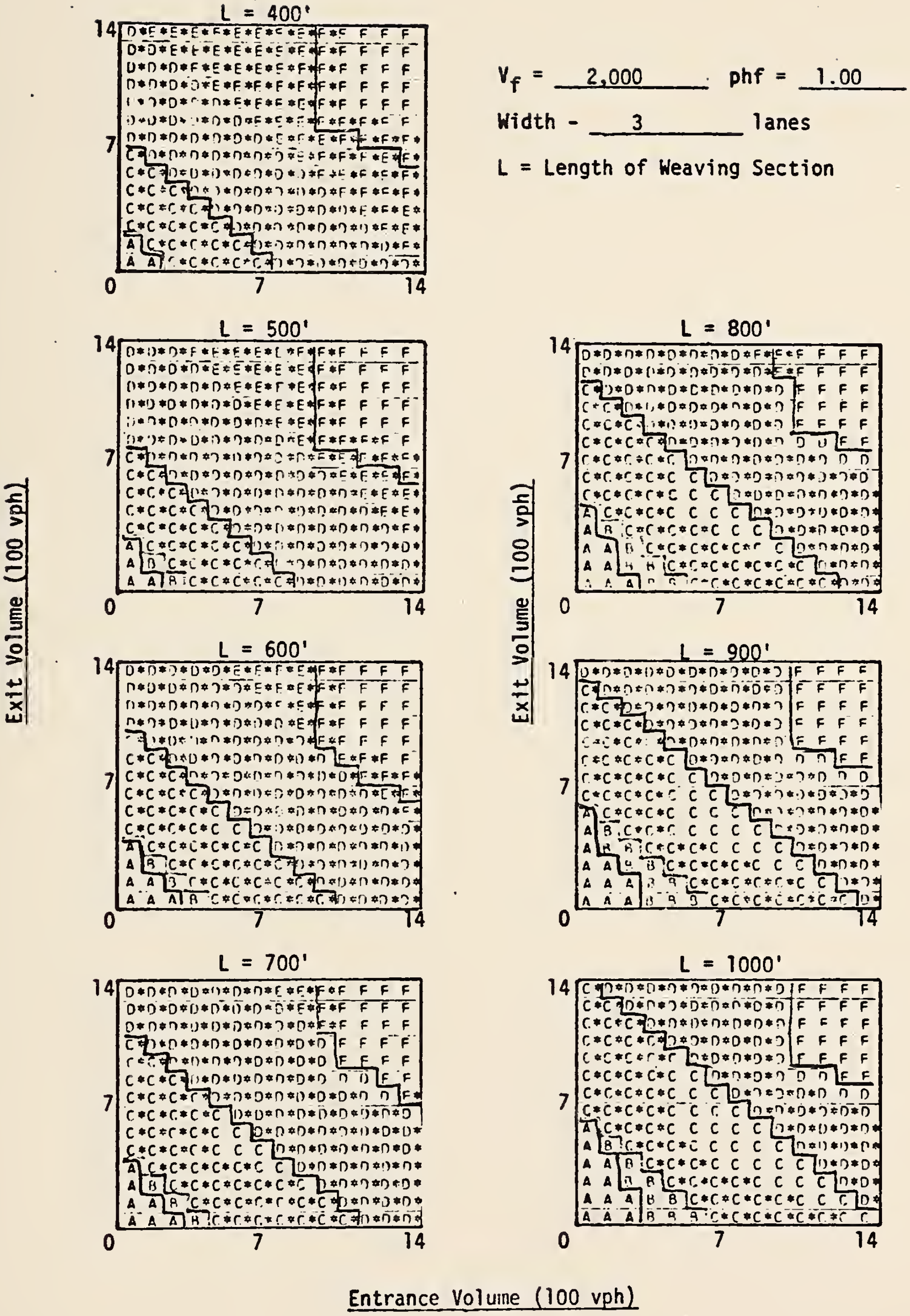

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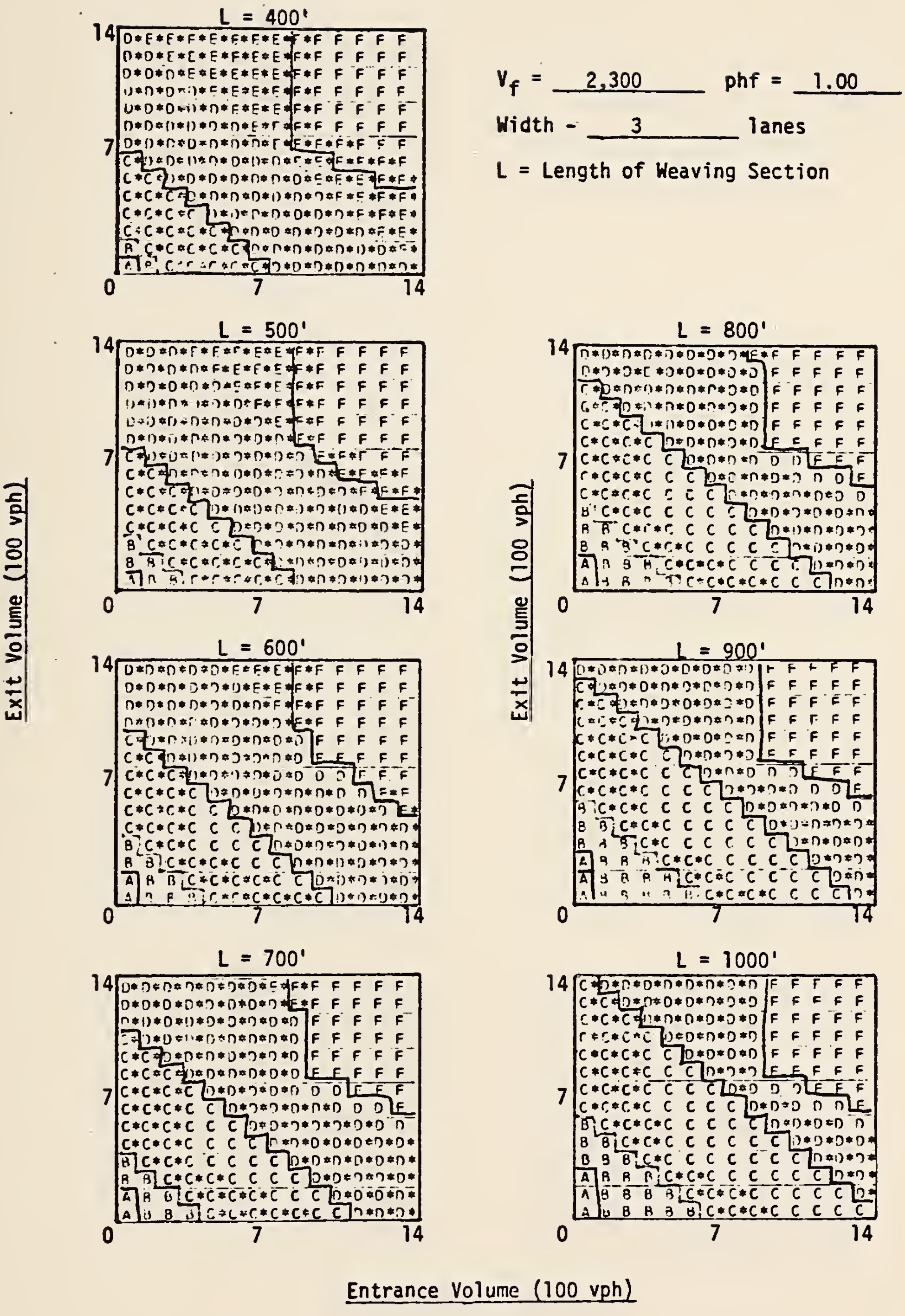

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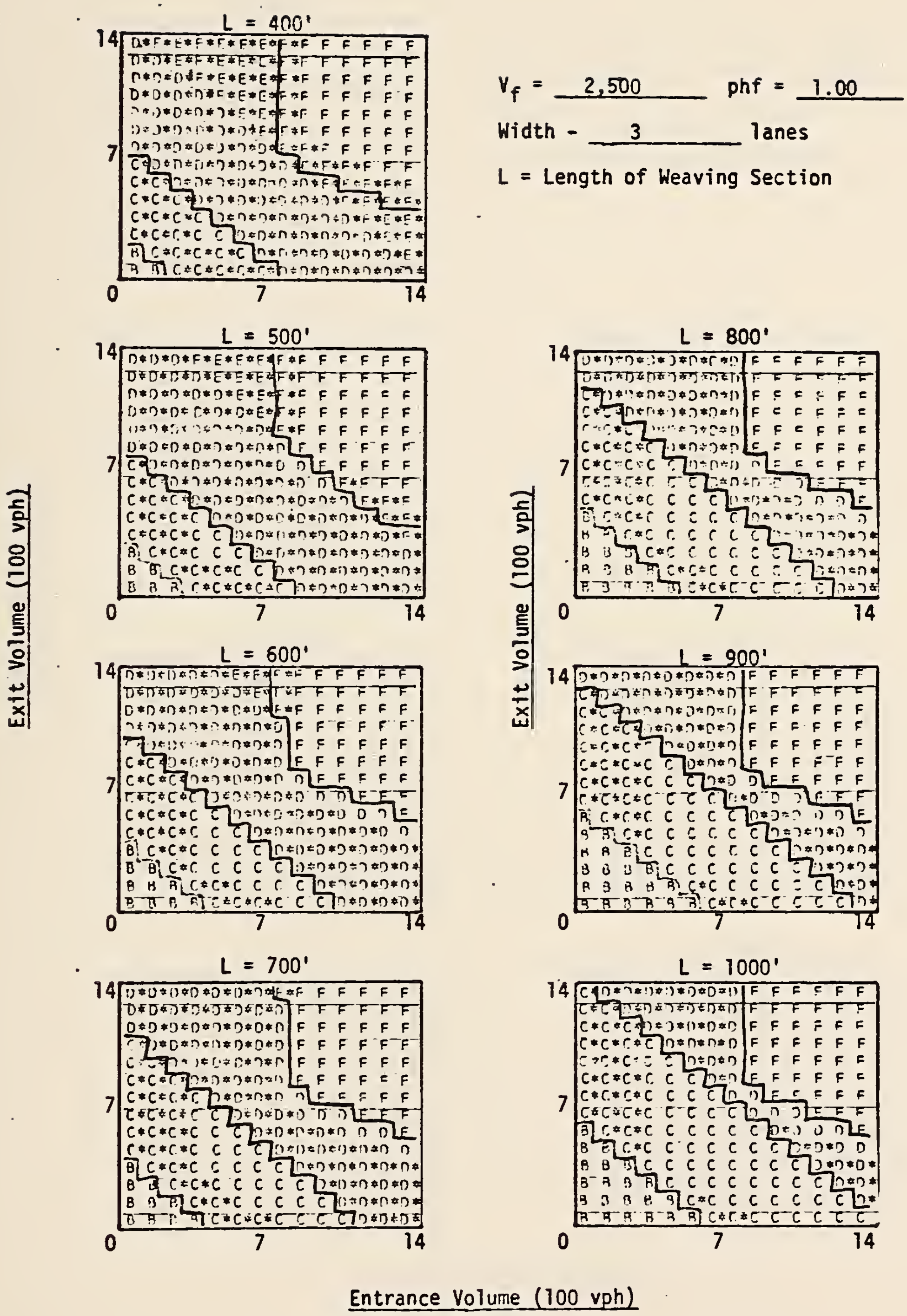

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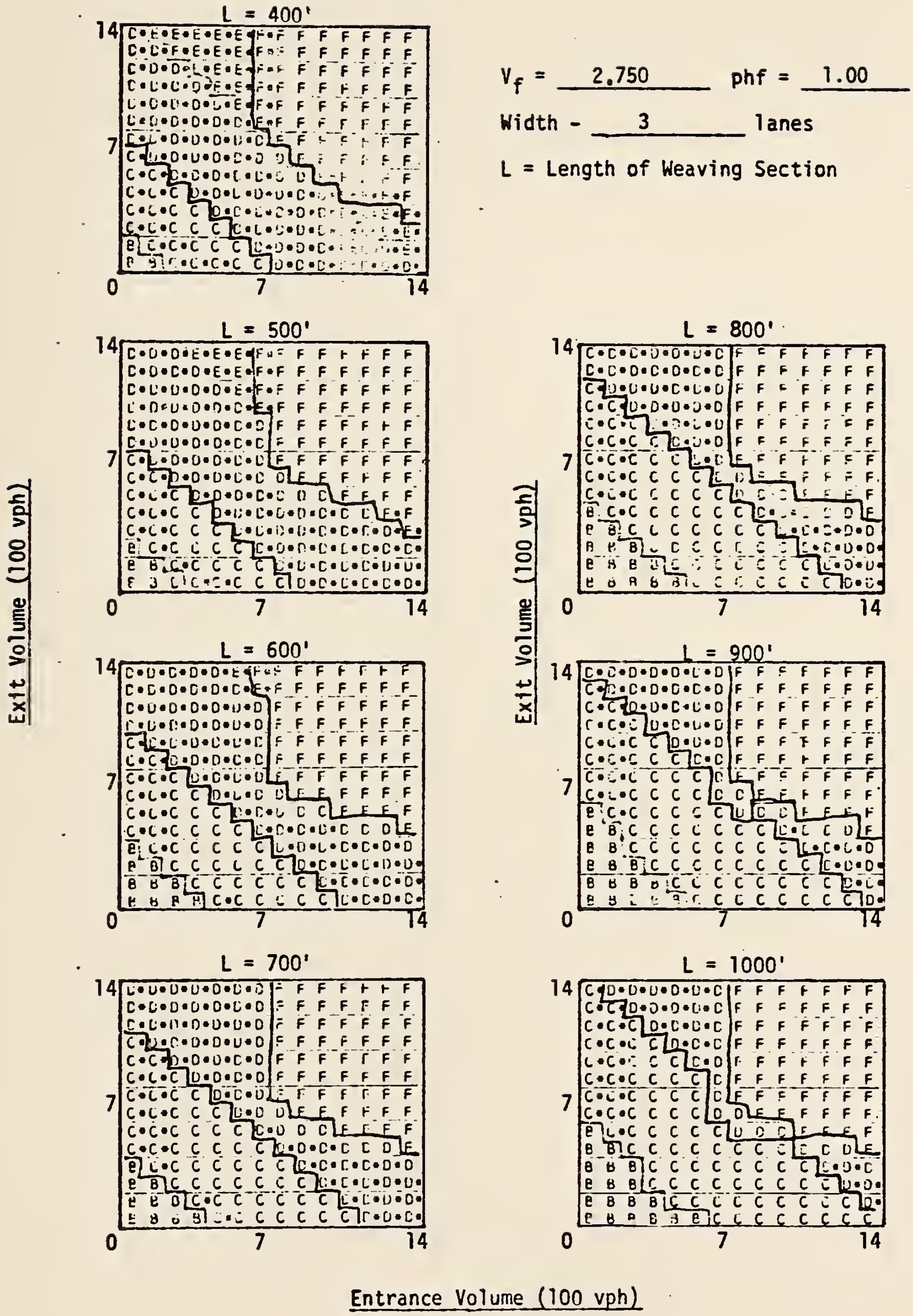

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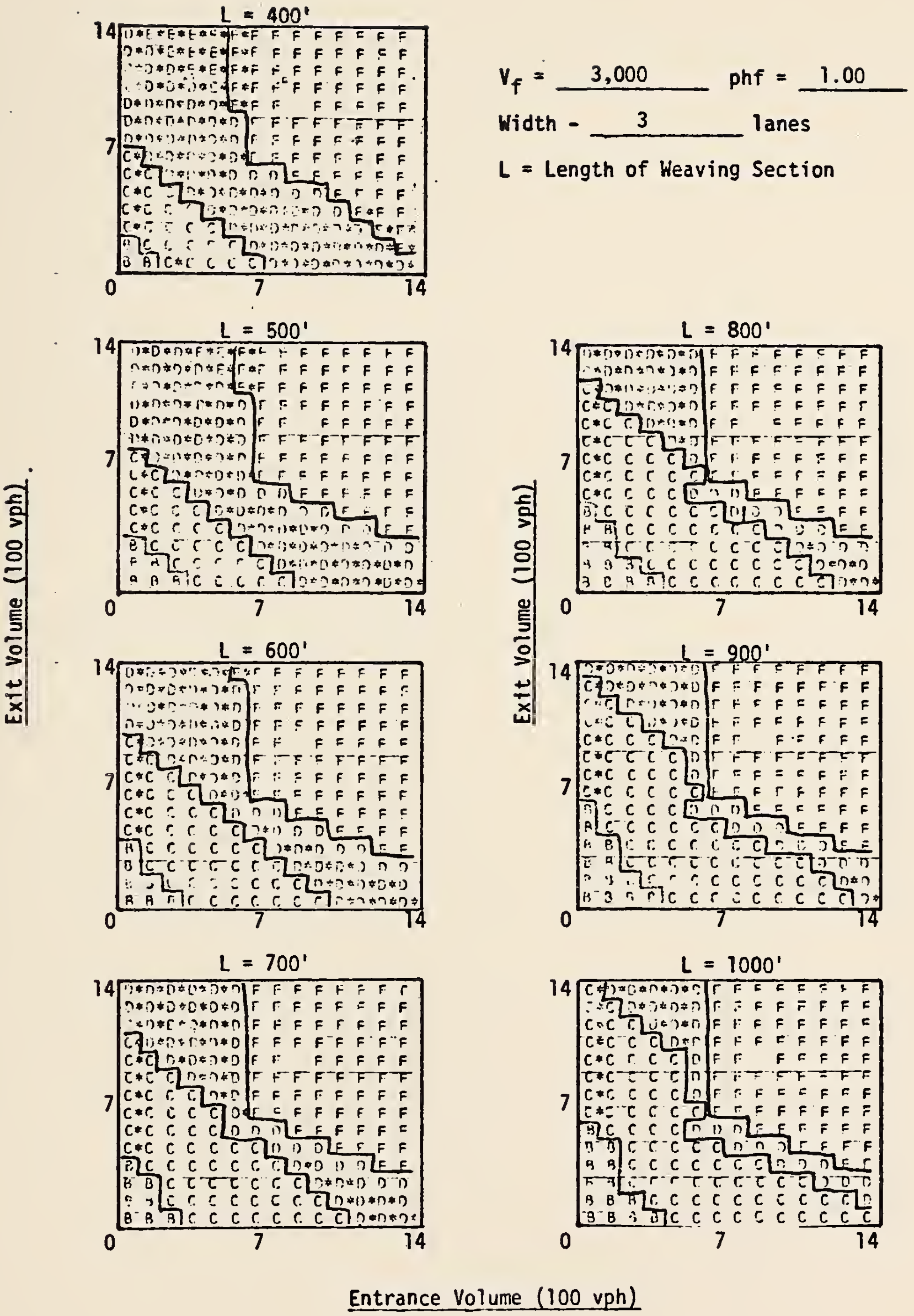

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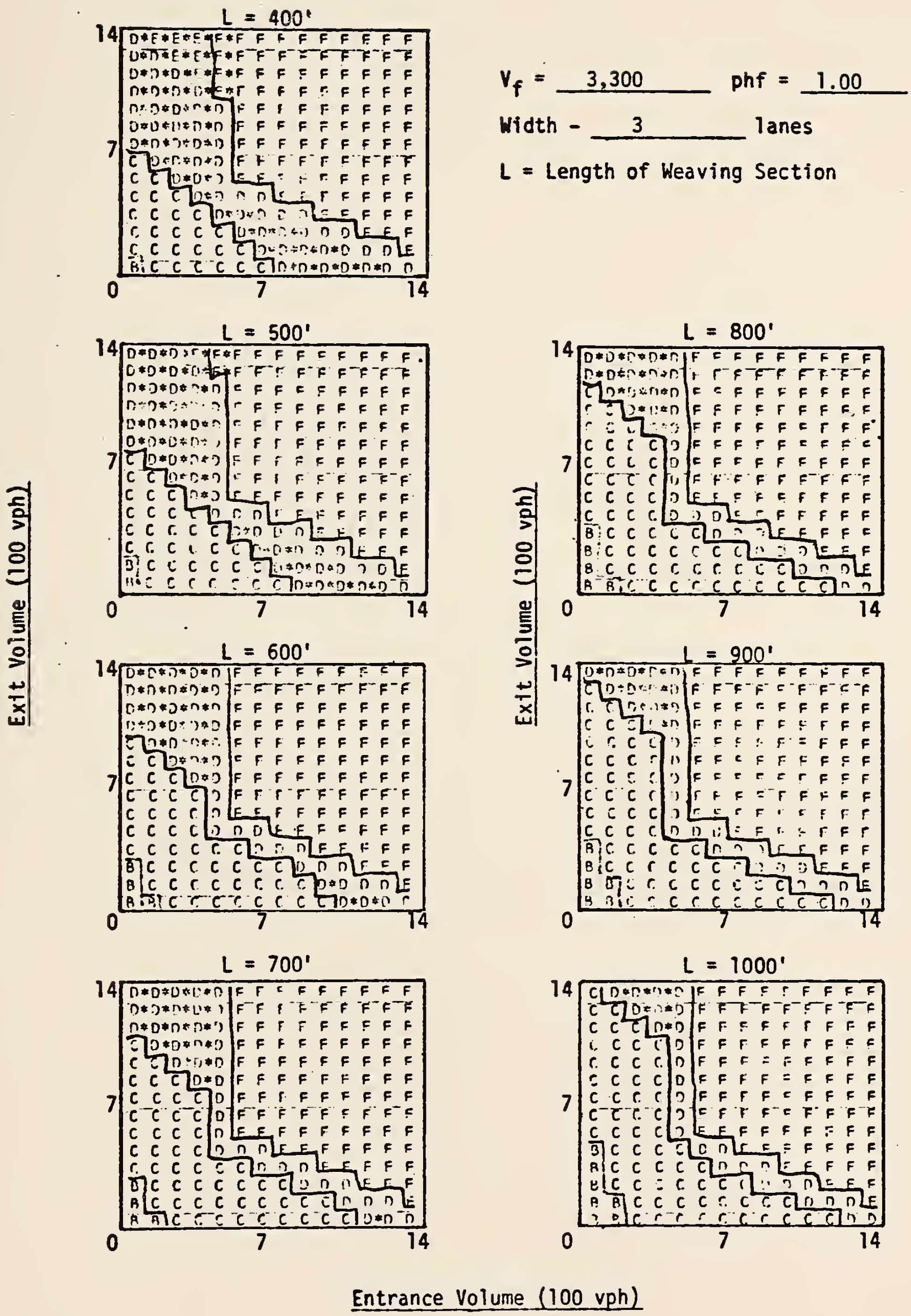

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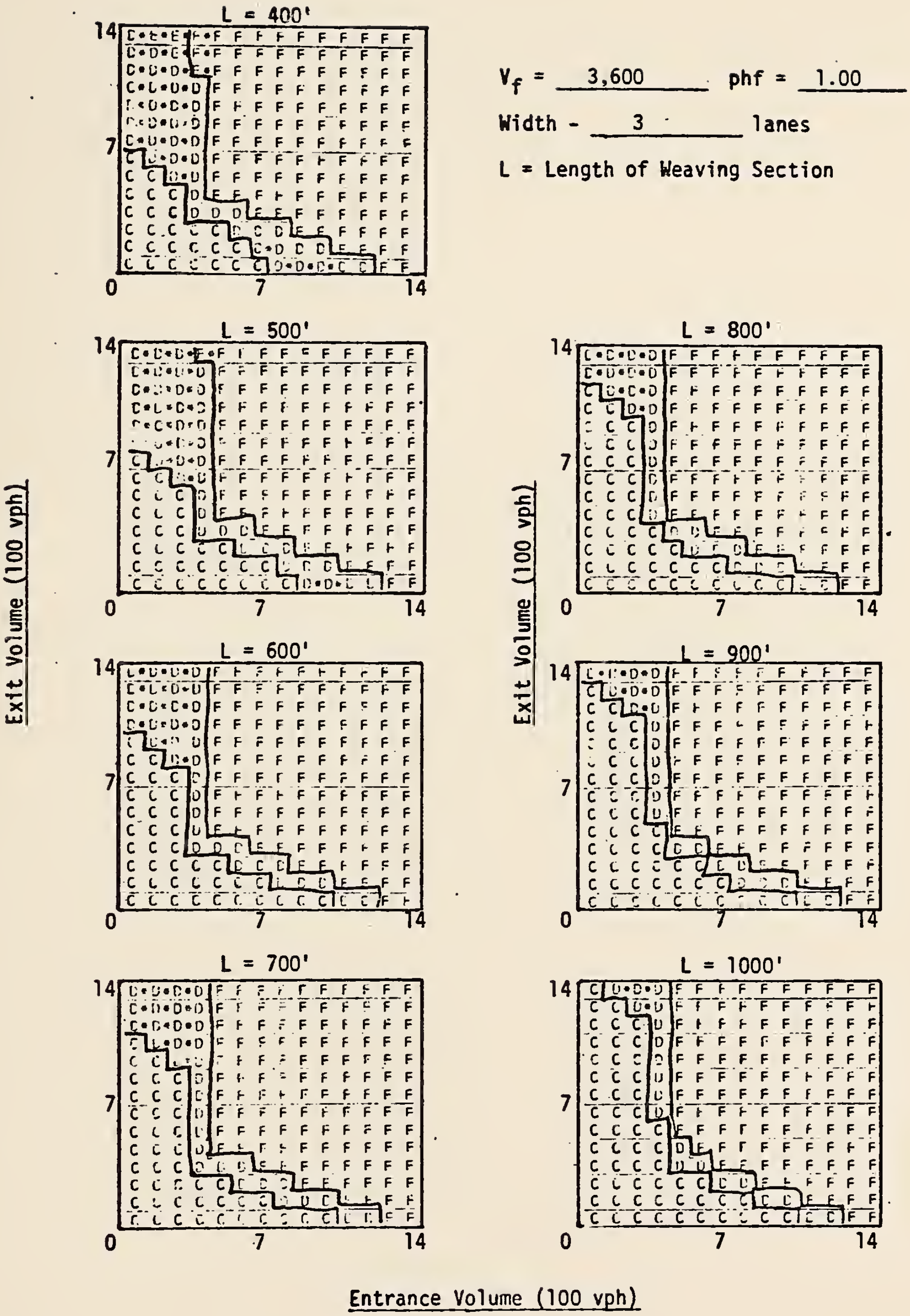

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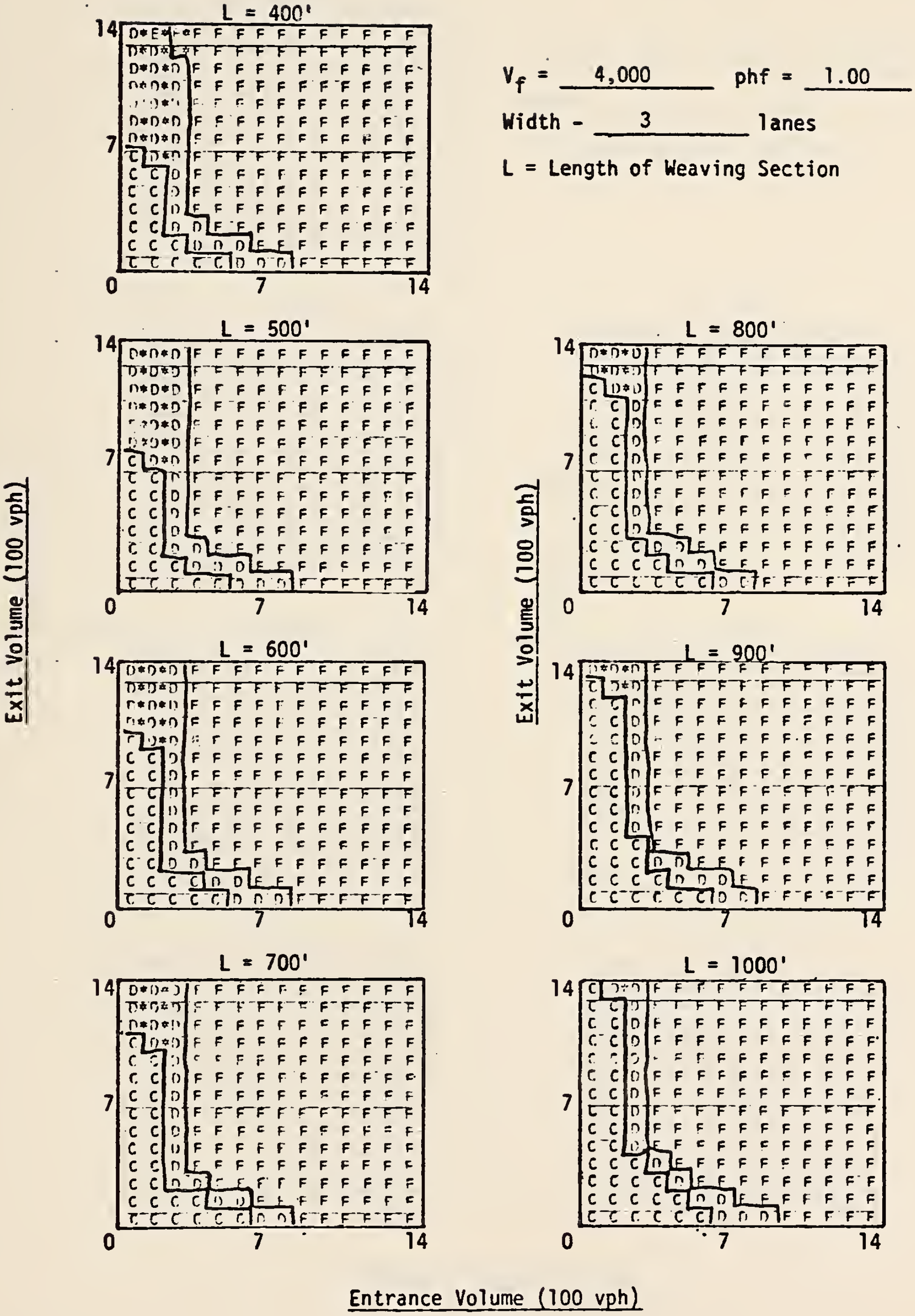

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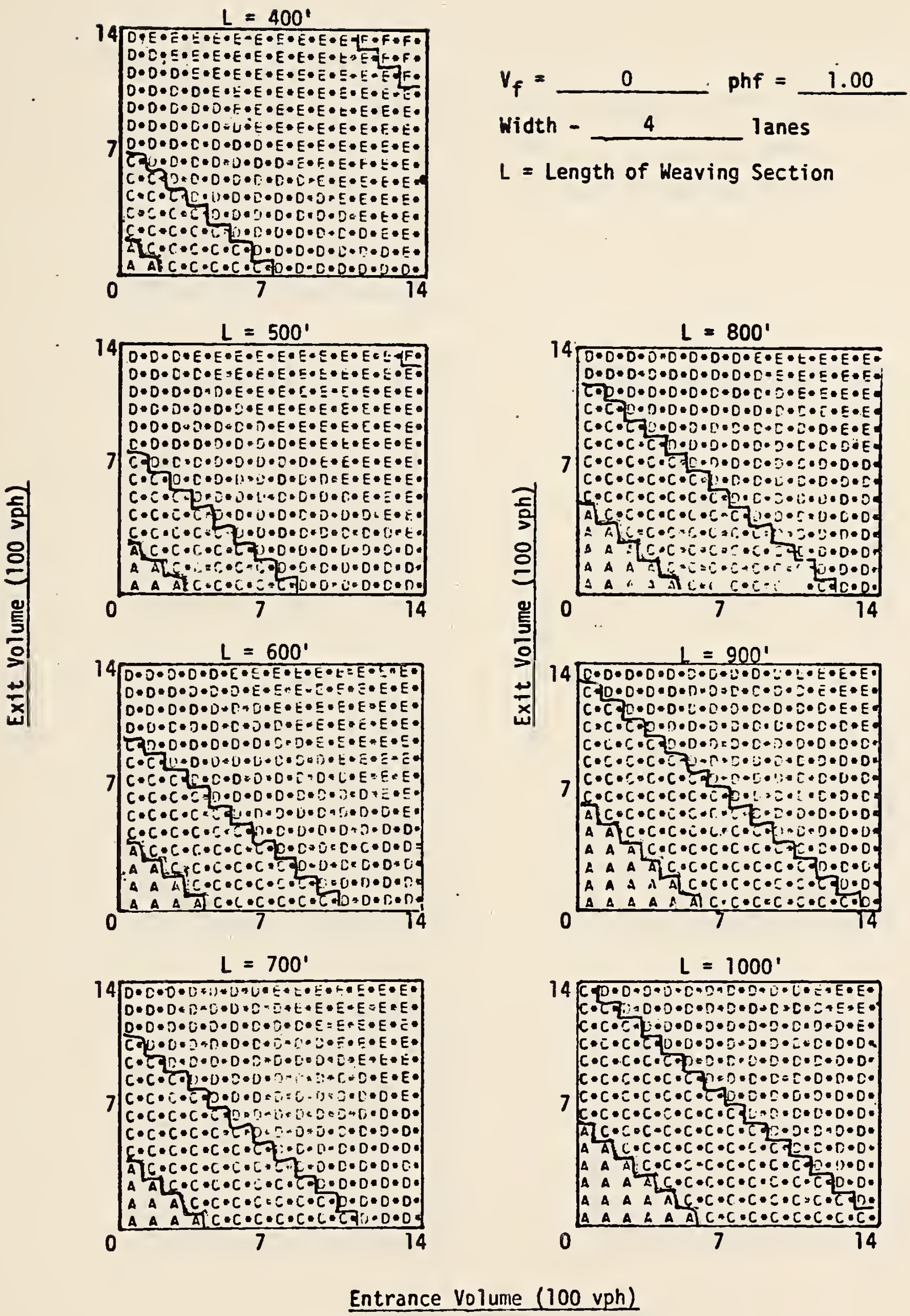

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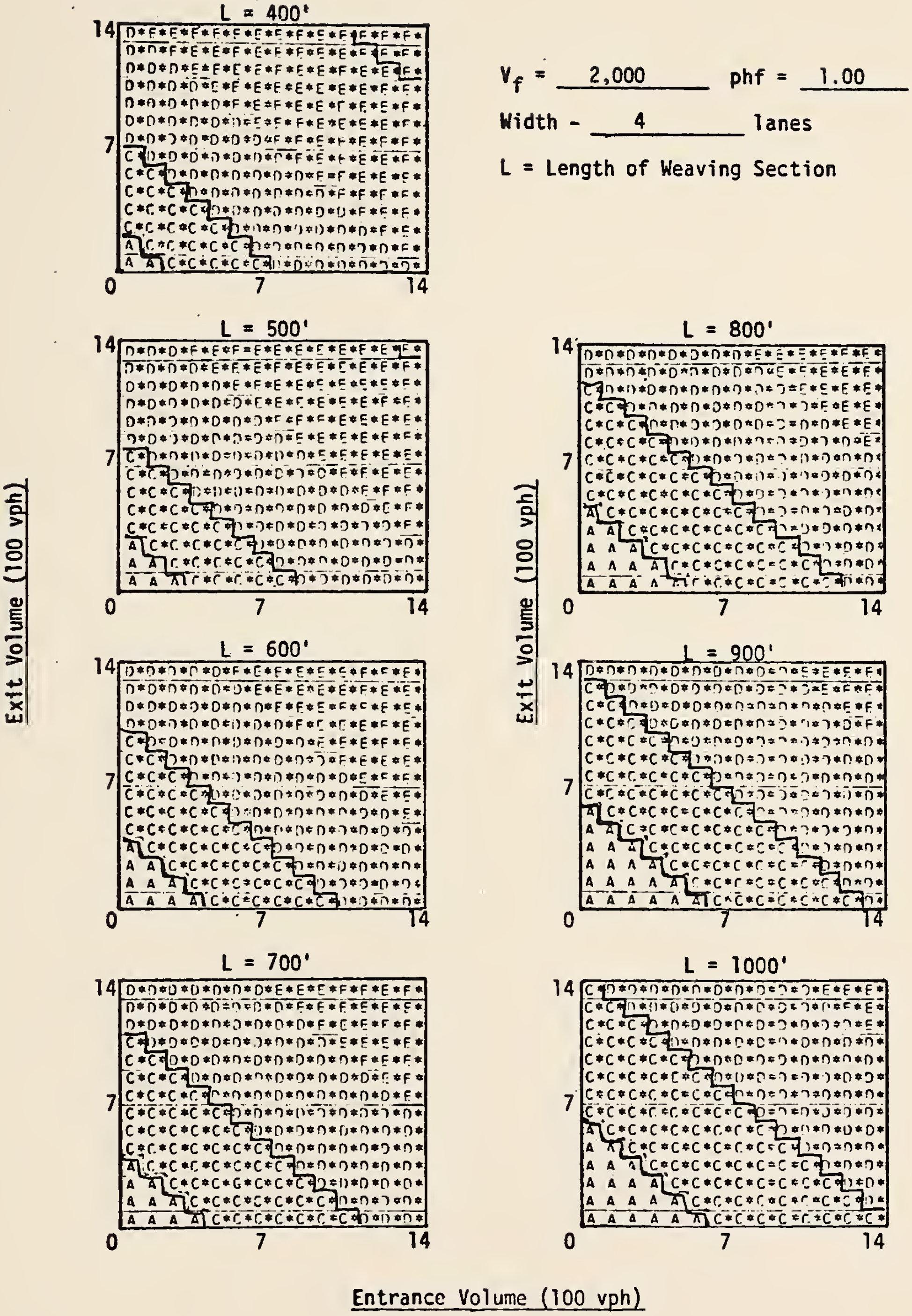

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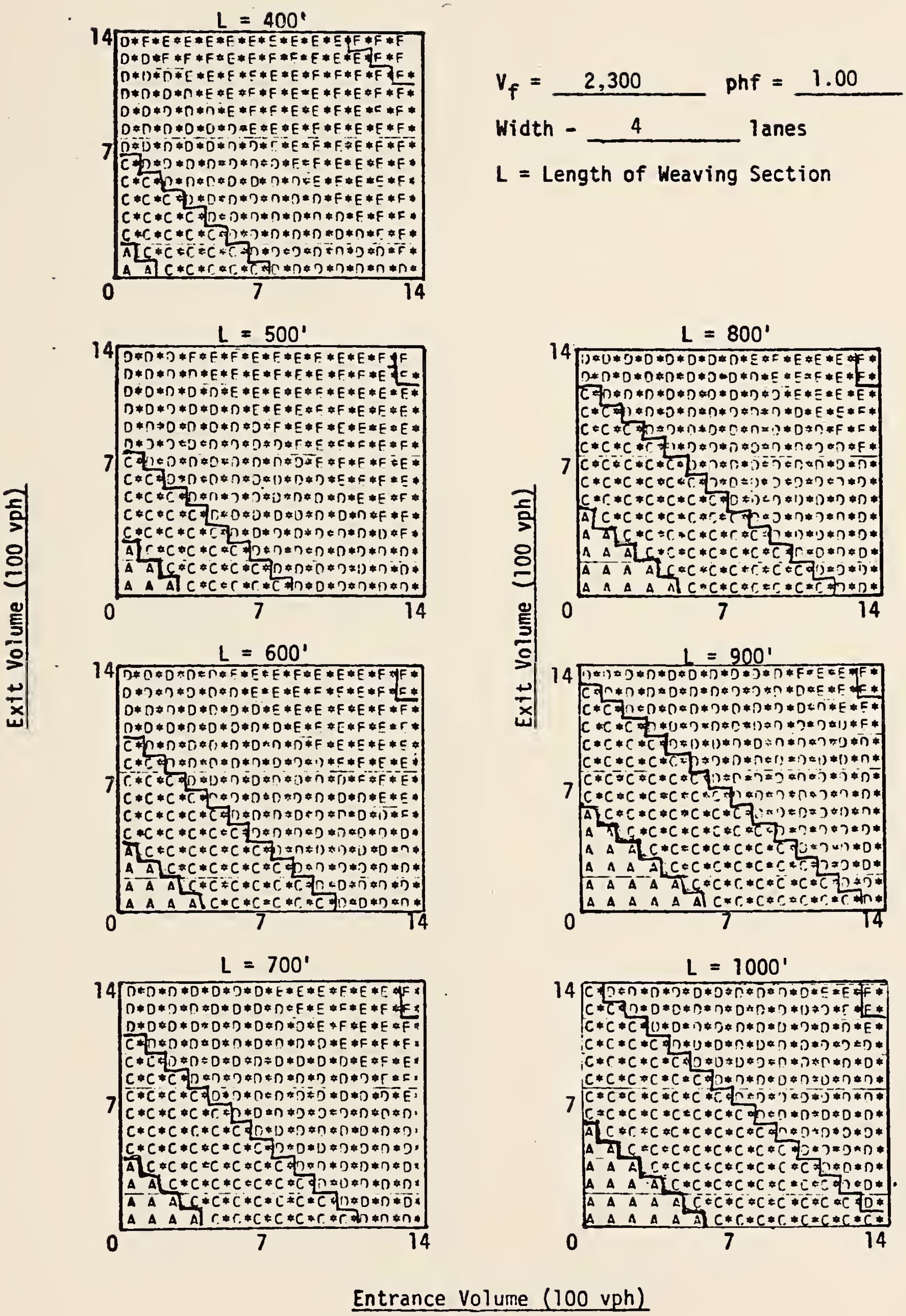

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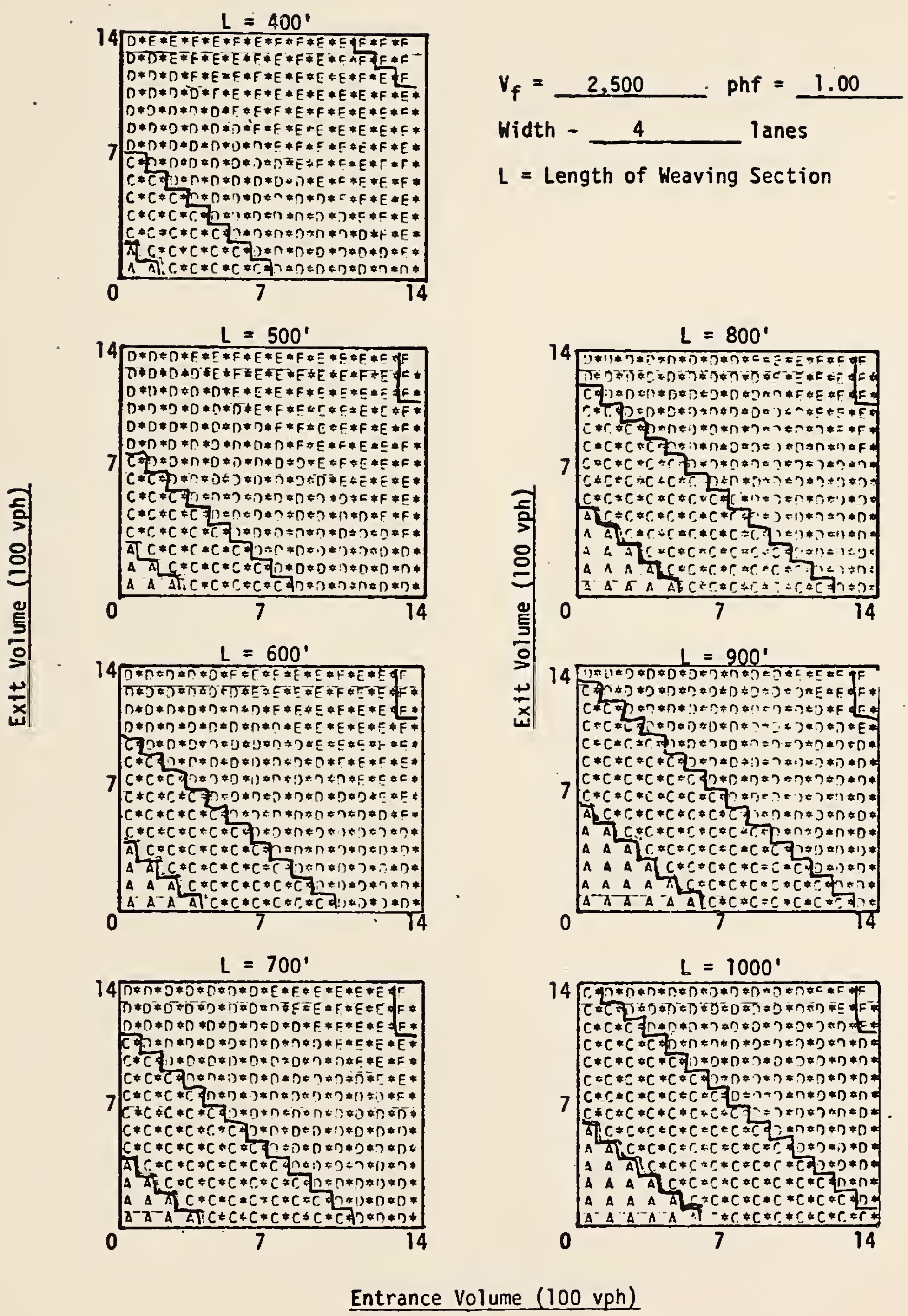

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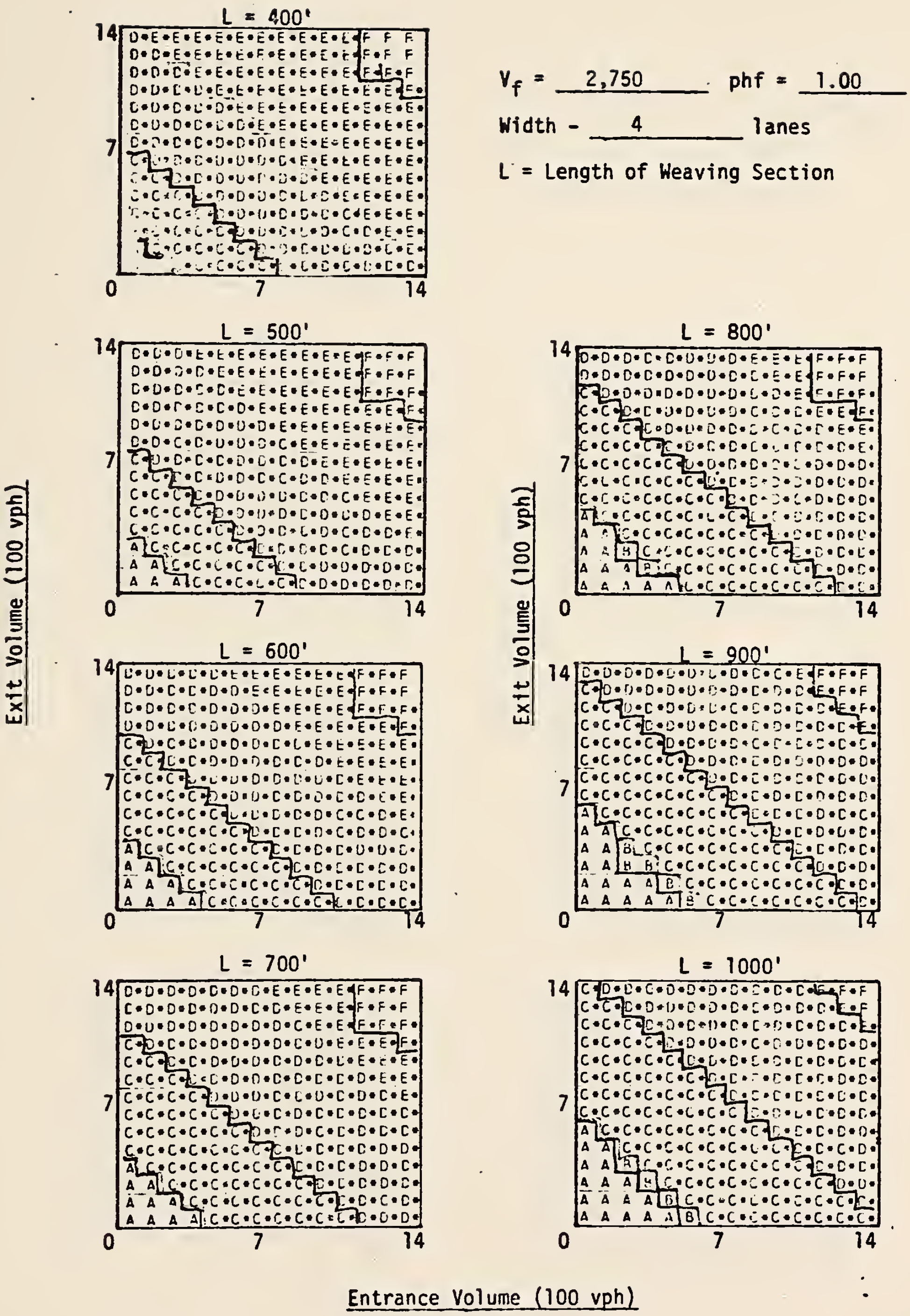

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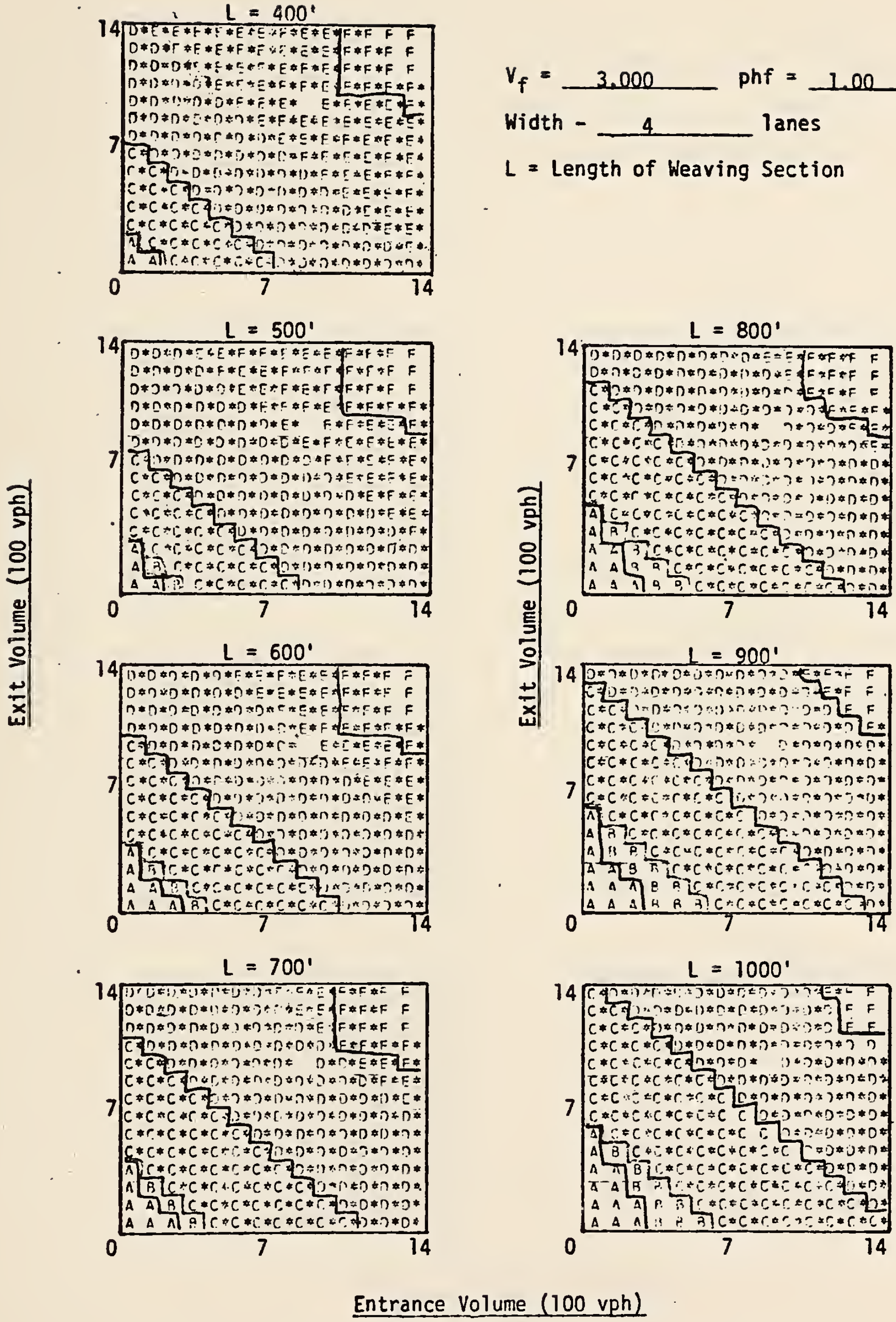

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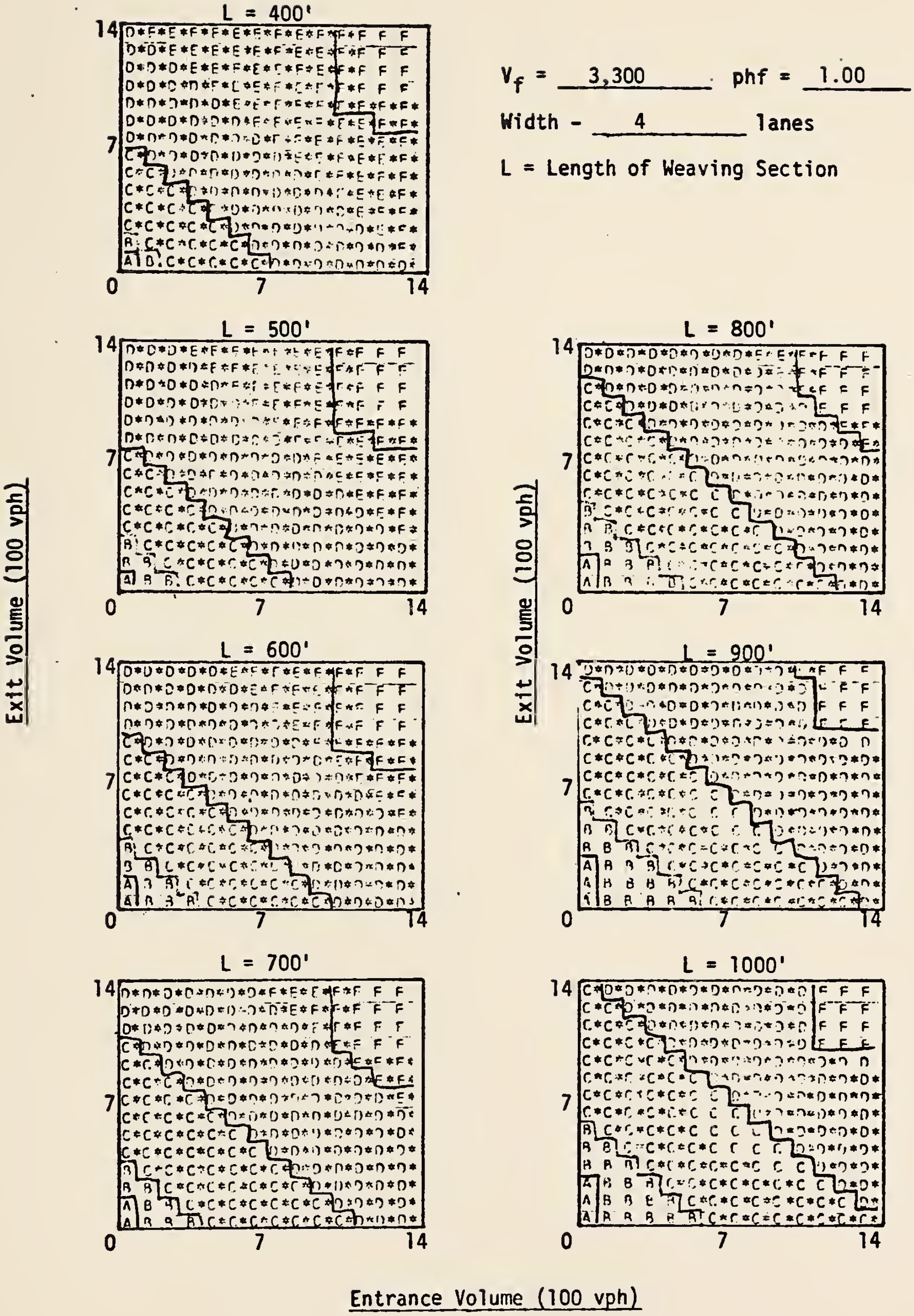

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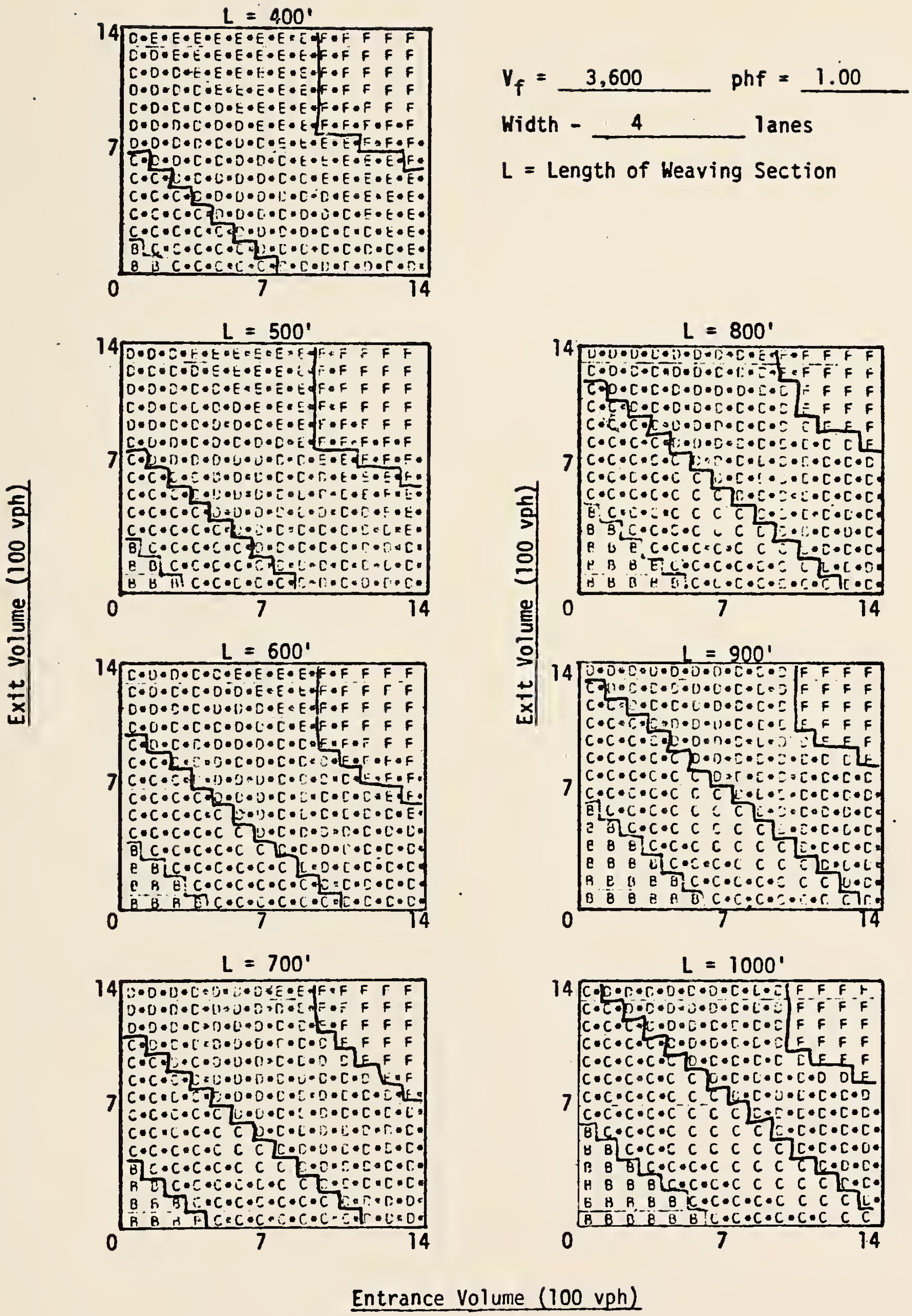

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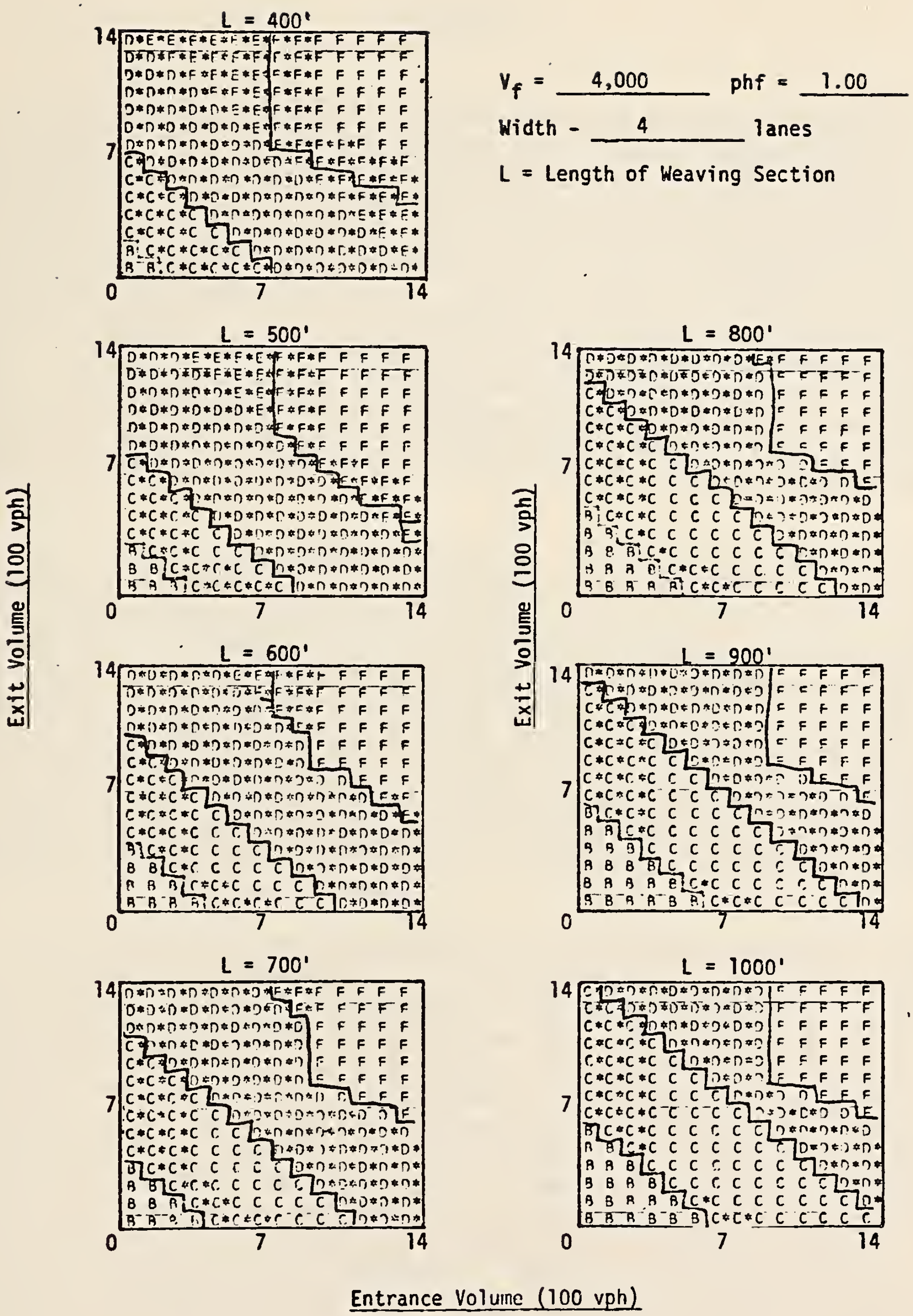

FIGURE 27. Continued

APPENDIX C

The telephone survey of design and/or operations engineers from ten states was conducted to determine the current operating conditions of existing, full cloverleaf interchanges without C-D roadways. These engineers were asked to evaluate the operating conditions qualitatively rather than quantitatively. Much has been written, especially in the accident reporting field, about the hazards of combining or comparing figures generated by two separate systems. It was felt that the same danger existed in conducting the survey if attempts were made to ask for specific values of traffic volumes, accident numbers, etc. Therefore, a survey procedure was needed which would allow each operations engineer or design engineer to describe cloverleaf operations using qualitative terms and concluding with an assessment of "what's wrong" with those cloverleafs that are not performing satisfactorily.

To fulfill these needs, the "elite" interviewing technique was selected rather than the "standardized" interviewing procedure. Interviews rather than questionnaires were used in order to insure getting the opinion of "experts" (i.e., engineers with years of experience and currently in policy-making positions) and to minimize the survey time period. The elite interviewing technique permits the person being interviewed to define the cloverleaf performance as he perceives it, whereas the standardized, poll-type survey is normally generated using a strict definition of the subject matter and the survey itself is merely being used to verify or dispute certain hypotheses. Since the main purpose was to determine if any problems existed, the elite interview technique was selected.

The survey involved ten states and consisted of telephone interviews with traffic operations personnel and/or design personnel from each of these states. The engineer responsible for traffic operations was normally interviewed first in order to determine if any or all cloverleaf interchanges were operating in an intolerable fashion. In the event that they were, the engineer's assessment of the nature of the problem, the proposed solution and perceived urgency to apply the improvement were obtained. In this manner, the priority of solving that type of problem was obtained. In the event that some improvement was planned or had already been accomplished, the engineer in charge of the design policy was interviewed in order to obtain a general description of the geometrics used in that state and to obtain a general understanding of their design policy. In order to give each engineer involved ample opportunity to collect his thoughts prior to being interviewed, a message was left with his office that project personnel would contact them in one or two days to "discuss the operation of full cloverleafs without C-D roadways" in their state.

Illinois

Mr. Robert E. Craven, Engineer of Traffic Operations, indicated that the Department of Transportation operated at least fifty (50) full cloverleaf interchanges, most of which are located in suburban to rural areas. He indicated that the majority of the interchanges are operating in a satisfactory manner. Some of the older cloverleafs are presenting some safety problems in that the tight geometrics resulting in tight loop ramps has led to the occurrence of loop ramp accidents. However, the geometrics have not resulted in sufficient disruption of flow in the area of the weave section to be classified as a problem. The only changes that have been made to existing cloverleafs have been to increase the super evaluation and lateral pavement skid resistance of the loop ramps. Full cloverleafs without C-D roadways are still constructed in Illinois.

New York

Mr. Robert Millspaugh of the Division of Traffic and Safety Engineering indicated that there are 20 to 30 full cloverleafs, mostly in the urban areas of New York City and Long Island. The crossroad is generally four lanes wide, but undivided, and the typical weaving length is 600' to 800'. Mr. Millspaugh indicated that the operation is satisfactory unless the loop on-ramp movement becomes excessive, resulting in the ramp backing up onto the crossroad and causing congestion and accidents. The problem is thought to originate in the weave section (lack of capacity) but no consideration has been or is being given to improving any interchange with this type of operational problem. Interchanges are upgraded if the entire freeway section is being upgraded. It is also the policy to attempt to lengthen short weave section by moving one or more of the loop ramps if the interchange is already scheduled for some other major improvements.

Virginia

Mr. J. P. Mills, Engineer, Bureau of Traffic and Safety, indicated that 17 full cloverleafs and several partial cloverleafs are being operated and that most loop ramps are three or five center curves. These cloverleafs are operating in a satisfactory fashion. Operational problems arise when the volumes reach the design volumes, but the interchanges are not considered a "bottleneck" because the whole freeway has reached that volume level. C-D roadways are added to interchanges when the facility is upgraded from four lanes to six lanes, but are not used on new four-lane facilities. Of course, provisions are made to add them if needed at a later date. Mr. Robert Mannell of the Bureau of Design provided the information about facility upgrading.

Michigan

Mr. Donald Orne, Director of Traffic Operations, indicated that Michigan has 13 full cloverleaf interchanges with eight located in urban areas and almost all are freeway-to-freeway. The typical weaving length is 400' to 600'. Mr. Orne and his staff feel that weaving sections do not operate that well, even with a C-D roadway and moderate volumes. Their opinions are based on observation. However, no plans are being made to alter any of the existing interchanges. New interchanges that under past policy would have been full cloverleaf are now being built as the Parclo A-4 type with signalized ramps in those areas where the crossroad is a heavily developed commercial or industrial area. This type of interchange permits efficient flow on the crossroad while permitting the necessary egress and ingress. In this situation, the flow along the crossroad is considered to be of equal importance to the flow on the mainline.

Massachusetts

Mr. K. Krekorian, Deputy Chief Engineer for Operations, indicated that MDOT operates 20 to 30 cloverleaf interchanges and that the crossroad is usually a divided highway carrying fairly high volumes (which justified the use of the cloverleaf in the first place). The weaving lengths vary from 800' (50 mph design) to 1,200' (70 mph design). Mr. Krekorian felt that the operation was fairly efficient except when volumes become excessive as during the peak period. In this situation, he felt that the problem was the capacity of the weave section and if the congestion were spread over more than just the peak period, then attempts would be made to upgrade to a fully directional interchange to eliminate the weave problem.

Mr. Peter J. Hunt, Highway Design Engineer and Mr. Robert J. McDonough, Deputy Chief Engineer for Highway Engineering, felt that problems also existed on the crossroad when it is not a full access-controlled facility and is in a well-developed area. They felt that the free-flow operation of the terminals leads to accidents on the crossroad. They also felt that they had some accident problems on their loop ramps (180' radius) as the result of vehicles not achieving the proper deceleration. However, no action has been taken to correct any of the deficiencies noted for full cloverleaf interchanges, nor is any planned for the near future.

Pennsylvania

Mr. J. Robert Doughty, Director, Bureau of Traffic Engineering, indicated that Penn DOT operates 20 to 30 cloverleaf interchanges. Mr. Doughty indicated that those interchanges with short weaving lengths and high volumes do cause operational problems, but that they

are not considered to be of significant magnitude to warrant the priority needed to consider them for improvement. Cloverleafs used as freeway-to-freeway connectors are built to higher standards and fewer operational problems are experienced in the weaving section. However, C-D roadways are not used, even with freeway-to-freeway interchanges.

Maryland

Mr. Thomas Hicks, Assistant Chief Engineer for Traffic Safety, indicated they operate approximately 40 full or partial (full in one direction of flow) cloverleaf interchanges, most of which are on the beltway which is either three, four or five lanes wide in each direction. The weave sections range in length from 300' to 600', with the majority being 400' to 500' in length. Almost all loop ramps have YIELD signs at their terminals prior to entering the weave section. Mr. Hicks felt that the operation of the interchange was fair to poor and varied directly with the magnitude of the mainline and weaving volume combination. The capacity of the weave section is inadequate and when the relative speed of the off-movement to the on-movement is high, the off-movement traffic will dominate flow through the weave section even though it may represent as little as 10% of the total flow through the section. This situation results in the on-ramp backing up and causing congestion on the crossroad. Many weave sections have had their width increased by paving the shoulder beside the auxiliary lane. The main purpose was to provide an escape lane for entering traffic (i.e., means of skirting stopped traffic). Additional operational problems have been encountered on cloverleaf interchanges with C-D roadways in that out-of-state traffic (presumably from Pennsylvania where C-D roadways are not used) does not follow the single exit signing since the exit is located so far in advance of the interchange. MDOT is currently considering moving the nose of the exit (loop ramp) and providing an escape taper or a continuous lane all the way to the outer connection ramp. However, no definite action is planned in the near future.

Mr. Irwin Hughes, Assistant Chief Engineer for Design, felt that problems existed at the crossroads where the terminals were designed without acceleration lanes. This causes congestion, resulting in a capacity problem. Stop signs have been placed at terminals like this. Full cloverleafs are still used without C-D roadways unless the turning movements on the loop ramps exceed 800 vph. This policy is based on AASHTO recommendations rather than on past operational experience.

Indiana

Mr. Clinton A. Venable, Chief of the Division of Traffic, indicated that they operate ten to fifteen full cloverleaf interchanges, almost all of which are freeway-to-freeway connections. The weaving lengths are typically 600' to 900' and the ramp design usually employs a 230' radius and requires 25 mph operation. The loop ramps are on center curves with spiral-like curves on each end. Mr. Venable felt the above described geometrics created a short weave section and prevented adequate deceleration. These conditions resulted in congestion and accidents in the weave section and in single vehicle accidents on the loop ramps. He felt that these geometrics and the speed differential between vehicles entering the weave section resulted primarily in accidents at low to medium volume ranges and primarily in congestion rather than accidents at medium to heavy volumes. No reconstruction is planned in an attempt to improve the performance through the weave section. However, one solution was attempted in which lane one was signed with a DROP LANE series in an attempt to remove through traffic from the lane. At first it was successful, then daily users of the interchange began to ignore the signs and conditions returned to their original state. Speed control signing was also tried but was ineffective.

Texas

Mr. R. H. Oliver, Engineer of Traffic, indicated that Texas operates around ten cloverleaf interchanges without C-D roadways, most of which have 400' weaving sections and loop radii ranging from 150' to 225'. He indicated that most have four-lane mainlines carrying between 10,000 and 25,000 ADT and that no problems are being experienced.

Mr. H. D. Cooner, Senior Design Engineer, felt that some problems will be experienced in the weaving section as the volumes increase, but are presently operating in a satisfactory manner. He thought that if the weaving operation deteriorated to the point that some corrective action was necessary, one of three actions would be taken:

1) add C-D roadway if structures permit (which is not too likely on an old interchange but more feasible as an improvement if the freeway goes over the crossroad),
2) attempt to convert to Parclo or Diamond if the crossroad is not a freeway, or
3) if crossroad is a freeway, go to a directional or a 3-level diamond which can ultimately be developed into a 5-level interchange.

Department policy calls for the use of a C-D roadway on all freeways within cloverleaf interchanges but not lower type roadways.

California

Mr. Parker Hall, Assistant Engineer of Planning and Design, indicated that very few cloverleafs without C-D roadways are still in operation in California (most have been altered) although some are still being built in the rural areas. It was their experience that weaving volumes of 1,800 vph caused problems on the mainline. At lesser volumes, speed differential would occasionally cause an on-ramp backup resulting in ramp/crossroad problems. Also, the free-flow operation of the ramp terminals on the crossroad would cause problems on those local crossroads that permitted left-turns, ingress/egress from the crossroad near the interchange, and signalization. The last type of problem encountered with cloverleafs was the lack of success in signing the double exit. Generally speaking, high numbers of accidents rather than peak-hour congestion was the reason for instituting an improvement even though the congestion led to the occurrence of the accidents.

Mr. Hall indicated that if a cloverleaf is a freeway-to-freeway connector and is experiencing problems (almost always will be capacity in the weaving section), then the solution will be to convert it to a partial or full directional interchange. If the funding is not available, then the next choice would be to add a C-D roadway. If the funding is not available for that improvement, then the last possible alteration would be to pave the shoulder outside the auxiliary lane, move the exit nose laterally to provide additional acceleration distance and pave the mainline shoulder prior to the weaving section to provide additional deceleration distance. This type of improvement, shown in Figure 27, is similar to adding a C-D roadway in many respects but involves less cost. This improvement has been tried several times in California and is considered to be of help in relieving congestion (determined through observation, no other data available). This type of improvement is fairly easy to accomplish (assuming sufficient width exists on weaving section) because of the California policy of using short weaving lengths in order to add deceleration distance past the exit gore but prior to the beginning of the loop ramp (150° radius) because they assume that the majority of drivers slow down after the weaving section rather than prior to it.

The only solution they try to implement when the interchange problem is on the crossroad rather than on the mainline weaving section is to convert the interchange to a Parclo A-4 with continuous right turns <u>from</u> the crossroad but not <u>to</u> the crossroad. This solution is highly desirable because it eliminates the weave on the mainline and it eliminates the free-flow entrances to the crossroad which is too congested to handle it. No data is available to document the degree of effectiveness of this improvement.

FHWA

R&D