California Freeway Capacity Study—1956

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During the present stage of development of the freeway system in California, some extremely high daily volumes are being experienced. One intersection of two freeways handles 319,000 vehicles per day. Despite high volumes, operation is normal at most places on the system; speeds are high and accident rates are low. Except for about two hours a day, it is possible to average 50 mph for about 28 miles right through the heart of the City of Los Angeles.

Eighty-three peak-hour observations of operating characteristics were made at 50 locations on 4-, 6-, and 8-lane urban freeways. The observations at each location consisted of recording traffic counts and speeds by 5-minute intervals in each lane. Traffic was classified by type of vehicle and descriptive notes on flow characteristics were made. This report contains tables of whole-hour volumes and speeds by lane for each of these observations, and 37 graphs showing speed-volume relationships and distribution of traffic by lanes under various geometric conditions.

• AS OF SEPTEMBER 1, 1956, the California State Highway System included 283 miles of full freeway open to public travel. These were classified as follows:

		Average Daily Traffic		
	Miles	At Highest Location	At Lowest Location	Average, All Mileage
Four-Lane	189	68,800	4,900	23,000
Six-Lane	79	140,000	12,400	60,500
Eight-Lane	15	180,000	31,900	108,000

On the whole, these freeways operate just as expected: speeds are fairly high and accident rates are low. There are a number of places, however, where possible capacity has been reached during peak hours and operating conditions are not satisfactory during those hours. Despite this congestion during peak hours, it is possible, during about 22 hours a day, to drive 28 miles in either direction right through the heart of the City of Los Angeles and several other contiguous communities in about 34 minutes. During the congested periods, travel time on the freeways is still about 20 percent less than on parallel surface routes.

The periods of very high volume offer an opportunity for studying traffic capacity and other characteristics. Because this information is of utmost importance in new freeway design, a study of high-volume locations in the freeway system was made in the summers of 1955 and 1956. This report supersedes the progress report (Freeway Capacity Study, 1955) issued in April 1956, and includes all of the data published in that report.

The field work basically consisted of counting and classifying traffic by type of vehicle in 5-minute intervals and in each lane; measuring and recording speeds; and keeping a descriptive record of the type of operation (that is, free-flowing, smooth but crowded, or congested). Motion pictures also were made for the purpose of illustrating the type of flow experienced at various volume levels and as affected by design features.

Although the studies made so far are

fairly comprehensive, it has not been possible to infer universal relationships between the many variables involved in traffic flow. That is, an instance can be cited where possible capacity has been reached at a given point where one grade, one number of lanes, one proportion of trucks, and one merging condition prevailed, and other instances can be cited where different values of each of these variables prevailed, but not enough different combinations were observed to determine quantitatively the relationship between the variables. In this connection, however, observations reported here were made at most of the points in the Los Angles and San Francisco freeway systems where volumes are critical, and the lack of comprehensive generalizations is due to a lack of observable situations as much as to a lack of observation.

Figures 1, 2, and 3 are aerial views of

Figure 1. Hollywood Freeway looking southerly with the four-level traffic interchange in the foreground. Location 15 is at the merge in the foreground, Location 26 is at the merge of traffic going away in the center right, Location 37 is just past the second overcrossing in the center of the picture. This intersection handles 319,000 vehicles per day (25,500 in the peak hour, with 6,700 making left turns).

Figure 2. Hollywood Freeway looking southerly toward Los Angeles Civic Center. Alvarado SB on-ramp (Location 18) just north of Bonnie Brae Street Bridge in foreground. Belmont Avenue pedestrian separation in center and Edgeware Street Bridge (Location 11) in background. This section is considered a typical 8-lane freeway with respect to geometric conditions affecting traffic operation.

three sections of the Hollywood Freeway showing some of the locations studied. This freeway is through a heavily-developed metropolitan area; however, the alignment is good (minimum curve radius 1,800 feet). Average spacing between access points is approximately ½ mile throughout the 7-mile length.

NOMENCLATURE

The following definitions and nomen-

Figure 3. Hollywood Freeway looking northerly (outbound) through the Cahuenga Pass. Highland NB on-ramp (Location 22) in center. Mulholland Bridge (Location 13) in background. The 3-lane section (one-way) inbound (center, Location 14 and lower right, Location 47) carries a peak hour of 6,600 vehicles.

clature are used throughout this report.

Capacity — The definitions used in the "Highway Capacity Manual" (*1*) are adhered to, and are repeated as follows:

Basic capacity — The maximum number of *passenger cars* that can pass a given point on a lane or roadway during one hour under the most nearly ideal roadway and traffic conditions possibly obtainable.

Possible capacity — The maximum number of *vehicles* that can pass a given point on a lane or roadway during one hour, under the prevailing roadway and traffic conditions.

Practical capacity — The maximum number of *vehicles* that can pass a given point on a roadway or in a designated lane during one hour without the traffic density being so great as to cause unreasonable delay, hazard, or restriction to the drivers' freedom to maneuver under the prevailing roadway and traffic conditions.

Volume — The number of vehicles that pass a given point on a lane or roadway during a specified time interval.

Stream — The total traffic flow in all lanes of one roadway.

Rate-of-flow — The volume during a time interval divided by the length of the time interval.

Average speed — The sum of the speeds of specified vehicles divided by the number of vehicles (*not* the sum of distances divided by sum of times).

Congestion — Non-acceptable operation, characterized by stop-and-go driving and small or large queues of standing vehicles.

Roadway — In this study, which is concerned wholly with divided highways, a roadway is the one-way traveled way on one side of the median.

Shoulder — The area next to the traveled way on the righthand side of the driver.

Median — The portion of a divided highway separating the traveled ways for traffic in opposite directions.

Lane — The roadway area, of uniform width, designated by stripes or edge of pavement, used for one file of vehicles. A vehicle crossing a lane stripe is supposed to yield to any vehicle in the lane being entered. Among experienced drivers, this yielding is generally accomplished by being certain to go faster than the next following vehicle in the lane being entered. Lanes are designated as follows:

Shoulder lane — The lane next to the shoulder.

Lane 1 or L_1 — The shoulder lane; that is, the right-hand lane of the roadway.

Lane 2 or L_2 — The second lane from the right-hand edge of the roadway.

Lane 3 or L_3 — The third lane from the right-hand edge of the roadway.

Lane 4 or L_4 — The fourth lane from the right-hand edge of the roadway.

Median lane — The lane next to the median.

Ramp

On-ramp — An entrance to the freeway; a merging lane.

Off-ramp — An exit from the freeway; a diverging lane.

Ramp designation — Two-lane ramps are shown as Ramp 1 and Ramp 2, or R_1 and R_2. Ramp 2 is usually adjacent to freeway lane 1.

Merging area — (a) The portion of a merging lane or on-ramp that is flush with the through roadway so that vehicles may move laterally into lane 1; (b) An area in which two lanes are merged into one by means of converging stripes, other delineation, or both.

COLLECTION OF DATA

Field Procedure

Data were collected by counting and classifying traffic and recording speeds at various freeway locations. Either three or four men were used at each location, depending on the number of lanes to be counted. One man never counted more than three lanes of traffic. The usual procedure was as follows:

1. One man would record on a special form the stopwatch time taken by vehicles to travel a specific distance. The speed traps were usually around 150 feet in length. Where convenient, cracks or joints in the pavement would be used as ends of the speed trap. Where no lines on the pavement were available, a bow-

string mounted on a universal joint was used to superimpose a sight line on the freeway perpendicular to its centerline. This line was used as the far end of the trap and any convenient object or point near the observer was used as the other end of the trap. Times were read to the nearest 0.05 sec (a 10-sec face stopwatch was used).

When counts were made at ramps or merging areas an attempt was made to have the speed trap begin at the nose. To make speed observations as random as possible, the timer was instructed to record by lane; that is, time a vehicle in lane 1, then in lane 2, etc. Time was measured for any vehicle that happened to be at the trap when the timer was ready. Timing would go on throughout the counting period. Between 20 and 40 speed observations could be made during a 5-min period, depending on traffic flow.

The average speed for a 5-min period was determined by dividing the length of the speed trap by the average time lapse. Although this is different from the average speed as previously defined, the difference is considered insignificant because of the small range in any 5-min period, and the calculations were greatly simplified.

2. One man would tally trucks by lane and number of axles on a special form devised for this purpose.

3. A third and fourth man would count total traffic by lane. When counts were made at ramps the counts were made at the nose. These data were shown on a special form which was also used for the office summary of the data on the other two forms.

Counting by Sample

For reasons explained later, traffic counts were recorded by 5-min periods. There was a break (usually 3 min) of non-counting between counted periods, these breaks being utilized for recording the counts. The breaks served two other purposes in that (a) simultaneous counts for each lane for exact time periods could be recorded, a nearly impossible task if the individual counters were run continuously, unless photographic methods were used, and (b) the alertness of the observers was preserved and fatigue and rhythmic errors were avoided. In figuring hourly volumes, the rate-of-flow during each break was assumed to be the average of the rates for the two adjacent counted periods.

A test was made to compare results obtained by this method and by continuous counting, and the difference was found to be negligible. On the Hollywood Freeway at the Highland Undercrossing, inbound (3 lanes), in addition to the sampling counts, two full-hour counts were made, with the following results:

	7:02-8:02 3 Lanes	8:07-9:07 3 Lanes
Full-hour count	6,048	6,512
Lane 1	1,819	2,025
Lane 2	2,119	2,234
Lane 3	2,110	2,253
Hour count based on 5-min counting and 3-min not counting, and for the missing period using the average of the two adjacent counted periods	6,168	6,481
Lane 1	1,907	2,007
Lane 2	2,191	2,223
Lane 3	2,070	2,251
Error	+120	−31
Percent error	2.0	0.5

Traffic flow during the period 8:07-9:07 was extremely smooth, although the rate-of-flow by 5-min intervals did fluctuate from a low of 5,450 per hour to a high of 6,876.

Another test of this counting method was made at the junction of the North Sacramento and Elvas Freeways (4 lanes one-way into 2 lanes), where volumes are considerably lower. The results were as follows:

	Elvas, 2 Lanes One Way	N. Sacto., 2 Lanes One Way	Total, 2 Lanes One Way
Full-hour count, 3:13 to 4:14 PM	512	756	1268
Estimated hour count	528	716	1244
Error	+16	−40	−24
Percent error	3.1	5.2	2.0

All subsequent hour counts mentioned are based on the foregoing sampling method (about 65 percent of the actual hour is counted).

RELATIONSHIP OF 5-MIN TO 1-HOUR COUNT

Early in the study it became apparent

that full-hour counts could not be used in determining operating characteristics (such as speed-volume relationships with other variables remaining constant). This is because there is considerable variability in geometric or other conditions between various locations, but there is no variability in peak-hour volume at a given location.

At many locations, the greater part of the peak-hour would be free-flowing, but congestion or stop-and-go operation would occur during part of the hour. Although counts of this type of operation could be useful in determining the possible volume per hour, the whole-hour count could not be used to determine acceptable volumes. However, a great deal was learned about various rates-of-flow during the portions of the hour that were not congested.

It is also impossible to determine practical capacity by counting the last free-flowing hour preceding the peak congestion, because an off-peak hour (when flow is smooth) on a freeway that is overcrowded in the peak hour does not have the same momentary fluctuations in rate as the peak hour. That an off-peak hour does not have the same characteristics as a peak hour can be illustrated as follows: Figure 4(a) is typical of the traffic on an overcrowded freeway where the off-peak-hour volume is 3,300 vehicles. Figure 4(b) is typical of a traffic demand where the peak hour volume is 3,300 vehicles but capacity is adequate. Note that the volume for this whole hour is the same as the off-peak on the overcrowded freeway. In the off-peak hour of 3,300 vehicles, the peak 5-min period was 12.5 percent of the hourly volume; but in the peak hour of 3,300 vehicles, the peak 5-min period was only 9.4 percent of the hourly volume. In other words, an off-peak hour will have short periods of greater congestion than would a peak hour of the same volume. This hypothetical example illustrates the dangers in using whole-hour counts in off-peak hours to determine "practical" capacity.

In view of the preceding, it was decided to use short counts (5 min) in developing freeway operating characteristics. The use of 5-min counts in deter-

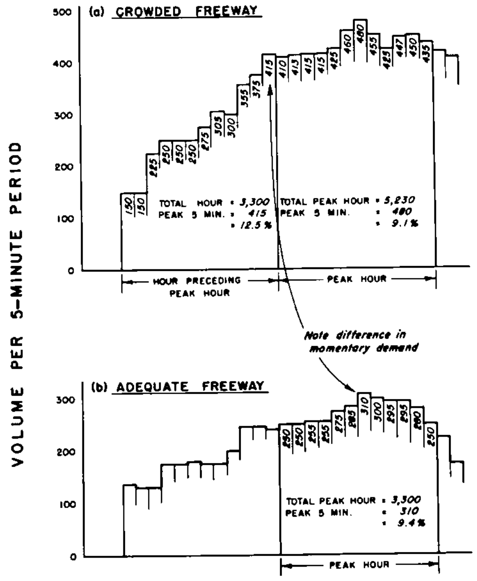


Figure 4. Pattern of freeway volumes.

mining practical capacities and the relationship of a 5-min rate-of-flow to an hourly volume are developed later, as are this method and its use.

To relate acceptable rates-of-flow computed on a 5-min base to hourly volumes, it is necessary to know what proportion of a peak hour will, or could, occur during the highest 5-min period. The main difficulty in finding an answer to this problem is in finding locations where metering by the capacity of the facility is at a minimum.

It is assumed that there will always be metering of the traffic flow through the surface street system. It is also reasonable to expect that there will be more metering, or leveling out of short-term fluctuations in demand, in large communities than in smaller ones. This could be caused by the greater number of traffic sources and the greater spread in approach distances, as well as by the capacity of the surface streets. Indications, as developed later, are that this assumption is valid.

The maximum and minimum 5-min volumes in terms of percentage of the total hour are shown for various locations in Figure 5. These are shown for

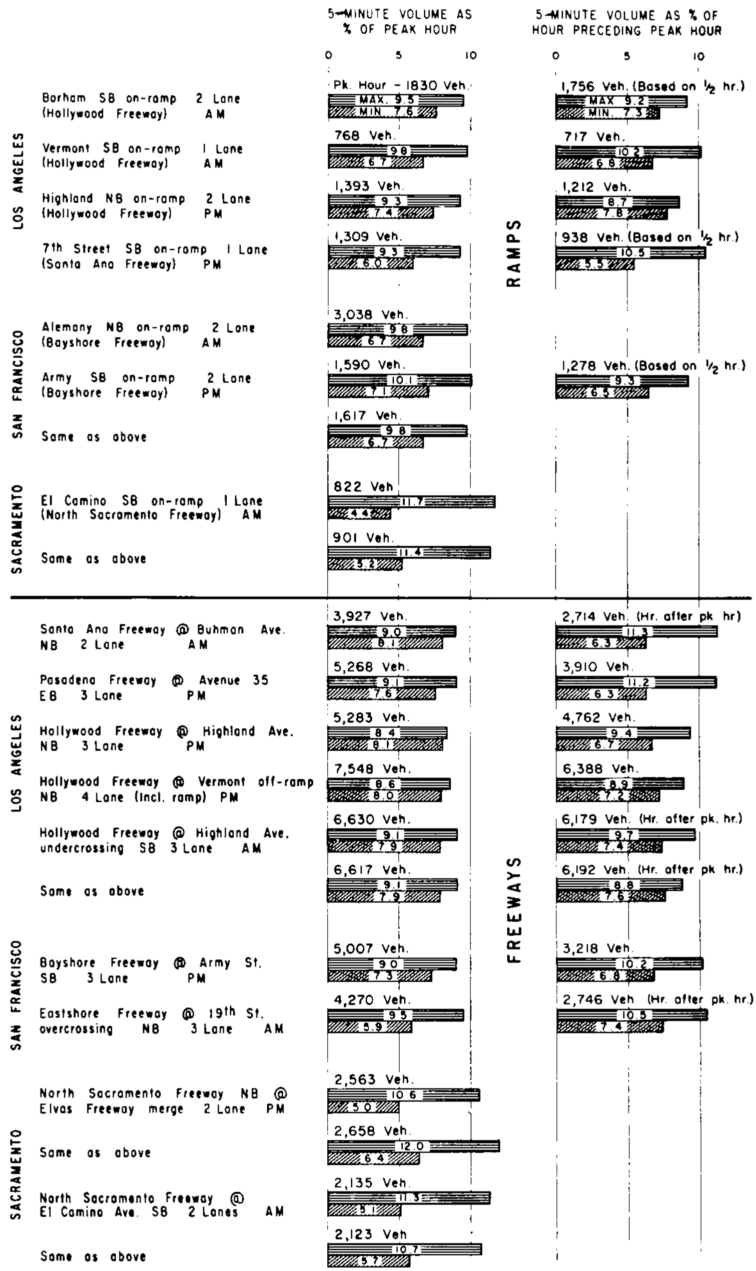


Figure 5. 5-min volumes as percentages of total hour volume.

the peak hours and also for a period before or after the peak hour when available. Figure 6 shows the variability of 5-min counts during a full hour at a typical ramp.

The metering effect at the particular

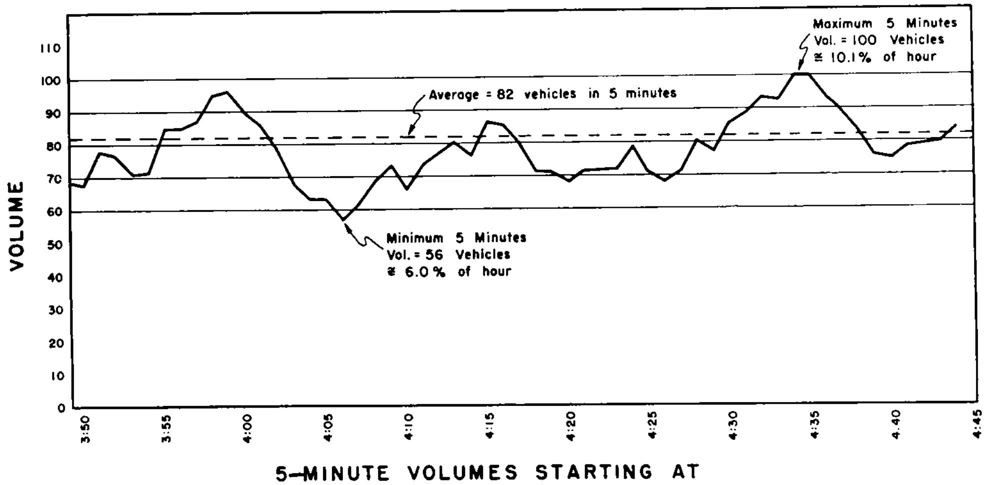


Figure 6. Vermont off-ramp hour count; total hour volume, 985 vehicles.

ramps shown in Figure 5 is negligible, as the freeways could usually handle anything the ramps supplied. The upper section of Figure 5 shows that during the peak hour the peak 5-min volumes on ramps are about 9.5 percent of the hour volume in Los Angeles, about 10 percent of the hour volume in San Francisco, and about 11.3 percent in Sacramento.

The 5-min volume as a proportion of the hourly volume cannot be greater on the freeway than on the ramps; on the contrary, it would be natural to assume that it would be less, because of the damping effect of many ramps. The lower part of Figure 5 shows this to be true. In Los Angeles, the 5-min percentage of the peak hour on the freeway is about 9.1 percent, in San Francisco it is about 9.5 percent, and in Sacramento about 11 percent.

Figure 7 is similar to Figure 5 for some locations on an expressway in Boston, Mass. These data are reproduced through the courtesy of Bruce Campbell and Associates, Boston, Mass., and their clients, the Commonwealth of Massachusetts Metropolitan District Commission.

During the lower volume periods, the spread between the maximum and minimum increases somewhat. The chart also shows that, for the Hollywood Free-

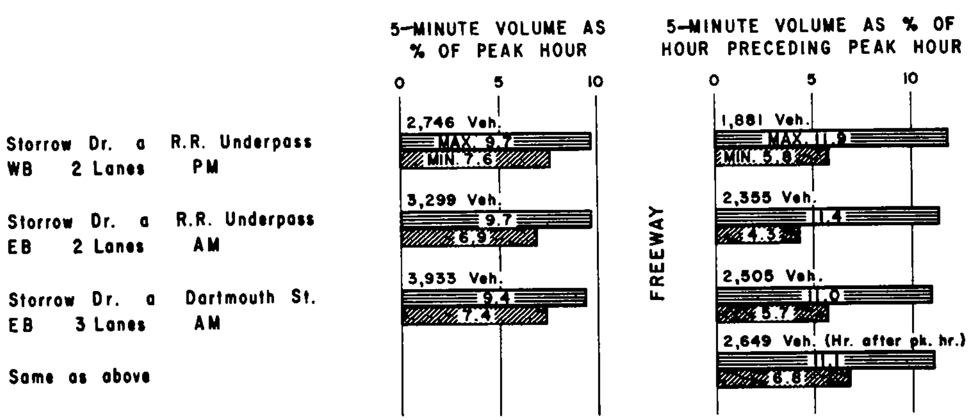


Figure 7. 5-min volumes as percentages of total hour volume on Storrow Drive, Boston, Mass.

way especially, the peak period is carried over more than an hour. In San Francisco traffic volume appears to drop off (or build up, as the case may be) much faster.

Complete information is not available for very small cities where the peaks possibly come from one large source at one time. Some information is available for Oceanside, where there are two cases of interest. There is, in the morning, a large peak going to Camp Pendleton on the northbound on-ramp (north of Oceanside) to the freeway. The peak hour on this ramp is about 400 vehicles, of which 125 (31 percent) occur in 15 minutes (if evenly divided during the 15 min, this would be 10.5 percent for each 5-min period).

At the south end of the Oceanside Freeway (south of Carlsbad) there was a power plant under construction on the old highway and at quitting time the construction workers would all use the ramp onto the freeway from the old highway. The peak hour here was 194 vehicles, of which 97 (50 percent) came in 15 min (if evenly divided during the 15 min, this would be 16.7 percent for each 5-min period).

It is concluded from what data are available, that in large metropolitan areas (1,000,000 or more) the volume during the highest 5-min period of a peak hour will be between 9 percent and 9.5 percent of the peak-hour volume. For smaller areas, the available data are so limited that definite statements would be unwarranted. Tentatively, however, it is concluded that for large volumes (2,000 vph or more) in smaller areas, a 5-min peak is about 11 percent of the hour.

It follows, then, that a given level of operating freedom would be associated with a design hourly volume of 1,500 vehicles in the Sacramento area, 1,700 in the San Francisco area, and 1,800 in the Los Angeles area.

MAXIMUM OBSERVED TRAFFIC VOLUMES

Before citing any numerical values (some of which are quite startling) under this heading, two things should be clearly understood: First, these volumes were attained under certain "prevailing roadway and traffic conditions" and seemingly small geometric changes or changes in truck volumes make a great deal of difference in prevailing conditions. Second, the prevailing traffic conditions when these highest counts were made were not always free and easy, and they are by no means design volumes.

California drivers are not different from other American drivers. In fact, a large proportion of them learned to drive in other states. However, experience in driving crowded freeways makes operation much smoother. In the Los Angeles area, where freeways have been in operation much longer and over a larger mileage than in other places, the drivers are more sure to take advantage of breaks and more alert to potential hazard. They keep the gaps closed up, which makes high volumes possible, but burn less rubber when they run into a jam.

In addition to this, the Traffic Division of the Los Angeles Police Department, which patrols the freeways in that city, is one of the finest and most experienced forces of its kind. It is probable that, with a little more experience, operation in other areas will be just as smooth as in Southern California.

Values given in Tables 1, 2, and 3 are full-hour volumes in one direction only, on 4-lane, 6-lane, and 8-lane freeways.

The peak-hour observations shown are not necessarily at capacity for that location. They are simply the maximum observed volumes and in many cases capacity was not reached, even during the peak hour. When studying these tables, the fluctuations between 5-min periods of the peak hour must be kept in mind.

In these tables the average speeds indicate to a certain extent the type of traffic flow during the peak hour. Where volumes and speeds were relatively uniform, the full-hour average speeds are shown in parentheses. Where no speeds are given flow ranged all the way from free flow to severe congestion. In the latter case, an average speed would not mean much. By congestion, it is meant there were stoppages or jerky operation at the point of the count. Grades shown are at the observation point only and are not always representative of grades in the vicinity. Plus grades are especially significant, as will be noted.

Congestion as denoted does not always indicate possible capacity. Sometimes it indicates that possible capacity has been reached at some location ahead of traffic in the direction of flow. Typical places where this can occur are on-ramps coming in to an already-full freeway, and off-ramps where the freeway drops a lane but the traffic demand does not drop proportionally. Also, it is possible for congestion to occur on a particular day as a result of stalled vehicles or other conditions peculiar to that particular observation.

A list of all locations studied is contained in Appendix A. Over-all views of some of the more important locations are shown in Figures 1, 2, and 3.

4-Lane Freeways

Table 1 shows that the Santa Ana Freeway at Locations 7, 8, and 21 carries very high volumes, especially in lane 2.

At location 7 (see Figure 8), it may be noted that lane 2 carried 2,437 vehicles in one hour at an average speed of 45 mph. The two-lane roadway expands to three lanes about 800 ft ahead of the observation point and therefore no back-pressure can develop. Because the demand, especially for lane 2, is very high, this is probably a good indication of true basic capacity of one freeway lane. There were only 10 trucks in lane 2 and about 70 in lane 1, which carried a total of 1,490 vehicles.

Figure 8. Location 7, Santa Ana Freeway looking southeast at Buhman Ave., 7:11 AM. Rate-of-flow WB during period 7:11-7:16: Lane 1, 1,512; Lane 2, 2,424. Note car passing on shoulder (less than 1 percent of vehicles counted did this).

Location 21 is 1.3 mi south of Location 7 and carries the same volume because there are no ramps in between. However, the operation at Location 21 was entirely different from Location 7, being very congested with long back-ups. This congestion was not due to the merging, as everything backed up from the north (ahead). After the peak hour and the demand fell off, it became obvious that one reason for the congestion was the slight grade to the north (about 800 ft of 1.7 percent). Traffic would be flowing smoothly at the observation point, but trucks could be seen going up the grade, with large numbers of cars catching up, and many brake lights could be seen going on. This would indicate that for that grade and number of trucks 3,900 to 4,000 vph is the possible capacity. On the other side of the hill (Location 7), possible capacity was not reached. This shows that grades as small as 1.7 percent must be considered in calculating the effect of trucks on capacity, even when the volume of trucks is as low as 2 or 3 percent.

It may be noted that the difference in lane 2 volumes between Location 7 and Location 21 is almost exactly the volume that entered from the right at Location 21, and that these 540 moved into lane 2 as soon as they could.

Location 8 (see Figure 9) was at the same place as Location 7, but traffic in the opposite direction (southbound) was counted. Flow at this point was congested, probably as a result of reaching possible capacity on a 2 percent grade ahead, but this was not determined for sure.

In Oakland on the Eastshore Freeway (Locations 3 and 5), volumes never approached the figures attained on the Santa Ana Freeway. Location 3 (see Figure 10) appeared to be running at possible capacity, as evidenced by long queues and occasional stoppage. Geo-

TABLE 1
TRAFFIC DURING PEAK HOUR, ONE WAY, 4-LANE FREEWAYS

Obs. No.	Location	Date	Ramp[a]	Lane 1[a]	Lane 2[a]	Total	% Trucks & Buses	% Grade
3A	Eastshore Freeway SB at Hegenberger Road off-ramp	6/23/55 Thur. PM	150 (31)	1,220 (38)	1,650 (39)	3,020	5	+0.2
B		6/28/55 Tue. PM	143 (30)	1,274 (33)	1,747 (34)	3,164	5	+0.2
5A	Eastshore Freeway SB at 1st Avenue off-ramp	6/20/55 Thur. PM	327 (37)	1,030 (44)	1,796 (45)	3,153	5	+0.4
7A[b]	Santa Ana Freeway NB at Buhman Avenue	7/21/55 Thur. AM		1,490 (44)	2,437 (45)	3,927	2	+0.3
8A	Santa Ana Freeway SB at Buhman Avenue	7/21/55 Thur. PM		1,534 (—)	2,208 (—)	3,742	3	—0.3
B		6/21/56 Thur. PM		1,752 (—)	2,119 (—)	3,871	2	—0.3
21A[b]	Santa Ana Freeway NB at Florence Avenue WB on-ramp	7/25/55 Mon. AM	540 (16)	1,504 (18)	1,918 (22)	3,962	2	+0.2
B[b]		7/23/56 Mon. AM	456 (—)	1,394 (—)	1,798 (—)	3,648	4	+0.2
28A	N. Sacramento Frwy. SB at El Camino Avenue on-ramp	6/11/56 Mon. PM	414 (14)	718 (50)	1,117 (58)	2,249	5	—0.5
B		6/12/56 Tue. AM	837 (14)	629 (44)	1,517 (48)	2,983	2	—0.5
C		6/13/56 Wed. AM	901 (16)	679 (48)	1,444 (57)	3,024	1	—0.5
29A	N. Sacramento Freeway NB at Marconi Avenue off-ramp	6/12/56 Tue. PM	995 (37)	413 (49)	845 (60)	2,253	3	+0.3
30A	Elvas Freeway NB at Arden Way off-ramp	6/13/56 Wed. PM	891 (41)	573 (47)	840 (54)	2,304	1	+0.3
31A	N. Sacramento Frwy. SB at Arden Way EB on-ramp	6/14/56 Thur. AM	493 (32)	549 (47)	976 (57)	2,018	c	—1.4
38A	N. Sacramento Frwy. SB between Arden Way and El Camino Ave.	3/28/56 Wed. AM		1,245 (46)	1,653 (50)	2,898	2	—0.1

[a] Value in parentheses is observed average speed of vehicles.
[b] Operating at or above practical capacity.
[c] Trucks not counted, approximately 1 percent.

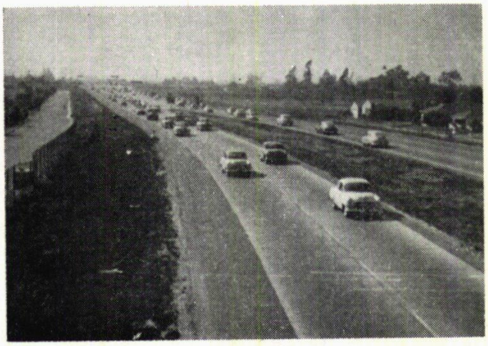


Figure 9. Location 8, Santa Ana Freeway looking northwest showing outbound traffic. Rt. 168 (Lakewood Ave.) interchange in background. Also note where freeway goes from 6 to 4 lanes. Photo taken at 5:02 PM. Rate during period 5:00-5:03: Lane 1, 1,596; Lane 2, 2,215.

metrically, the Eastshore locations were much the same as the Santa Ana locations in that they had wide medians and shoulders, and were in fairly open country. There were no appreciable grades at the Eastshore locations. However, trucks constituted 5 percent of total traffic instead of 2 percent. It appears that the added 3 percent trucks on level grade are approximately equivalent to 800 autos per hour.

Locations 28, 29, 30, 31 and 38 never became congested and operation was very good, as noted by the speeds. However, these locations are in Sacramento and, because of the larger fluctuations in the traffic volume in the smaller community, practical capacity was approached during the highest 5-min counts.

6-Lane Freeways

Table 2 shows peak hours obtained in observations of 6-lane freeways.

The highest average lane volume with the smoothest operation was observed at Location 14. As shown, the hourly volume runs more than 2,200 per lane, averaged over all three lanes. During two 5-min periods, rates-of-flow of 7,250 vph were observed. During both periods, traffic flow was very smooth.

Figure 11 shows various rates of traffic flow at this location. It can be noted that, even at a 7,200 vph rate, flow is so smooth that there are still gaps in the traffic stream.

The main reason for the remarkable traffic flow at this point is that the freeway is on a downgrade about 3.2 mi in length. The observation point is about one-third of the way down the grade. For this reason, trucks can maintain speeds comparable to autos and are no problem. There were very few truck-passing-truck movements. There is also a continuous demand furnished by 4 lanes coming over the hill from the San Fernando Valley.

High volumes continue at this point for more than 1 hr, with counts on two separate days being 12,800 in 2 hr, an average of 2,130 per lane per hour. This location appears to be a typical 6-lane freeway. The southbound roadway drops from 4 to 3 lanes at the Highland Avenue off-ramp and goes to 4 lanes again at the

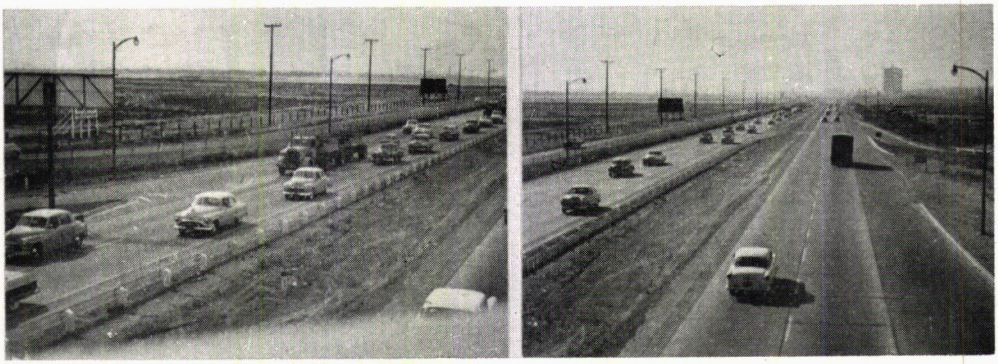


Figure 10. Location 3, Eastshore Freeway in Oakland at Hegenberger Road (airport interchange) looking northerly, (left) during period 4:40-4:45 PM, June 28, 1955, with SB rate-of-flow 3,000 vph at 30 mph (including ramp, and with stoppages during next period), and (right) at 6:00 PM, with SB rate-of-flow 3,000 vph at 40 mph (including ramp).

TABLE 2
TRAFFIC DURING PEAK HOUR, ONE WAY, 6-LANE FREEWAYS

Obs. No.	Location	Date	Ramp[a]	Lane 1[a]	Lane 2[a]	Lane 3[a]	Total	% Trucks & Buses	% Grade
4A	Eastshore Freeway NB at 19th Street	6/29/55 Wed. AM		1,100 (46)	1,640 (51)	1,530 (53)	4,270	4	0.0
9A	Santa Ana Freeway NB at Greenwood Avenue	7/22/55 Fri. AM		1,343 (—)	1,824 (—)	1,952 (—)	5,119	2	0.0
B		6/18/56 Mon. AM		1,217 (45)	1,911 (46)	2,107 (47)	5,235	3	0.0
10A[b]	Pasadena Freeway EB at Avenue 35	7/22/55 Fri. PM		1,278 (42)	1,838 (44)	2,152 (46)	5,268	0	+1.0
14A[b]	Hollywood Freeway SB at Highland Ave. Undercrossing	7/29/55 Fri. AM		1,954 (39)	2,343 (42)	2,320 (43)	6,617	3	—1.5
B[b]		8/3/55 Wed. AM		2,034 (33)	2,339 (38)	2,257 (39)	6,630	3	—1.5
C[b]		8/24/56 Fri. AM		1,943 (35)	2,261 (40)	2,225 (42)	6,429	3	—1.5
24A	San Bernardino Freeway at Marengo Street on-ramp	8/4/55 Thur. AM	226[c] (—)	1,354 (—)	1,687 (—)	1,628 (—)	4,895	2	—0.3
B[b]		6/22/56 Fri. AM	207[c] (44)	1,475 (42)	1,954 (43)	1,900 (46)	5,536	4	—0.3
25A[b]	Santa Ana Freeway SB at 7th Street on-ramp	7/28/55 Thur. PM	1,309 (—)	647 (—)	1,348 (48)	1,619 (51)	4,923	5	+3.6
B[b]		6/20/56 Wed. PM	1,127 (25)	603 (35)	1,502 (42)	1,897 (44)	5,129	5	+3.6
32A[b]	Pasadena Freeway EB at Sycamore Avenue	6/18/56 Wed. PM		1,629 (37)	1,937 (40)	2,099 (41)	5,665	0	+1.3
35A[b]	San Bernardino Freeway WB at Garvey Avenue on-ramp	6/21/56 Thur. AM	564[c] (—)	1,914 (—)	2,072 (—)	1,621 (—)	6,171	3	—1.6
36B	Hollywood Freeway SB at Spring Street	7/23/56 Mon. PM		1,748 (—)	1,724 (—)	1,758 (—)	5,230	6	—4.8
40A	Santa Ana Freeway NB at Lakewood Boulevard on-ramp	7/18/56 Wed. AM	767 (—)	694 (—)	1,417 (—)	1,706 (—)	4,584	d	+2.0
42A[b]	Santa Ana Freeway SB at Mott Street	7/20/56 Fri. PM		1,624 (35)	2,070 (35)	2,091 (38)	5,785	5	—0.1
B[b]		7/25/56 Wed. PM		1,346 (37)	2,014 (41)	1,971 (45)	5,331	5	—0.1
43A	San Bernardino Freeway WB Between Del Mar Avenue and Almansor Avenue	7/24/56 Tue. AM		1,259 (—)	1,542 (—)	1,585 (—)	4,386	3	+2.2
44A	San Bernardino Freeway EB at Warwick Road	7/24/56 Tue. PM		1,435 (—)	1,760 (—)	1,937 (—)	5,132	2	+1.4
45A	San Bernardino Freeway WB at Atlantic Boulevard	7/25/56 Wed. AM		1,186 (—)	1,852 (—)	1,921 (—)	4,959	3	+0.4
46A[b]	Santa Ana Freeway NB at Long Beach Freeway	8/20/56 Mon. AM		1,215 (43)	1,899 (44)	2,331 (47)	5,445	3	—0.8
47A[b]	Hollywood Freeway SB Between Highland Avenue and Cahuenga Boulevard[e]	9/13/55 Tue. AM	290 on 500 off	1,890 (35)	2,180 (42)	2,360 (45)	6,430[e]	3	—1.3
B[b]		8/21/56 Tue. AM	215 on 362 off	1,888 (43)	2,192 (46)	2,297 (47)	6,377[e]	3	—1.3
50A	Santa Ana Freeway NB Between Atlantic St. and 7th Street[e]	8/23/56 Thur. AM	66 on 825 off	1,732 (45)	1,724 (50)	1,912 (55)	5,368[e]	4	—3.6

[a] Value in parentheses is observed average speed of vehicles.
[b] Operating at or above practical capacity.
[c] Left-hand on-ramp, 2 lanes.
[d] Trucks not counted, approximately 2 percent.
[e] Common auxiliary lane, ramps not included in total.

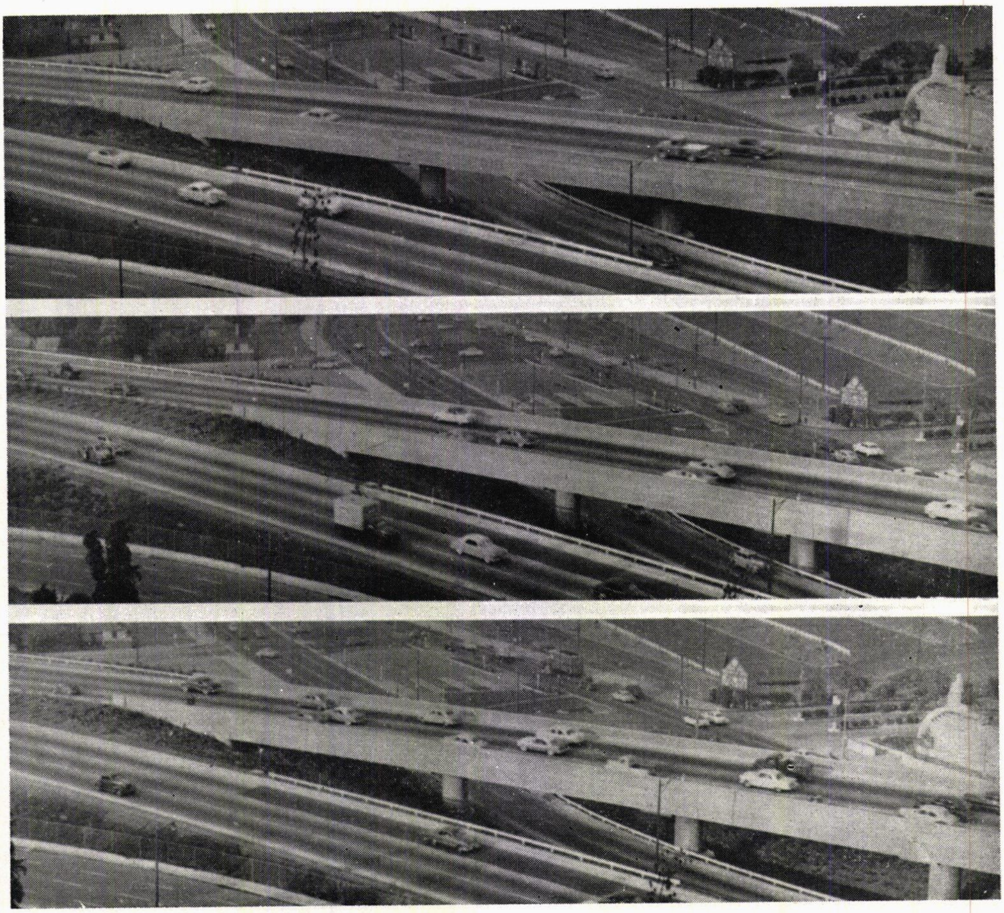
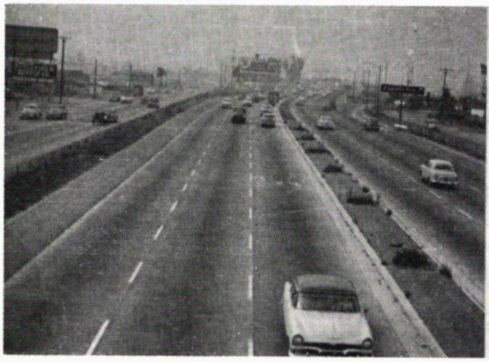


Figure 11. Location 14, Hollywood Freeway looking southerly, with inbound lanes on bridge. Upper photo: 6:30 AM; rate during 6:30-6:35 period, 3,600 vph; average speed $L_1 = 48$ mph, $L_2 = 52$ mph, $L_3 = 56$ mph.
Middle photo: High volume, smooth flow, at 7:10 AM; rate during 7:02-7:07 period 6,324, 7:11-7:16 period 6,168, average speed $L_1 = 44$ mph, $L_2 = 47$ mph, $L_3 = 48$ mph.
Lower photo: Use very heavy and smooth. Taken at 7:20 AM; rate during 7:19-7:24 period, 7,224 vph.

Hollywood Boulevard on-ramp, a total distance of 9,400 ft (1.78 mi). In this length, there are three on-ramps and five off-ramps (excluding the transition ramps).

Location 47 is 600 ft south of Location 14 and is at the nose of the Highland southbound on-ramp which is combined with the Cahuenga southbound off-ramp. There is a 700-ft auxiliary lane connecting these two ramps. Merging, diverging and weaving movements cause almost no trouble at these heavy volumes. After traffic has passed the Cahuenga ramp, there is a slight drop because the off-volume exceeds the on-volume. The peak-hour volumes beyond this off-ramp were 6,220 and 6,230 vehicles.

For the first observation at Locations 9 and 24 (see Figures 12 and 13), the congestion indicated does not mean that possible capacity at these locations was reached. In both cases, congestion started at some point ahead due to unknown causes. This is borne out by the second observations, during which higher volumes were passed without undue congestion.



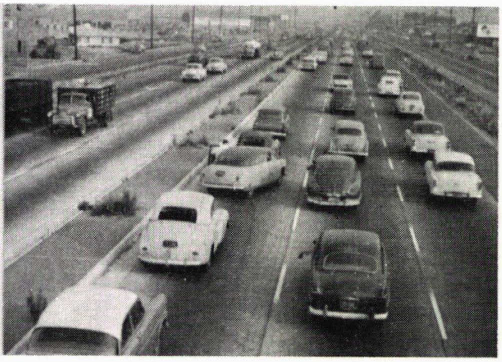


Figure 12. Location 9, Santa Ana Freeway at Greenwood Ave. pedestrian separation looking easterly (left) at 6:50 AM, WB traffic L_1 = 912 vph at 45 mph, L_2 = 1,716 vph at 50 mph, L_3 = 2,040 vph at 50 mph, total = 4,668 vph including 2.5 percent trucks; and looking westerly (right) at 7:40 AM, WB traffic at 5,500 vph then backed up. (Note minor rear-end accident, no damage.)

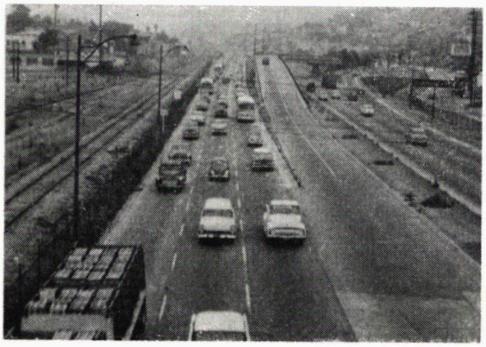


Figure 13. Location 24, San Bernardino Freeway at Marengo on-ramp looking east at 7:15 AM, WB traffic L_1 = 1,644 vph at 33 mph, L_2 = 1,872 vph at 38 mph, L_3 = 1,800 vph at 41 mph, R = 72 vph at 45 mph.

Locations 4, 10, 25, 32, 42, 46 and 50 never reached possible capacity. Operations at these locations were generally very smooth.

At the 7th Street southbound on-ramp on the Santa Ana Freeway (Location 25) there was periodic congestion because the on-ramp volumes of 1,309 and 1,127 vph were delivered in platoons from a nearby signal on 7th Street. However, the freeway never backed up, because lanes 2 and 3 carried only 3,967 vph on the first day and 3,399 vph on the second day at speeds of 42 to 51 mph. During the first observation at this location, the combined ramp and lane 1 volume was greater (1,956 vph) than on the second day (1,730 vph) and accounts for the congestion. The merging operation works well at this location until the combined rate-of-flow for the ramp and lane 1 reaches about 1,900 vph, after which stoppages occur.

Locations 10 and 32 on the Pasadena Freeway operate very well despite narrow (11-ft) lanes and sinuous alignment. This is attributed to the complete absence of trucks.

Locations 42 and 46, on the Santa Ana Freeway, are just back of points where the 3-lane roadway expands to four lanes. In the case of Location 42, the added lane is adjacent to the shoulder, and for Location 46 the added lane is adjacent to the median. The situation at Location 46 is very similar to that at Location 7, and the hour volume observed in the median lane was almost as high (2,331 vph) and the speed was slightly higher (47 mph).

At Location 4 (see Figure 14), the

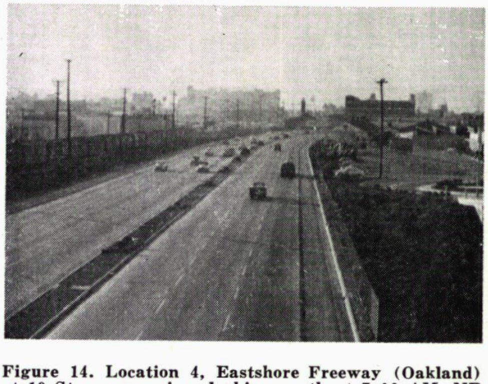


Figure 14. Location 4, Eastshore Freeway (Oakland) at 19 St. overcrossing, looking south at 7:06 AM, NB traffic 4,575 vph.

volume never reached practical capacity. The high speeds at Location 50 result from the downgrade and relatively large movement to the off-ramp, which leaves only 4,609 vph on the three lanes ahead.

The volume observed at Location 35 is considered to be near possible capacity for the conditions and this fact at least partly accounts for the congestion. At this location a left-hand on-ramp enters an already-full freeway and lane 1 is overloaded because of vehicles entering the Eastern Avenue off-ramp immediately ahead. The terminal conditions for this ramp are such that it cannot accommodate the demand and traffic is backed onto the freeway.

The congestion at Location 44, which is about 0.2 mi behind Location 35, is probably a reflection of conditions at Location 35 and one intervening on-ramp.

The congestion at Location 43 appeared to be due to heavy gravel trucks and the 2.2 percent upgrade.

The cause of the congestion at Locations 36, 40, and 45 was not determined. Possible capacity was not reached at any of these locations and the congestion reflects some condition ahead.

8-Lane Freeways

Table 3A shows observed peak-hour volumes on 4-lane roadways.

On the Bayshore Freeway in San Francisco at 22nd Street (Location 1), the volume was limited by the capacity of the Army Street interchange area ahead, where the southbound roadway necks down to 3 lanes. The lack of demand for the Army Street southbound off-ramp kept lane 1 nearly empty, because traffic not using the ramp must merge with lane 2 at the ramp nose.

The high full-hour volume (7,964 vehicles) for a 4-lane roadway was observed on the Hollywood Freeway northbound at Edgeware Road, Location 11. This point is just 1,200 ft north of the nose of the Pasadena-Harbor Freeway on-ramp, Location 15 (Table 3B). The peak hour is, therefore, about the same at both locations. However, the operation was much better at Location 11, with the average speed being about 40 mph. Despite the generally good operation, there were some stoppages here, which could indicate that 7,950 is about the possible capacity of the section to the north, which has a 2 percent upgrade for about 600 ft. There was a considerable amount of lane changing in the vicinity of Location 11, but it did not seem to cause much trouble.

Location 12, Hollywood Freeway northbound at the Vermont off-ramp, is about 2¼ mi north of Edgeware Road. Flow was very smooth at this point, and the 934 vehicles that used the ramp (diamond interchange) caused no trouble.

At the Mulholland Bridge on the Hollywood Freeway, northbound (Location 13, see Figure 15), the freeway is on a plus 5.4 percent grade for 4,600 ft. Presumably because of the grade, the peak-hour volumes are considerably less than at the previously cited 4-lane roadway locations, even though the demand was present. The operation was also very jerky and congested. Figure 15 is a photograph of this location during peak-hour operation. As indicated by the four observations at this location, the peak-hour volume is variable. This can be at least partially explained by metering before the point of observation. The most

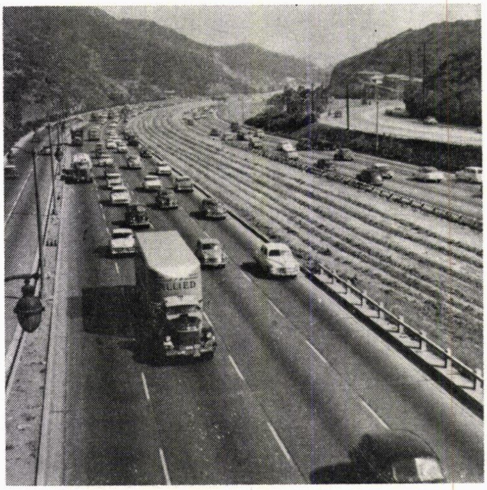


Figure 15. Location 13, Hollywood Freeway at Mulholland Bridge, at 4:12 PM, WB traffic during 4:11-4:16 period L_1 = 288 vph at 19 mph, L_2 = 1,332 vph at 33 mph, L_3 = 1,752 vph at 41 mph, L_4 = 2,196 vph at 42 mph.

TABLE 3A
TRAFFIC DURING PEAK HOUR, ONE WAY, 8-LANE FREEWAYS

Obs. No.	Location	Date	Ramp[a]	Lane 1[a]	Lane 2[a]	Lane 3[a]	Lane 4[a]	Total	% Trucks & Buses	% Grade
1A	Bayshore Freeway SB at 22nd Street	6/16/55 Thur. P.M.		1,243 (—)	1,425 (—)	1,584 (—)	1,750 (—)	6,002	2	—4.0
11A[b]	Hollywood Freeway NB at Edgeware Road	7/25/55 Mon. PM		1,488 (33)	1,787 (34)	2,157 (35)	2,226 (36)	7,658	3	—0.4
B[b]		8/20/56 Mon. PM		1,532 (37)	1,788 (37)	2,156 (40)	2,235 (42)	7,711	3	—0.4
C[b]		8/23/56 Thur. PM		1,696 (36)	1,822 (37)	2,254 (39)	2,192 (42)	7,964	2	—0.4
12A[b]	Hollywood Freeway NB at Vermont Street off-ramp	8/1/55 Mon. PM	893 (36)	1,230 (42)	1,575 (44)	1,771 (46)	2,079 (46)	7,548	3	—3.1
B[b]		7/16/56 Mon. PM	934 (35)	946 (43)	1,818 (44)	1,910 (45)	2,029 (46)	7,637	2	—3.1
13A[b]	Hollywood Freeway NB at Mulholland Drive	7/27/55 Wed. PM		915 (23)	1,571 (25)	1,690 (21)	1,674 (24)	5,850	2	+5.4
B[b]		8/2/55 Tue. PM		909 (24)	1,682 (23)	1,882 (25)	1,946 (26)	6,419	2	+5.4
C[b]		6/19/56 Tue. PM		732 (—)	1,337 (—)	1,861 (—)	2,008 (—)	5,938	2	+5.4
D[b]		6/22/56 Fri. PM		841 (—)	1,509 (—)	1,839 (—)	1,915 (—)	6,104	2	+5.4
17A	Hollywood Freeway SB at Vermont Street on-ramp	7/27/55 Wed. AM	717 (16)	1,260 (19)	1,606 (26)	1,767 (29)	1,782 (29)	7,132	3	—0.5
B		7/19/56 Thur. AM	763 (—)	1,188 (—)	1,633 (26)	1,716 (29)	1,773 (29)	7,073	3	—0.5
18A[b]	Hollywood Freeway SB at Alvarado Street on-ramp	8/5/55 Fri. AM	303 (24)	1,453 (28)	1,709 (30)	1,836 (32)	2,036 (35)	7,337	3	+0.6
B[b]		7/20/56 Fri. AM	382 (—)	1,347 (—)	1,581 (—)	1,872 (—)	2,057 (—)	7,239	[c]	+0.6
37B	Hollywood Freeway NB at Hill Street	7/16/56 Tue. AM		1,203 (—)	880 (—)	1,386 (—)	1,830 (—)	5,299	4	+4.8
41A[b]	Harbor Freeway NB at NB Distributor on-ramp	7/18/56 Wed. PM	1,332[d] (—)	889 (—)	1,431 (28)	1,741 (34)	1,709 (39)	7,102	[e]	—2.4
48A	Hollywood Freeway SB at Sunset Boulevard on-ramp	8/22/56 Wed. AM	395 (39)	809 (48)	1,290 (53)	1,664 (54)	1,864 (55)	6,022	3	—2.4
49A	Hollywood Freeway NB at Sunset Boulevard off-ramp	8/22/56 Wed. PM	510 (—)	765 (—)	1,170 (—)	1,467 (—)	1,609 (—)	5,521	[c]	+2.4

[a] Value in parentheses is observed average speed of vehicles.
[b] Operating at or above practical capacity.
[c] Trucks not counted, approximately 3 percent.
[d] Ramp vehicles are using shoulder to make two lanes.
[e] Trucks not counted, approximately 1 percent.

TABLE 3B

TRAFFIC DURING PEAK HOUR, ONE WAY, 8-LANE FREEWAYS AT TRANSITION ON-RAMPS (3 TO 4 LANES)

Obs. No.	Location	Date	On-Ramp[a] (2 Lanes)	Lane 1[a]	Lane 2[a]	Lane 3[a]	Total	% Trucks & Buses	% Grade
2A[b]	Bayshore Freeway SB at Army Street	6/21/55 Tue. PM	1,540 (29)	1,396 (30)	1,672 (35)	1,828 (39)	6,436	2	+0.2
B[b]		7/12/55 Tue. PM	1,617 (—)	1,385 (—)	1,798 (—)	1,869 (—)	6,669	1	+0.2
C[b]		7/13/55 Wed. PM	1,590 (30)	1,361 (—)	1,711 (—)	1,858 (—)	6,520	2	+0.2
D[b]		5/9/56 Wed. PM	1,804 (31)	1,605 (34)	1,709 (35)	1,889 (40)	7,007	3	+0.2
E[b]		5/10/56 Thur. PM	1,507 (—)	1,403 (—)	1,686 (—)	1,862 (—)	6,458	3	+0.2
6A	Bayshore Freeway NB at Alemany Street	7/13/55 Wed. AM	3,038 (27)	447 (—)	1,397 (—)	1,576 (—)	6,458	2	+1.0
15A[b]	Hollywood Freeway NB at Harbor-Pasadena Merge	7/29/55 Fri. PM	3,152 (18)	1,115 (13)	1,669 (19)	1,857 (24)	7,793	3	+3.8
B[b]		8/4/55 Thur. PM	3,111 (20)	915 (17)	1,651 (26)	1,858 (27)	7,535	3	+3.8
C[b]		8/21/56 Tue. PM	3,251 (17)	1,020 (16)	1,703 (21)	1,939 (28)	7,913	2	+3.8
16A[b]	Hollywood Freeway SB at Barham Avenue	8/1/55 Mon. AM	1,830 (23)	1,313 (20)	2,006 (27)	2,018 (31)	7,167	2	+5.0
22A[b]	Hollywood Freeway NB at Highland Avenue	7/26/55 Tue. PM	1,393[c] (33)	1,403 (33)	1,863 (33)	2,017 (26)	6,676	2	+1.0
B[b]		7/19/56 Thur. PM	1,238[c] (33)	1,229 (40)	1,875 (38)	2,074 (37)	6,416	3	+1.0
27A[b]	Bayshore Freeway NB at Army Street	5/10/56 Thur. AM	1,183 (37)	1,631 (39)	1,907 (44)	1,991 (48)	6,712	3	−0.2
B[b]		5/11/56 Fri. AM	1,163 (40)	1,709 (43)	1,926 (45)	2,005 (50)	6,803	2	−0.2

[a] Value in parentheses is observed average speed of vehicles.
[b] Operating at or above practical capacity.
[c] This ramp is on the left and merges with lane 3.

TABLE 3C

TRAFFIC DURING PEAK HOUR, ONE WAY, 8-LANE FREEWAYS AT TRANSITION OFF-RAMPS (4 TO 3 LANES)

Obs. No.	Location	Date	Lane 1[a,b]	Lane 2[a]	Lane 3[a]	Lane 4[a]	Total	% Trucks & Buses	% Grade
19A[c]	Bayshore Freeway SB at Alemany Street	6/29/55 Wed. PM	1,559 (—)	1,718 (—) 490[e]	1,564 (40)	1,913 (45)	6,754	[d]	−1.0
20A	Bayshore Freeway NB at Army Street	6/30/55 Thur. AM	816 (39)	1,815 (—) 1,695[f]	1,882 (—)	1,919 (—)	6,372	[d]	−2.2
39A	Hollywood Freeway SB at Highland Avenue	7/17/56 Tue. AM	773 (52)	1,909[g] (39)	2,077 (41)	2,157 (44)	6,916	[d]	−5.0

[a] Value in parentheses is observed average speed of vehicles.
[b] All to ramp.
[c] Operating at or above practical capacity.
[d] Trucks not counted, approximately 2 percent.
[e] Through traffic, including 10 vehicles that got out of lane 1 within 150 ft of gore; 1,228 vehicles to ramp.
[f] Through traffic, including 36 vehicles that got out of lane 1 within 150 ft of gore; 120 vehicles to ramp.
[g] Includes 183 vehicles that got out of lane 1 within 300 ft of gore.

common cause of this metering is stalled vehicles, which block a lane, sometimes for a full hour. The heavy grade and warm weather apparently contribute to stalls, especially from "vapor-lock."

On the Hollywood Freeway, inbound at the Vermont and Alvarado on-ramps (Locations 17 and 18), operation was smooth much of the time, but was congested periodically. At Vermont, congestion was due in part to the on-ramp merging and partly due to back-ups from the east. This ramp is on a 6.0 percent upgrade and has only 340 ft of merging area. The Alvarado on-ramp worked fairly well.

The congestion at Location 37 is believed to be a combination of grade, weaving, and high truck percentage.

At location 41, there is an over-loading of lane 1 as a result of the high combined volume of the ramp and lane 1, and considerable weaving is required to distribute traffic to the Hollywood, Santa Ana, and Pasadena Freeways.

The high speeds at Location 48 result from the downgrade that prevails for some distance in each direction. Practical capacity was not reached at this point.

Operation was not good at Location 49, even at the low volume. This is probably because of the dropping of a lane about 800 ft ahead, combined with the effect of the continuous upgrade for the next three miles.

Table 3B shows peak hours observed on freeways where 2-lane ramps merge with a 3-lane roadway to make a 4-lane roadway going away. Table 3C shows peak hours observed on 4-lane roadways where one lane is dropped at a ramp to make a 3-lane roadway going away.

Locations 2 and 6 (Table 3B) are on the Bayshore Freeway at the Army Street southbound and the Alemany Street northbound on-ramps. Locations 19 and 20 (Table 3C) are at the Alemany Street southbound and Army Street northbound off-ramps. The freeway between the on-ramps and off-ramps is used as a weaving area about 3,600 ft in length for southbound traffic and 2,800 ft in length for northbound traffic. Figure 16

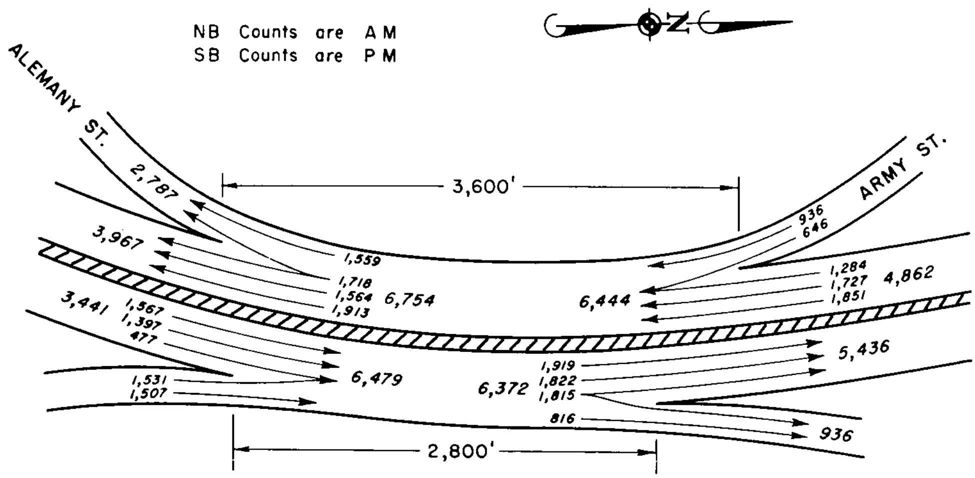


Figure 16. Peak hours on the Bayshore Freeway, Locations 2, 6, 19 and 20 (see Tables 3B and 3C).

shows a sketch of the location with the peak hour volumes indicated. Locations 2 and 6 are shown in Figures 17 and 18, respectively. In the southbound direction, the traffic backs onto the freeway from the Alemany off-ramp, thus making the merging and weaving at Army Street worse than normal. When traffic does not back up from the Alemany Street off-ramp usually the operation is good. But some stoppage occurs in lane 1 and on the ramp when ramp vehicles attempt to enter lane 1 at the nose and stop if a gap is not available. Some drivers will stop despite an open lane ahead. In the northbound direction, the capacity of this section was not reached, but traffic operation was poor because of back-ups from the north (causes unknown).

Location 15 (see Figure 19) on the northbound Hollywood Freeway at the junction of the Harbor-Pasadena on-ramp is 1,200 ft south of Location 11 (see Table 3A) and the same traffic must pass the two locations. Consequently, the highest volume observed here, 7,913 vph, is almost the same as the highest observed at Location 11. But, as pointed out in the comments on Location 11, the operation was not good at Location 15 when the traffic reached this volume. At rates-of-flow up to 7,000 vph the merge works smoothly, but at low speeds of 25 to 30 mph. Above this rate-of-flow, the operation is jerky with many stops and long back-ups. But even during the peak hours, traffic flows smoothly beyond the merge area. Figure 19 shows this location at typical peak hour operation.

Locations 16 and 22 (SB Barnham on-ramp, NB Highland on-ramp, see Figure 20) never reached possible capacity for this type of traffic movement. The low speeds and total volume resulted from a back-up of traffic from plus grades ahead.

Possible capacity was never reached at Location 27 (Table 3B) or Location 39 (Table 3C).

Southbound Merge of Hollywood-Santa Ana Ramp with Pasadena Freeway

Table 4 indicates the results obtained on five different days at this location. During the first observation, the situation was as indicated in Figures 21(a) and 22 (top). The table shows that a large peak hour volume was handled on this day, more smoothly than on subsequent days, as the average speeds indicate. On this day (July 26), traffic seldom backed up from the merge, although there was quite often congestion at the merge. The congestion, for the most part, was caused by traffic backing all the way from the point where the 5-lane section branches into a 3-lane freeway and a 2-lane distributor road 1,800 ft beyond the point of merging.

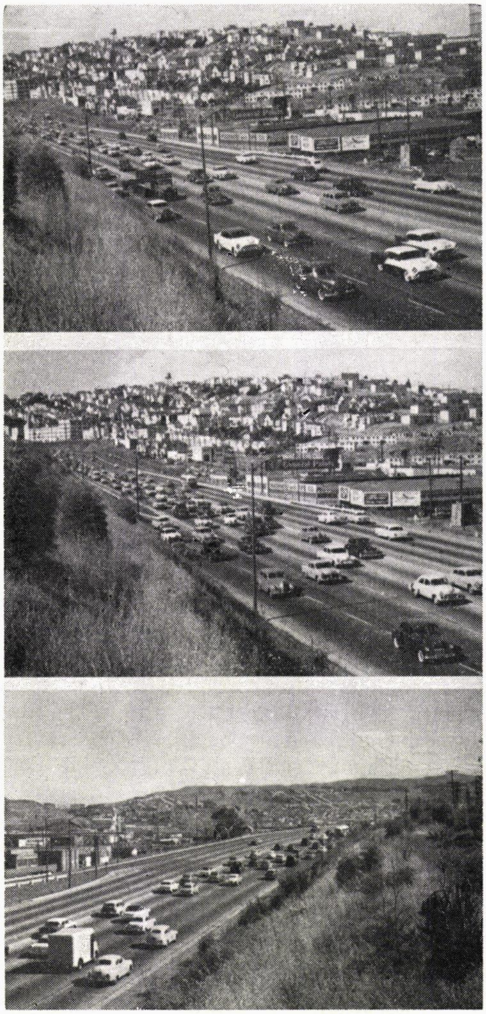


Figure 17. Location 2, Bayshore Freeway (San Francisco) at Army Street on-ramp: (top) looking northerly, SB 4:35-4:40 PM, 6,750 vph; (center) SB 4:55-5:00 PM, 6,000 vph; (bottom) looking southerly, SB 4:55-5:00 PM, 6,000 vph.

During the second observation (July 28), cones were used to channelize the Pasadena approach from 3 lanes to 2. (Figure 21(b)). The cones were badly placed, encroaching into lane 3 of the Hollywood-Santa Ana ramp. As a result, operation was not very good and there was a drop of 400 vehicles in the peak hour. The volume was never great enough to load the 3-lane section 1,800 ft south of here. The Pasadena approach was backed up practically the full hour.

During the third observation (August 2), the placement of the cones was improved considerably (Figures 21(c) and 22 (center)). They only extended about 120 ft from the nose (previously extended about 200 ft). Also, the Hollywood-Santa Ana approach was given its full 3-lane width. The operation on this day was somewhat better. At least enough cars could get through the merge to load the 3-lane section to the south. Again the Pasadena was backed up during the full hour.

At the time of the fourth observation, lane 4 was eliminated by painting arrows on the pavement (Figure 21(d)). Also, the nose was not extended appreciably. As a result, operation was much better than existed when the cones were in place, but the speed of the Pasadena approach was still less than existed before channelization. Table 4 shows that the highest peak hour occurred on this day, but the increase over the first observation is in lanes 1 and 2 and not in the critical weaving lanes (lanes 3 and 5). Much of the improvement over the cones was due to the increased maneuverability and because many people used lane 4 despite the pavement markings. A fifth observation was made with the same geometric conditions as the fourth observation. On this day there was considerable congestion on the Hollywood-Santa Ana approach and the volume was about 500 less than the previous observation.

Because of the congestion on the 3-lane roadway of the Harbor Freeway at the exit end of the weaving area, it is difficult to evaluate the effect of the channelization. However, it is apparent that the traffic on the Pasadena approach has been slowed considerably due to the channelization.

Weaving on Rosemead Boulevard at Temporary End of San Bernardino Freeway

Figure 23 shows the observed peak hour on this weaving section. It is unknown how many of the 1,540 vehicles shown leaving the San Bernardino Free-

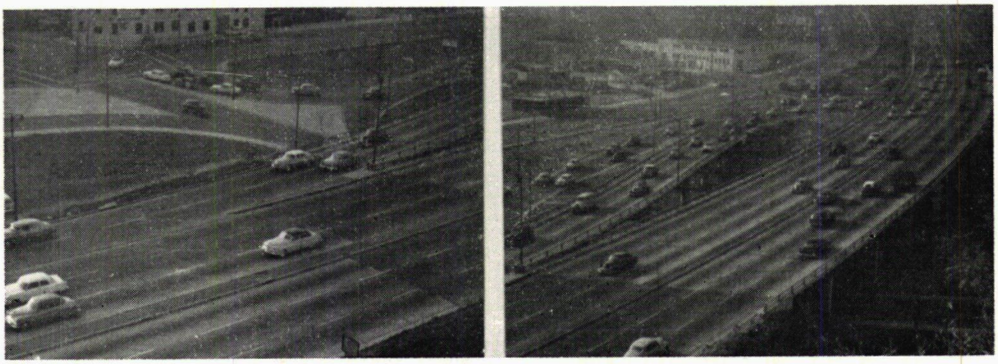


Figure 18. Location 6, Bayshore Freeway (San Francisco) at Alemany Street NB on-ramp: (left) at 7:07 AM, traffic R = 2,676 vph at 36 mph, L_1 = 330 vph at 40 mph, L_2 = 1,236 vph at 50 mph, L_3 = 1,200 vph at 50 mph, total = 5,442 vph (incl. 100 trucks); (right) at 7:37 AM, traffic total = 7,350 vph (including 140 trucks), R = 3,550 vph at 30 mph, L_1 = 34 mph, L_2 = 41 mph, L_3 = 50 mph.

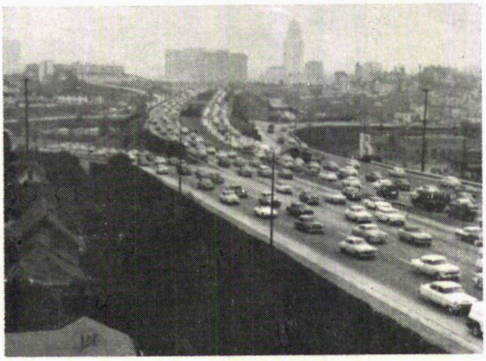


Figure 19. Location 15, Hollywood Freeway WB at Harbor-Pasadena merge (near side) at 4:58 PM. Traffic backed in all directions at 7,548 vph, or just about possible capacity; R_1 = 1,620 vph at 16 mph, R_2 = 1,332 vph at 14 mph, L_1 = 1,044 vph at 10 mph, L_2 = 1,716 at 30 mph, L_3 = 1,836 vph at 24 mph. (Traffic jam in other direction caused by construction operations ahead.)

way are included in the 1,394 vehicles making a right turn at the end of the weaving section. However, it is believed that it is a negligible amount. The operation at this weaving section was usually good, and the volume did not appear to be greater than practical capacity.

The highest 5-min period was 342 vehicles (4,104 vph), at which time there was some minor congestion in weaving. If the right turn to the freeway were not so sharp the operation would be even better. Much of the time there were queues waiting to make this turn.

Incidentally, the 1,540 vehicles on the off-loop represent the possible capacity of this loop at this location. There was a continuous reservoir of waiting cars on the freeway approaching the ramp.

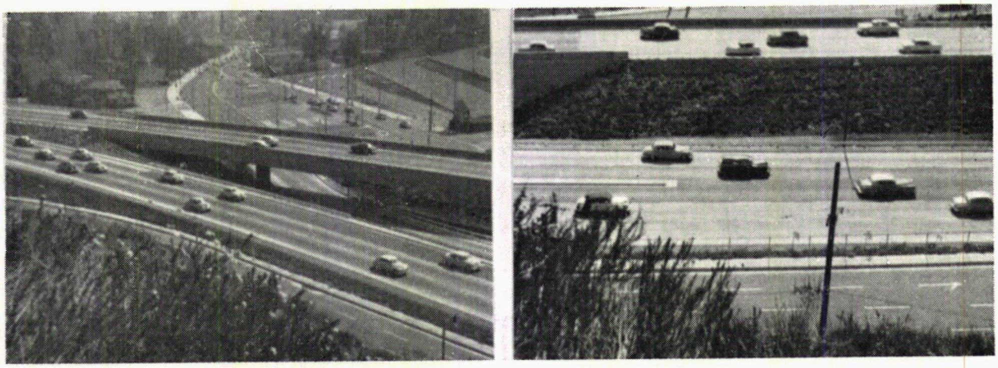


Figure 20. Location 22, Hollywood Freeway at Highland on-ramp at 3:50 PM: (left) NB, near side, previous to merge, 4,000 vph at 45 mph, very free-flowing; (right) merging area just to right of left view, 1,000 vph merging.

TABLE 4
LOCATION 26, PEAK HOUR SOUTHBOUND MERGE OF HOLLYWOOD-SANTA ANA RAMP WITH THE HARBOR FREEWAY[a]

Date	Lane 1[b] (Hollywood-Santa Ana)	Lane 2[b] (Hollywood-Santa Ana)	Lane 3[b] (Hollywood-Santa Ana)	Lane 4[b] (Pasadena)	Lane 5[b] (Pasadena)	Lane 6[b] (Pasadena)	Total
7/26/55 Tue. AM	1,575 (38)	1,317 (33)	1,472 (26)	814 (25)	1,180 (37)	1,546 (42)	7,904
7/28/55 Thur. AM	1,652 (33)	1,318 (26)	1,317 (18)	[c](—)	1,522 (19)	1,735 (25)	7,544
8/2/55 Tue. AM	1,650 (33)	1,429 (28)	1,362 (20)	[d](—)	1,604 (19)	1,810 (28)	7,855
9/15/55 Thur. AM	1,674 (35)	1,518 (28)	1.423 (22)	[e](—)	1,681 (21)	1,786 (38)	8,082
1/5/56 Thur. AM	1,507 (24)	1,320 (21)	1,199 (17)	[e](—)	1,727 (23)	1,793 (29)	7,546

[a] Distance between nose of this merge and point where freeway diverges into a 2-lane off-ramp and 3 lanes ahead on the main line is 1,800 ft. There are between 1 and 2 percent trucks and buses at this location and the grade at the merge is —1.0 percent.
[b] Value in parentheses is observed average speed of vehicles.
[c] Lane 4 (right lane of Pasadena approach) eliminated by cones; also encroached into lane 3 somewhat; extended nose, in effect, about 200 ft.
[d] Lane 4 again eliminated by cones; this time lane 3 given full width and nose only extended about 120 ft; worked much better, but not as well as with no restrictions at all.
[e] Lane 4 eliminated by arrows and a wide white line painted on pavement; a considerable number of vehicles still used this lane (included in L_5).

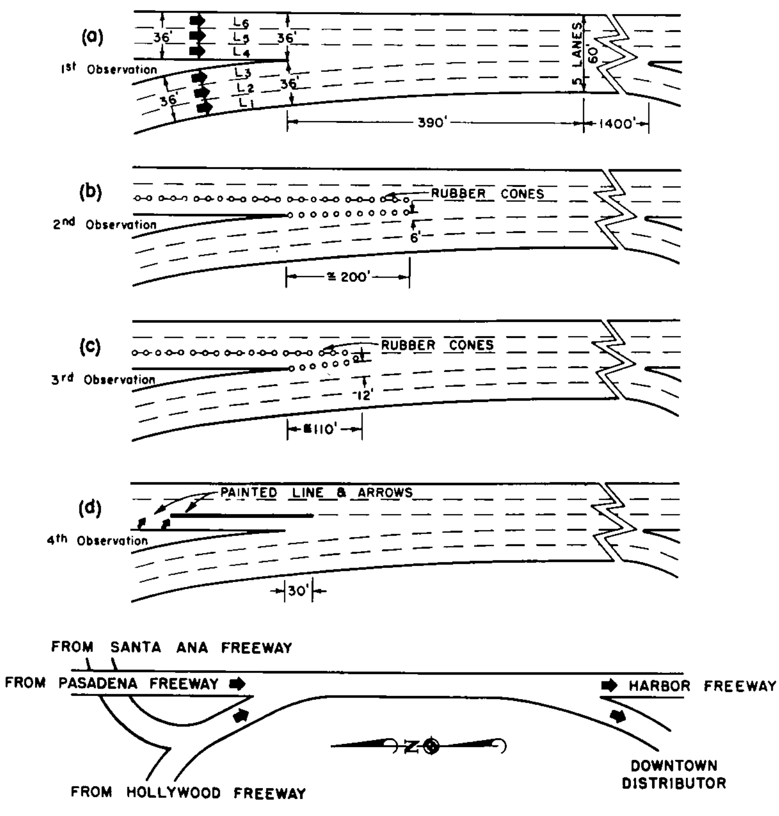


Figure 21. Geometric conditions at merge of Hollywood, Santa Ana, and Pasadena Freeways.

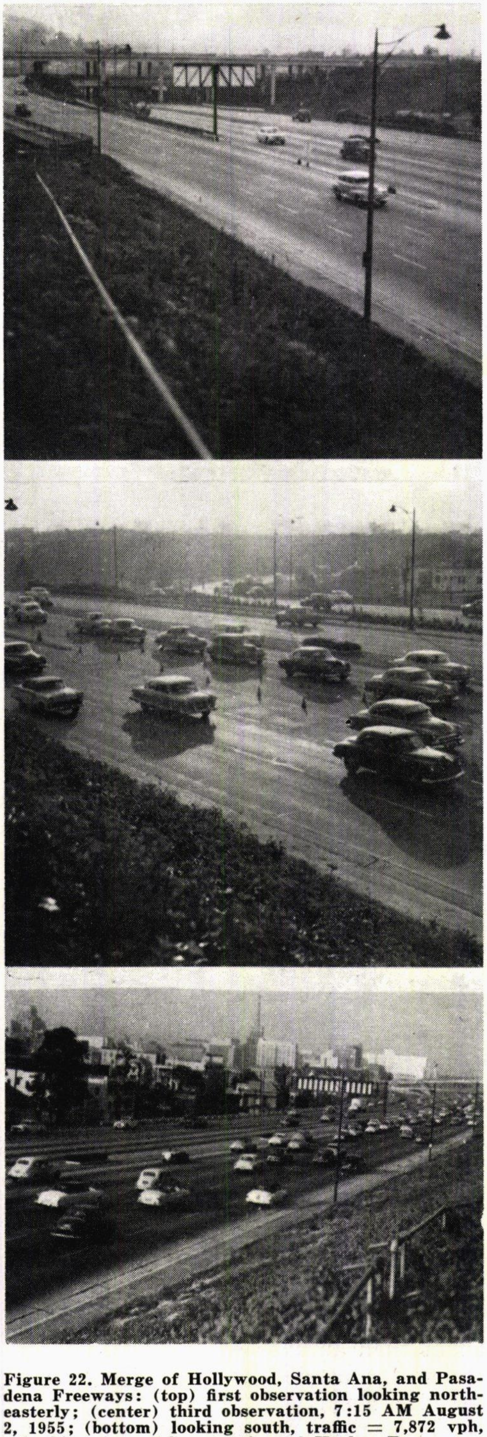


Figure 22. Merge of Hollywood, Santa Ana, and Pasadena Freeways: (top) first observation looking northeasterly; (center) third observation, 7:15 AM August 2, 1955; (bottom) looking south, traffic = 7,872 vph, backing from 3-lane section of Harbor Freeway.

Merging at Junction of North Sacramento and Elvas Freeways

At this point, two 4-lane freeways join and form a single 4-lane freeway. Four lanes of one-way traffic must merge into 2 lanes. Figure 24 shows the location and the volumes observed. The highest 5-min volume observed was a total of 283 vehicles and at this volume there is some congestion, with some vehicles almost stopping and slight queuing, and with most cars applying brakes. The peak-hour volume at this location (2,511) is probably close to maximum without serious congestion developing at times, because of the sharp intra-hour peak noted in smaller metropolitan areas. Most of the peak hour was free-flowing, with the congestion previously described lasting only about 10 to 15 min.

FREEWAY OPERATING CHARACTERISTICS

In previous sections, peak-hour volumes were given for freeways and merging ramps. In this section, an attempt will be made to show some operating characteristics of freeway traffic. In the following graphs, traffic volume is given in terms of 5-min periods. If it is desired to expand a particular point on a graph to an hour volume, it should be kept in mind that for high 5-min volumes it is not correct to multiply by 12 (see "Relationship of 5-Min to 1-Hr Count"). In very large metropolitan areas, a multiplying factor of 10.5 to 11 would be approximately correct for converting high 5-min volume to hourly volume.

For the purpose of showing operating characteristics of freeway traffic, the only locations used were those where operation was considered to reflect the true characteristics of the particular location, with a minimum of influence from the geometric features farther ahead in the direction of travel. Speed-volume relationships and proportional distribution of traffic by lane at these locations are shown in Figures 25 through 36.

The plotted points through which curves were drawn in Figures 25-36 are group-averages. This is a departure from

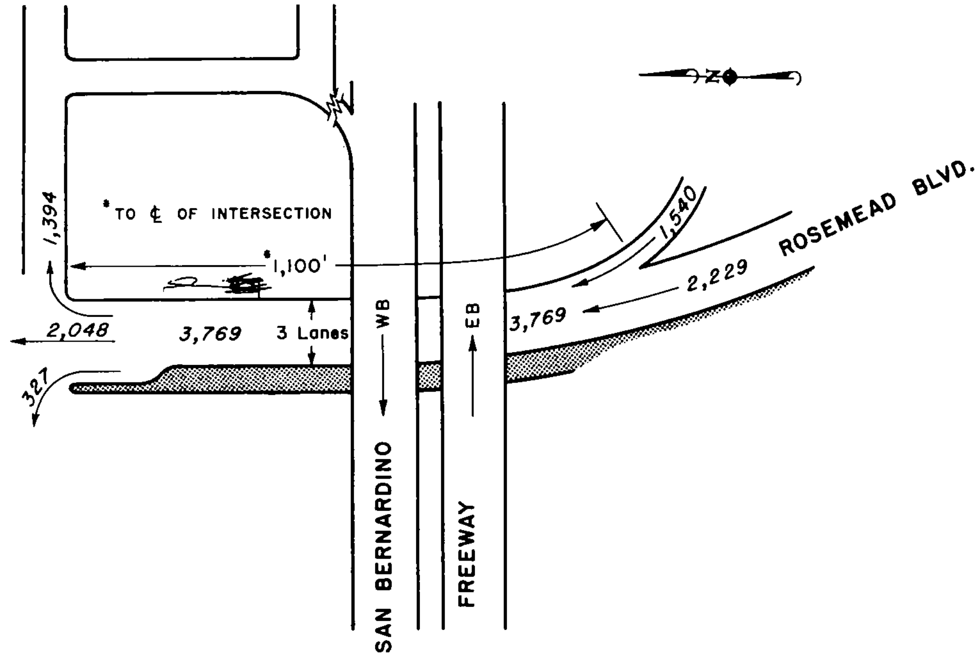


Figure 23. Peak hour at Rosemead Boulevard at end of San Bernardino Freeway, Location 23.

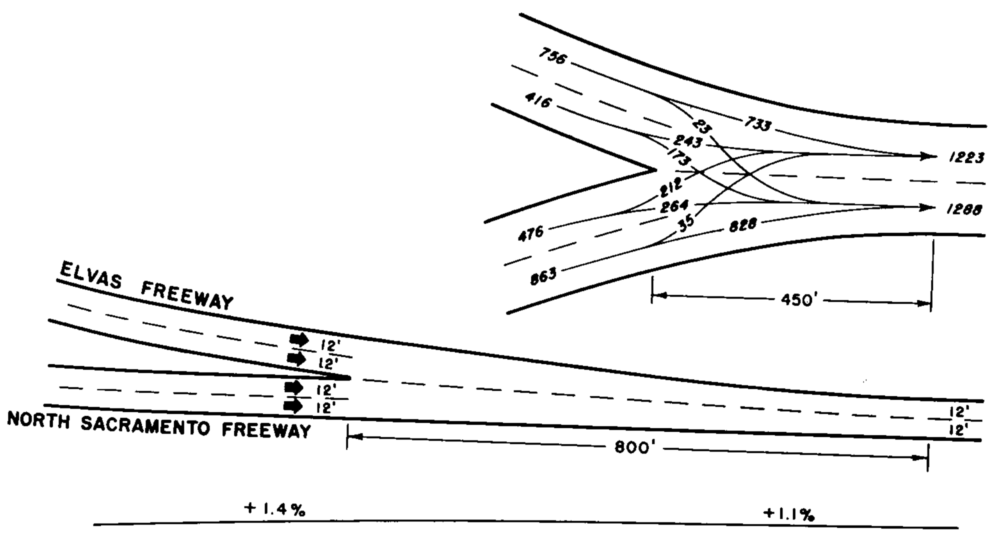


Figure 24. Merge of North Sacramento and Elvas Freeways (1 to 1.5 percent trucks and buses) peak hour on October 19, 1955.

the previous report ("Highway Capacity Study 1955, Progress Report"), in which curves representing speed-volume relationships were boundary curves enclosing the observed points. Additional observations and study have led to the belief than an average curve would represent the conditions most likely to be found at a particular location, and hence would be more useful in defining operating characteristics that would be useful in design.

Furthermore, it was found that even though operation in individual lanes was influenced considerably by the operation of adjacent lanes, boundary curves representing limiting conditions for the individual lanes bear no relationship to boundary curves representing the operation of the whole traffic stream or the several lanes of a roadway as a unit. By plotting group-averages, good correlation was established and this disparity was obviated.

The 5-min observations at a given location were grouped in class intervals, each class interval being 25 vehicles of volume in the stream. Observations which were apparently in large disagreement with the majority were eliminated. For each group, the average speed and average volume in each lane were computed. Between 7 and 14 groups were formed, depending on the range in observed volumes. Curves (a) and (c) of each location were then fitted by inspection to the plotted group-averages, and graph (b) of each figure was constructed by reading values from graphs (a) and (c).

As will be noted, considerable "freedom" was permitted in the fitting, resulting in sinuous curves which are close to each group-averaged plotted point.

In each case, graph (a) shows the speed in each lane and average speed of all lanes as a function of the volume in the stream. Graph (c) shows the volume in each lane as a function of volume in the stream. Graph (b) is a composite of graphs (a) and (c), showing a three-way relationship between volume in each lane, volume in the stream, and speed in each lane.

In reading these graphs, speed may be interpreted as an index of the type of operation. Although the particular curves plotted do not show speeds as low as 25 mph, observations were made at several locations covering a wide range of speeds, and very slow speed prevails at many locations during portions of the peak hour. When freeway speeds go below approximately 25 mph, operation is almost always congested and one can be sure that there is stopping and starting and very jerky operation either at the observation point or in the near vicinity. At most of the latter locations, the congestion, or the reason why speeds were reduced, was at a point farther ahead in the direction of travel.

The maximum rate of flow observed at any of the locations where speeds were reduced to stop-and-go operation (for example, Location 15) was about 35 vpm per lane, and ordinarily 30 vpm per lane is about the most that can be depended on. On the other hand, the volume during hours when stop-and-go operation prevailed was at least as great as the volume ever obtained at that same location, regardless of speed.

When the possible capacity has been reached at a given point (for example, where a ramp brings in 1,500 vph to a 3-lane freeway already carrying an average of 1,500 vph per lane) some vehicles have to wait. The freeway going away from this point may have a possible capacity of 5,500 and with 6,000 arriving, either the surplus will be forced to wait, or the arrival rate will be slowed down.

The way it seems to work out, as the rate approaches this condition, is that there is always a melee of cars stopping in the near vicinity of the bottleneck. They soon start up again, after enough time has elapsed to absorb the load back to their particular location. Approaching drivers seeing the jam ahead naturally slow down, hoping to keep moving and knowing that if they maintain normal speed they will have to stop. Successively, the rear-end of the melee moves backwards with each approaching car adding a little more slack by adjusting its speed downward. By the time the rear-end moves back, or "accordians", a mile or more, all of the vehicles are moving, but are moving slowly.

If an observation is made 3 or 4 miles back of this situation, speeds will drop as the volume picks up, but this drop in speeds has nothing to do with the geometric conditions at the point of observation. It is simply that this pick-up in volume is enough to exceed possible capacity at some point ahead.

Speeds over approximately 35 mph usually mean operation is relatively smooth and stoppages are the exception rather than the rule as in the former case. Speeds on ramps or merging areas do not follow these rules, however, but usually depend on conditions at each location. Merging speeds of 25 mph are still fairly good, with real congestion beginning when merging speeds go lower than 20 mph.

Distribution of Traffic by Lanes

Traffic volumes are not evenly divided among all lanes. Lane 1 never carries as much as other lanes, except at ramps where traffic has not had a chance to redistribute itself. Tables 1, 2 and 3 show that during peak hours lane 1 usually carries at least 300 vph less than the adjacent lanes. This is because most drivers want to travel at faster speed than can be maintained in lane 1. Speeds comparable to other lanes cannot be maintained in lane 1 for the following reasons:

1. Trucks usually stay in lane 1 and (even on level grades) usually travel at less than the desired rate of speed of passenger cars.
2. There are a certain number of drivers that prefer to travel at only 35 to 45 mph. And they also, as the law requires, ordinarily stay in lane 1.
3. Points of conflict, such as ramps, are usually adjacent to lane 1.

It has been suggested that placing some ramps on the left would even out the lane volume distribution. This is doubted, as points 1 and 2 in the foregoing would still tend to keep drivers out of lane 1. Having ramps on the left, especially off-ramps, would merely reduce the efficiency of the median lane and, therefore, reduce capacity. Also, slow vehicles would be forced to weave across the faster lanes when entering or leaving the freeway. That slow drivers or trucks will increase their speed to make this weave has not been borne out by observation.

Graph (c) of Figures 25 through 36 indicates that the proportional distribution of traffic among lanes is relatively uniform regardless of the total volume. These curves also confirm that lane 1 always carries considerably less than the other lanes, except where influenced by ramps or certain other features of the location.

The outstanding characteristics influencing operation at each location are discussed briefly in the following sections.

Typical Freeway Operation

Under this heading, operating characteristics will be discussed for several locations representing different geometric conditions to be found on a typical freeway. The effects of trucks and grades are discussed in subsequent sections.

Locations 3, 7 and 8 (Figures 25, 26 and 27) are on 2-lane roadways (4-lane freeways). Location 7 (Figure 26) expands to a 3-lane roadway by adding a lane in the median about 800 ft ahead of the observation point. Location 8 (Figure 27), being at the same place but with observations in the opposite direction, is the reverse situation in which a 3-lane roadway narrows to a 2-lane roadway by dropping the median lane. The grade is nearly level for both locations and trucks are about 2 percent of the total traffic. However, operation of Location 8 is possibly influenced at high volumes by a 2 percent upgrade about 1,500 ft ahead.

Location 3 (Figure 25) is just beyond the Hegenberger Road off-ramp, but the ramp has very light usage and is not considered to have much influence on the freeway operation. The grade is nearly level and trucks are about 5 percent of the total traffic. Geometrically, this location is comparable to Locations 7 and 8, but the truck volume is higher and the location is on a continuous 2-lane roadway.

Locations 25, 42, and 46 (Figures 28 through 30) are 3-lane roadways.

Location 25 (Figure 28) is at a heavily

used on-ramp, but the ramp is downgrade so the speed of entering vehicles is higher than average for a ramp. Drivers on the freeway leave lane 1 almost empty, thus creating large gaps for entering vehicles. Stoppages occur in lane 1 when the combined rate-of-flow for the ramp and lane 1 reaches about 1,800 or 1,900 vph. Lanes 2 and 3 are usually relatively empty and operation in these lanes continues to be good except when lane 1 vehicles attempt to change lanes after having stopped or greatly reduced speed.

The roadway expands to 4 lanes just ahead of Locations 42 and 46 (Figures 29 and 30). The lane is added to the outside (right-hand side of lane 1) ahead of Location 42, and on the inside (median side) ahead of Location 46. The expansion ahead of Location 46 is actually a left-hand on-ramp merging with three lanes to make a 4-lane roadway going away. But at the time of observation, the ramp had negligible use because the Long Beach Freeway was under construction. Grades are approximately level in the vicinity of each location. Trucks are 5 percent of total traffic at Location 42 and 3 percent at Location 46. It is noted that lane 2 operation is almost the same at Locations 42 and 46, but the operation of lane 1 is slightly better and the operation of lane 3 is considerably better at Location 46. This probably indicates that the faster drivers take immediate advantage of the added lane at Location 46, but at Location 42 the slower drivers must change lanes and are slow to do so.

Locations 2, 11, and 18 (Figures 31, 32, and 33) are 4-lane roadways.

A 2-lane on-ramp joins a 3-lane roadway at Location 2 (Figure 31) to make a 4-lane roadway going away. This may be considered typical for this type of roadway. There are no steep grades ahead and the truck volume is only about 2 percent. Operation is generally good except for a few stoppages, which apparently result from overloading of the Alemany off-ramp about 0.7 mi ahead. Occasional stoppages occur in lane 1 at the ramp nose because of faulty merging.

Location 11 (Figure 32) is considered to be typical of 8-lane urban freeways. It is 1,200 ft north of the merge of the Hollywood and Pasadena-Harbor Freeways where low speeds prevail at high volumes. There are no ramps or steep grades in the vicinity and operation is usually smooth. The highest volume for a 4-lane roadway was observed at this location. Trucks are 2 to 3 percent of the volume.

Location 18 (Figure 33) is similar to Location 11 except for the on-ramp. However, speeds are generally lower because of a long upgrade of 1 to 2 percent, with a section of plus 3.5 percent about 0.5 mi ahead.

Other contributing factors toward the lower average speeds are the merging from Alvarado on-ramp and the anticipation by freeway traffic of a frequently occurring jam that backs up from the junction of two freeway streams about a mile ahead (see Location 26).

Effects of Trucks on Operations

Determining the effect of trucks and grades is very difficult because of inadequate data. In other words, the variation in observed volumes of trucks was too small to extrapolate for other volumes which may occur elsewhere. Gathering adequate data would probably require controlled experiments (such as no trucks at a particular location one day, 50 the next, and so on). Despite this lack of data, some general conclusions can be drawn concerning the effect of trucks on capacity.

There is undoubtedly a decrease in practical capacity due to grades alone, with no trucks or buses present. This effect is probably small and will not be considered in this report. This assumption is believed to be consistent with the accuracy required for practical design problems.

Figure 34 gives the speed-volume relationship obtained on the Pasadena Freeway at Location 32 (Sycamore Avenue). At this point, the freeway lanes are only 11 ft, the median is only 2 ft wide with a wire mesh fence, and there are no shoulders. Also, traffic from the on-ramps enters from a full stop. However, no

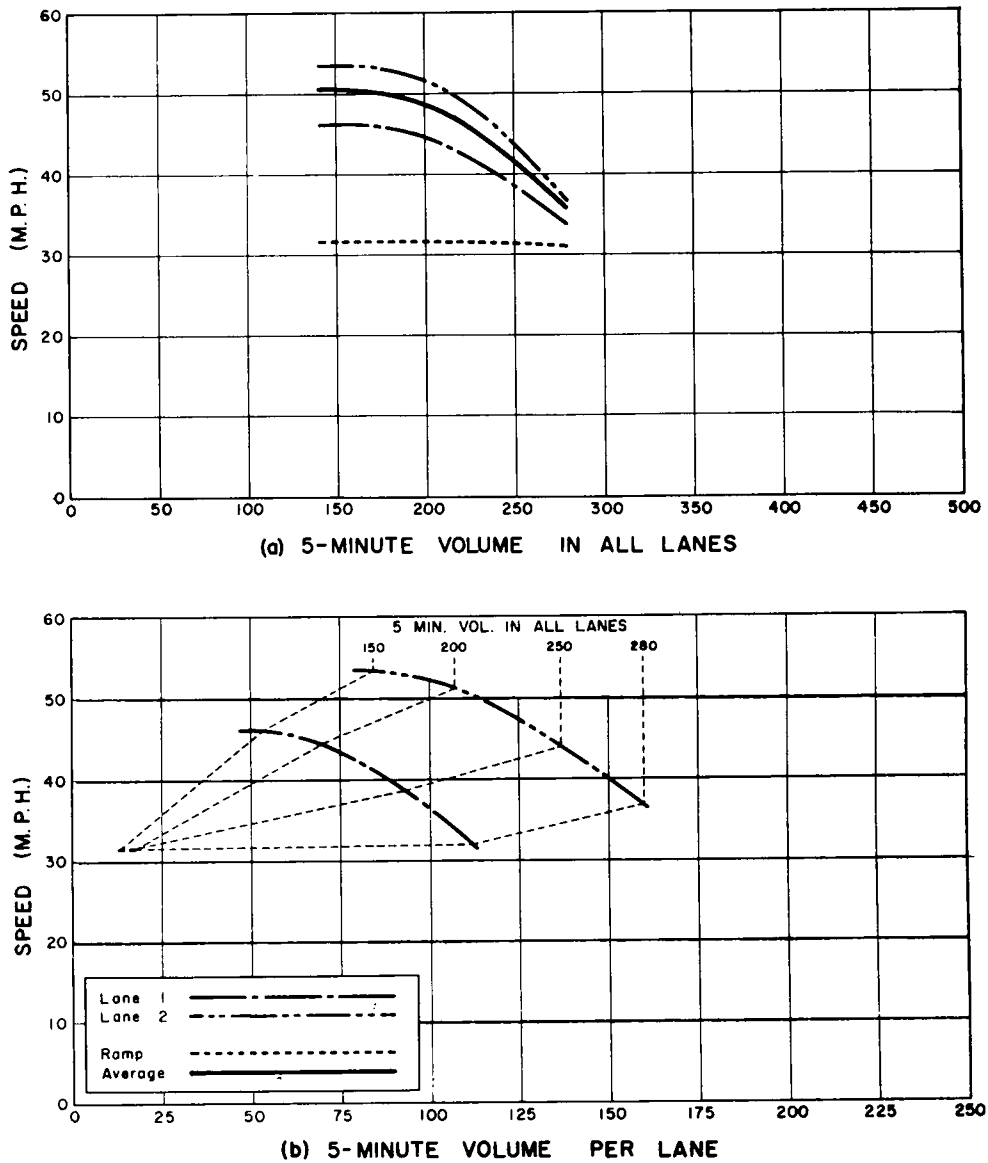


Figure 25. Speed-volume relationship, Location 3, Eastshore Freeway SB at Hegenberger Road off-ramp.

trucks use this freeway and, as a result, the operation here appears to be quite a bit better than at Location 11 (Figure 32) or Location 18 (Figure 33). Operation is at least equal to Locations 42 and 46 (Figures 29 and 30), both of which are "expanding" situations.

A comparison of Location 32 (Figure 34) with Locations 42 and 46 (Figures 29 and 30) shows that operation in lanes 2 and 3 is better for Locations 42 and 46. This is probably due to the wider lanes and better alignment of the Santa Ana Freeway. But the operation in lane 1 is slightly better for Location 32 than for either Locations 42 or 46, and a high-

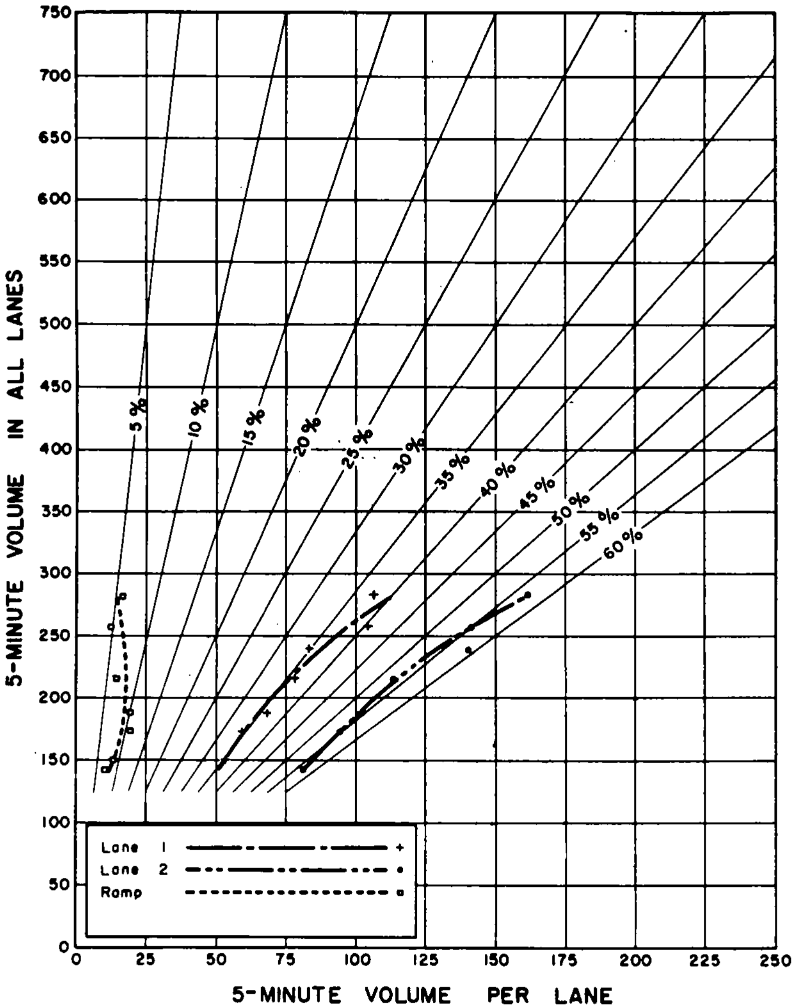


Figure 25(c). Lane distribution, Location 3, Eastshore Freeway SB at Hegenberger Road off-ramp.

er proportion of the traffic is carried in lane 1 at Location 32, particularly at high total volumes.

Basically this difference is due to trucks, but it is impossible to relate the absolute difference in operating characteristics to the number of trucks because of the difference in geometric features of the locations, and because the percentage of trucks observable does not have a "spread" with other conditions remaining constant.

Effect of Grades on Operation

As pointed out earlier, upgrades as small as 2 percent seriously reduce capacity when truck volumes are appreciable. On downgrades of considerable length, average volumes of 2,000 vph per lane can be carried with no congestion. When upgrades approach 3 percent or more and are long enough for trucks to decelerate significantly, capacity is greatly reduced.

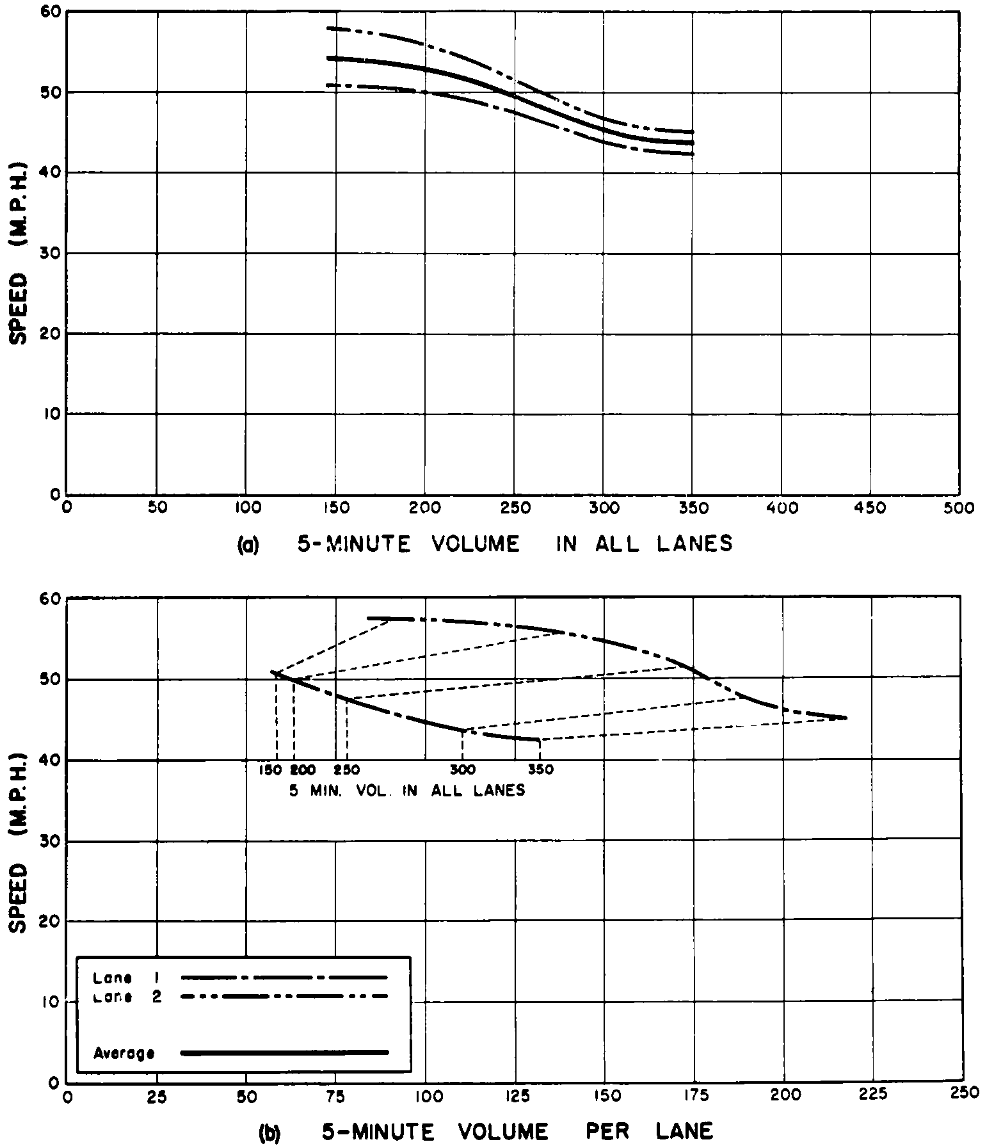


Figure 26. Speed-volume relationship, Location 7, Santa Ana Freeway NB at Buhman Avenue.

Figure 35 (Location 14) shows operation on a downgrade more than 3 mi in length. The downgrade is 5 percent approaching the location, flattens to 1.5 percent at the point of observation, and continues for about 2 mi beyond. The smoothest operation and highest average lane volume was observed here. The average lane volume is over 2,000 vph for two full hours.

Figure 36 (Location 13) shows operation three-fourths of the way up a 4,600-ft, 5.4 percent grade with about 150 trucks and buses per hour. Figure 36 shows that here about 350 vehicles in 5 min would be enough to reduce the average freeway speed (excluding the trucks themselves) to 45 mph. This would be a

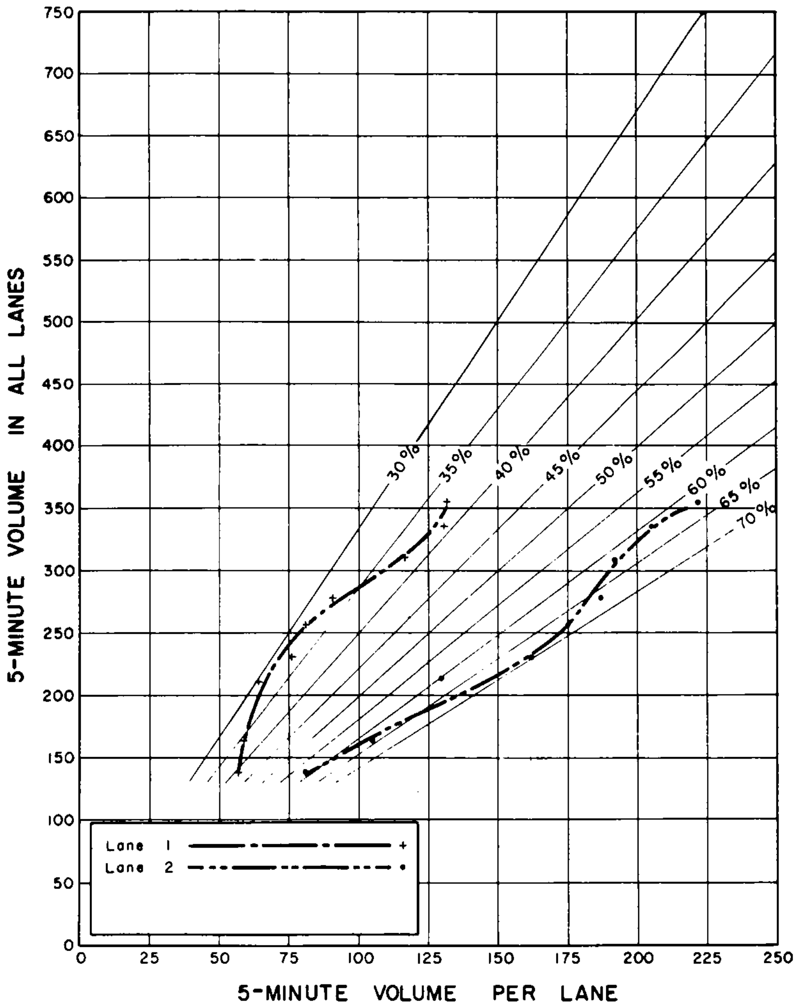


Figure 26(c). Lane distribution, Location 7, Santa Ana Freeway NB at Buhman Avenue.

peak hour of only 3,850 vehicles, or an average of about 960 per lane. The traffic is distributed as follows:

	Traffic, vph	Speed, mph
Lane 1	440	25
Lane 2	900	39
Lane 3	1,170	46
Lane 4	1,340	50
Total	3,850*	

* Including about 150 (4 percent) trucks and buses.

Observation confirms that this volume is about all that a 4-lane roadway can handle under these circumstances without occasional jams which extend into lanes 3 and 4.

Each truck is equivalent to something between 10 and 20 autos, on this particular 8-lane freeway. In other studies made on 6 percent grades in California, it has ben inferred that it is not valid to say "1 truck is equivalent to *n* autos," because 1 truck in 100 vehicles is equivalent to as high as 50 autos, whereas 10 trucks in 100 vehicles might only be about equivalent to 15 or 20 autos apiece. When the truck volume on the two uphill lanes of a 4-lane highway on a 6 percent grade

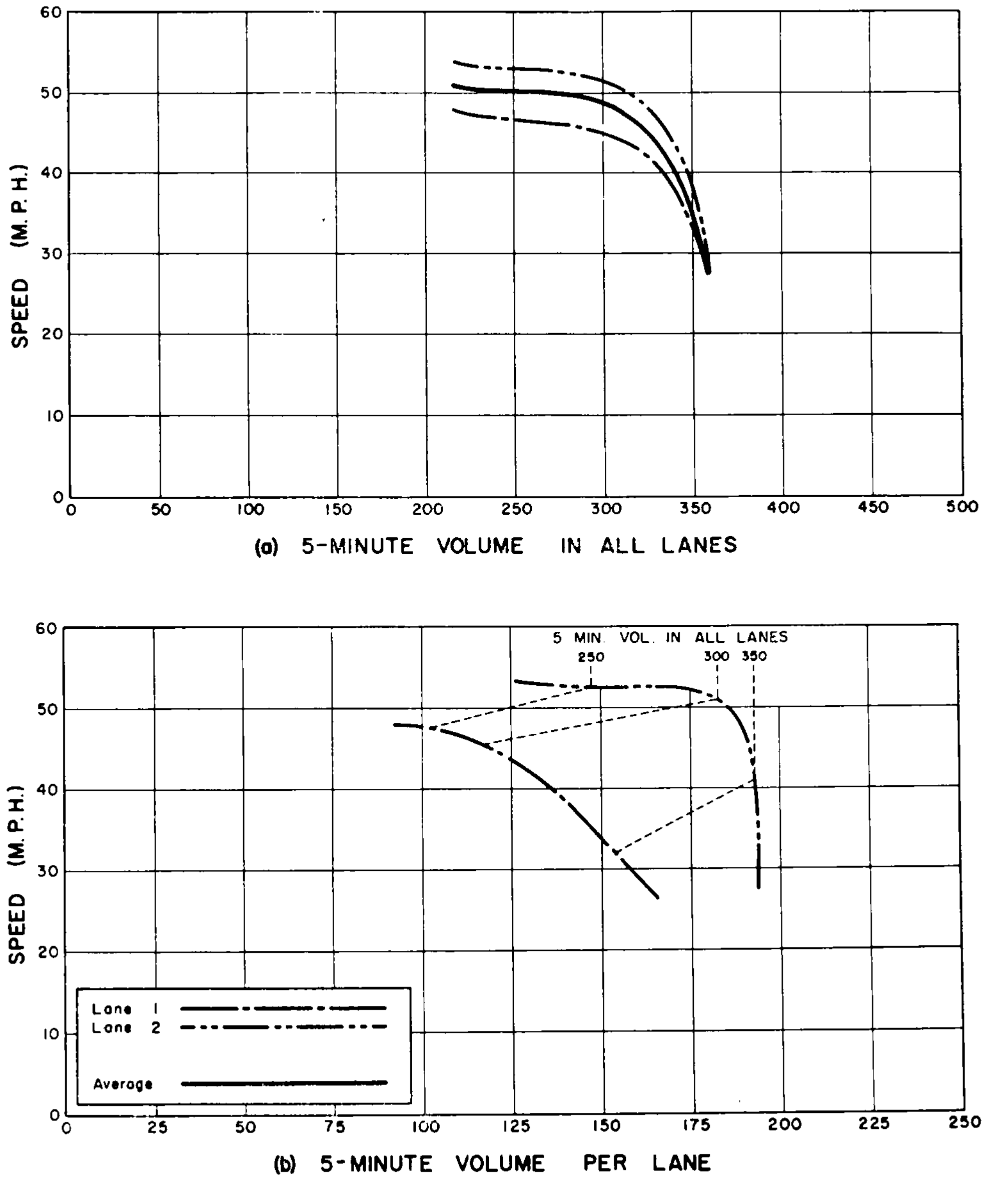


Figure 27. Speed-volume relationship, Location 8, Santa Ana Freeway SB at Buhman Avenue

approaches 100 per hour, there is no "practical" capacity left for any autos at all, if "practical" means freedom to maneuver and reasonable continuous speeds. At about this volume the number of truck-passing-truck maneuvers constitute intermittent blocking of the highway frequently enough so that slowing to a crawl is unavoidable.

Much more study would be required to establish quantitative values for this effect on highways having more than 2 lanes in the uphill direction.

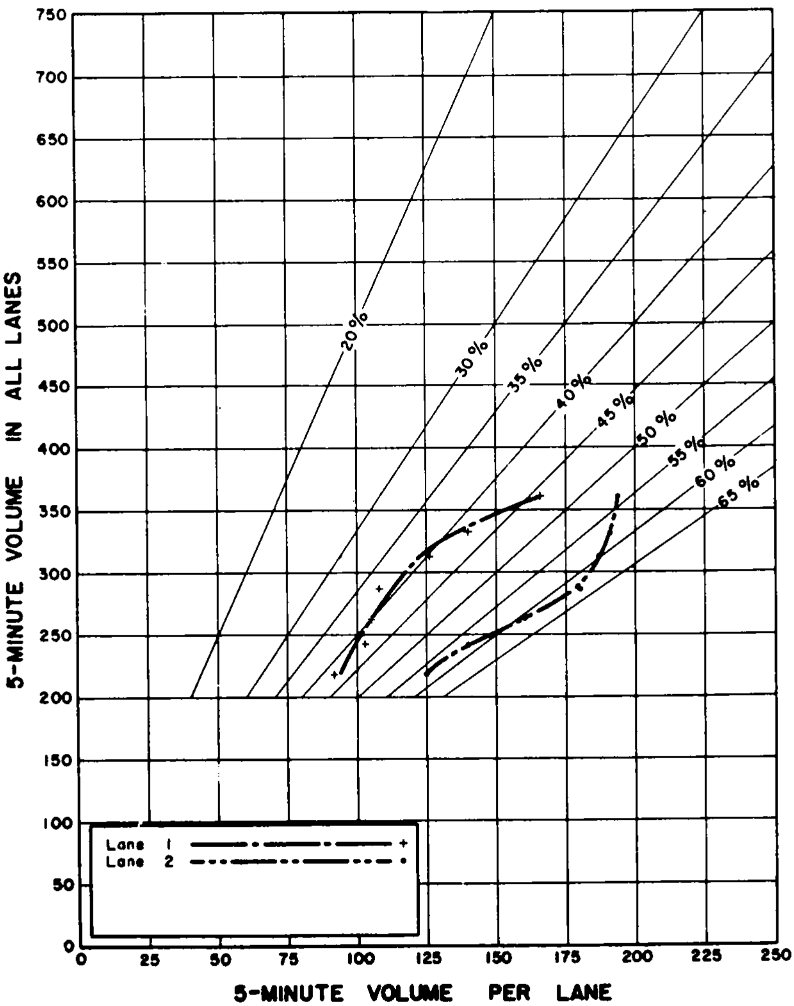


Figure 27(c). Lane distribution, Location 8, Santa Ana Freeway SB at Buhman Avenue.

Relation Between Speed and Average Lane Volume

Figure 37 shows the average freeway speed as a function of the average 5-min lane volume for each of the locations covered by Figures 25 through 36. These curves may be considered an indication of the lane efficiency at each location. In examining these curves, however, it is important to remember that, in addition to the number of lanes, other geometric conditions and the traffic demand have a marked influence on the operation at each location.

For comparative purposes, curve 2 from Figure 7 of the "Highway Capacity Manual 1950" (*1*) (representing average operation for 2-lane roadways) has been reduced to average lane volume for 1/12 and 1/11 hr and plotted on the graph. Of course, 1/12 hr would represent an average 5-min period whereas 1/11 hr would represent a maximum 5-min period

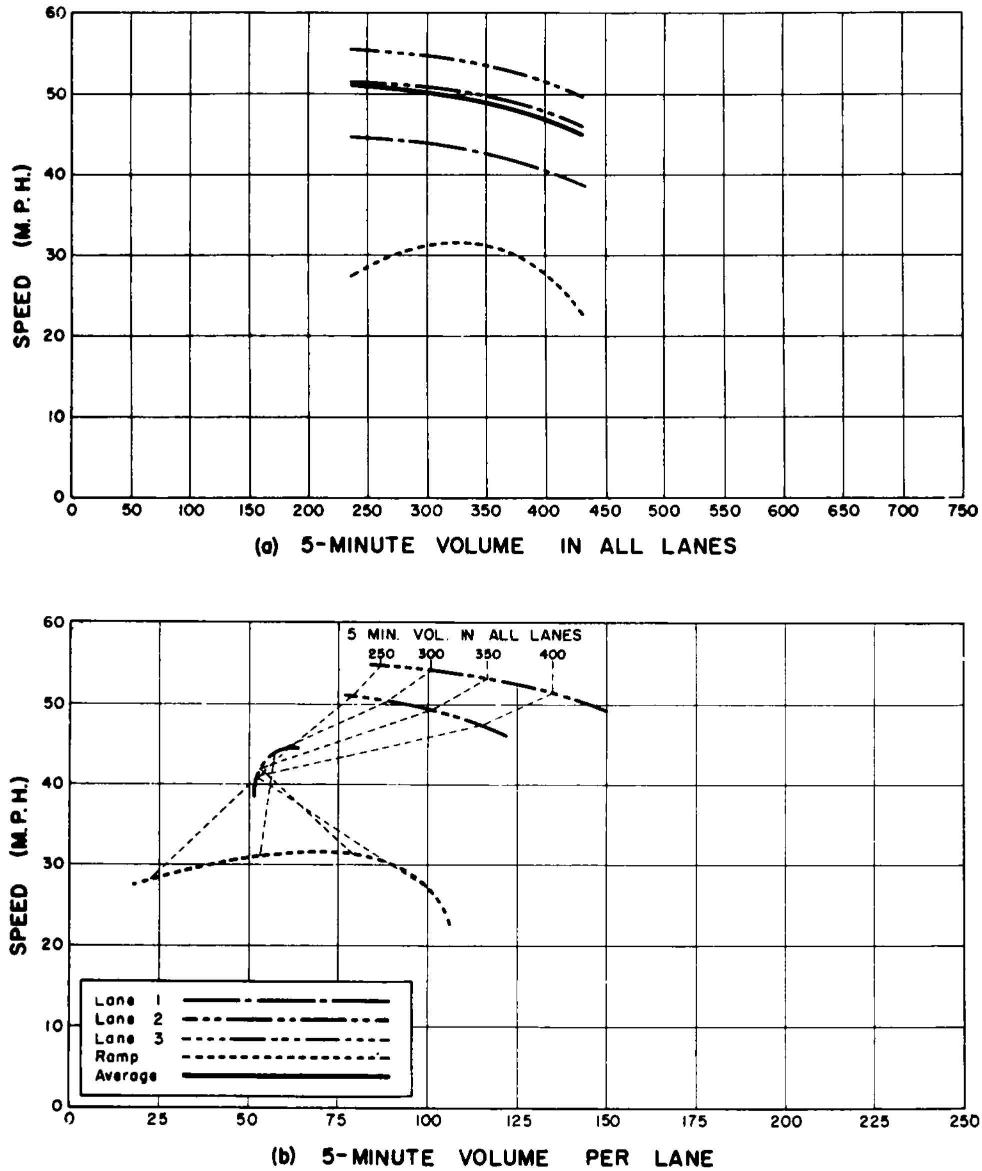


Figure 28. Speed-volume relationship, Location 25, Santa Ana Freeway SB at 7th Street.

to be expected during a peak hour in a large metropolitan area (such as Los Angeles).

Effect of Merging and Ramps on Operation

Isolating cause and effect of merging and various types of ramps is difficult due to the many variable conditions of merging. Some of the variables affecting merging operation are:

1. The actual volume merging; that is, the sum of the ramp and the freeway.
2. The percentage of trucks on the

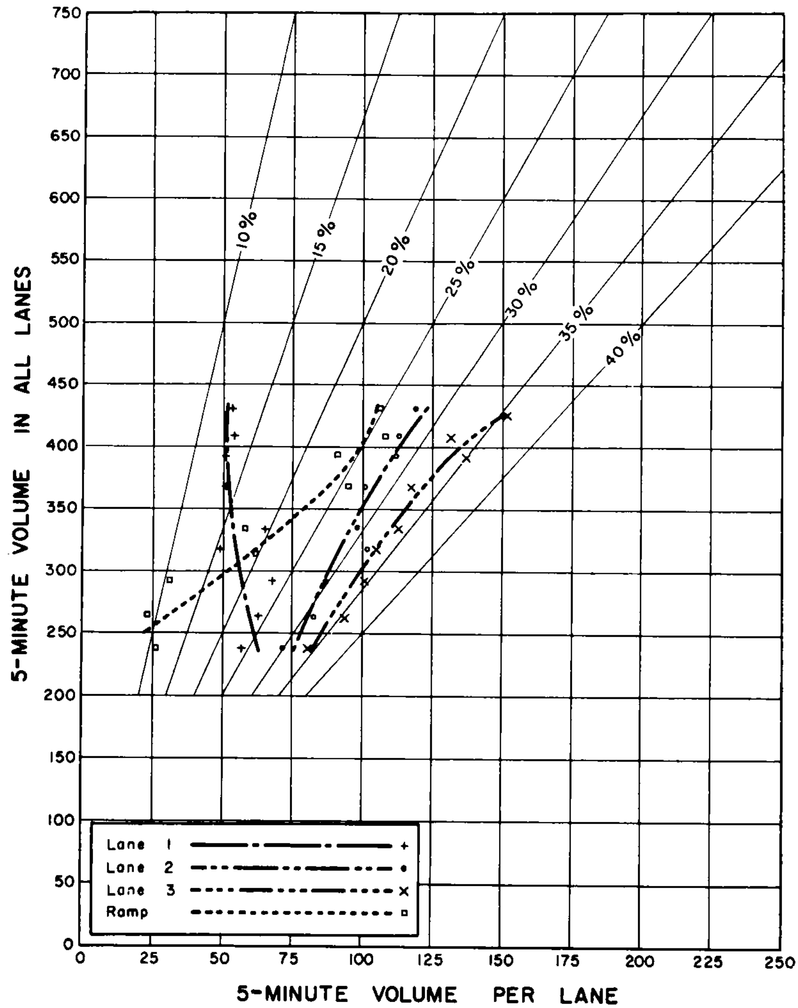


Figure 28(c). Lane distribution, Location 25, Santa Ana Freeway SB at 7th Street.

ramp and on the freeway.

3. Grades of the ramp and the freeway.
4. Approach speeds on the freeway and the ramp.
5. Length of acceleration lane.
6. Other ramps in the vicinity.

With the available data, most of these conditions cannot be separated except in general terms.

The most important factor in merging operation is the sum of the ramp volume and the lane 1 volume, regardless of number of lanes or total volume. Some might feel that the total freeway volume should be used as the main factor in merging operation. This would obscure the fact that if there were a heavy off-ramp movement subsequent to the on-ramp, more vehicles would stay in lane 1 than would if there were no interchange for some distance, thus making the merge worse than would be normal for the same total volumes. It also appears that merging has little effect on the median lanes of roads having more than 2 lanes in each direction. It was

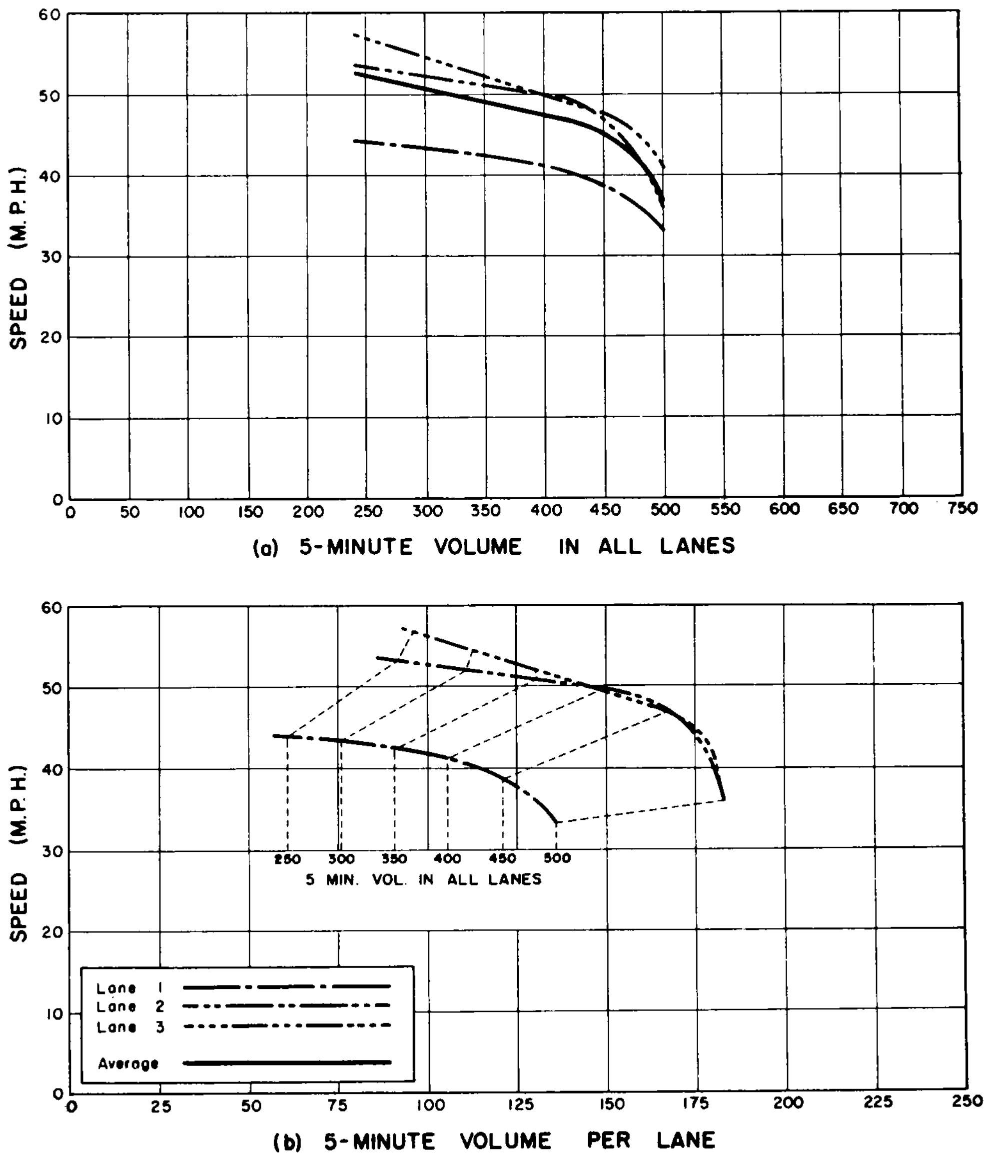


Figure 29. Speed-volume relationship, Location 42, Santa Ana Freeway SB at Mott Street.

observed frequently that a specific merging volume (that is, the sum of the volumes on the ramp and lane 1) resulted in just about the same congestion whether the other lanes were running full or not.

The volume at which merging breaks down always seems to be when about 170 vehicles try to squeeze into one lane at the end of the merging area in 5 min. This is a headway of 1.8 seconds and represents possible capacity of the going-away lane. The volume must remain considerably below this, however, if freeway speeds are to continue uninterrupted by entering vehicles. It does not seem to

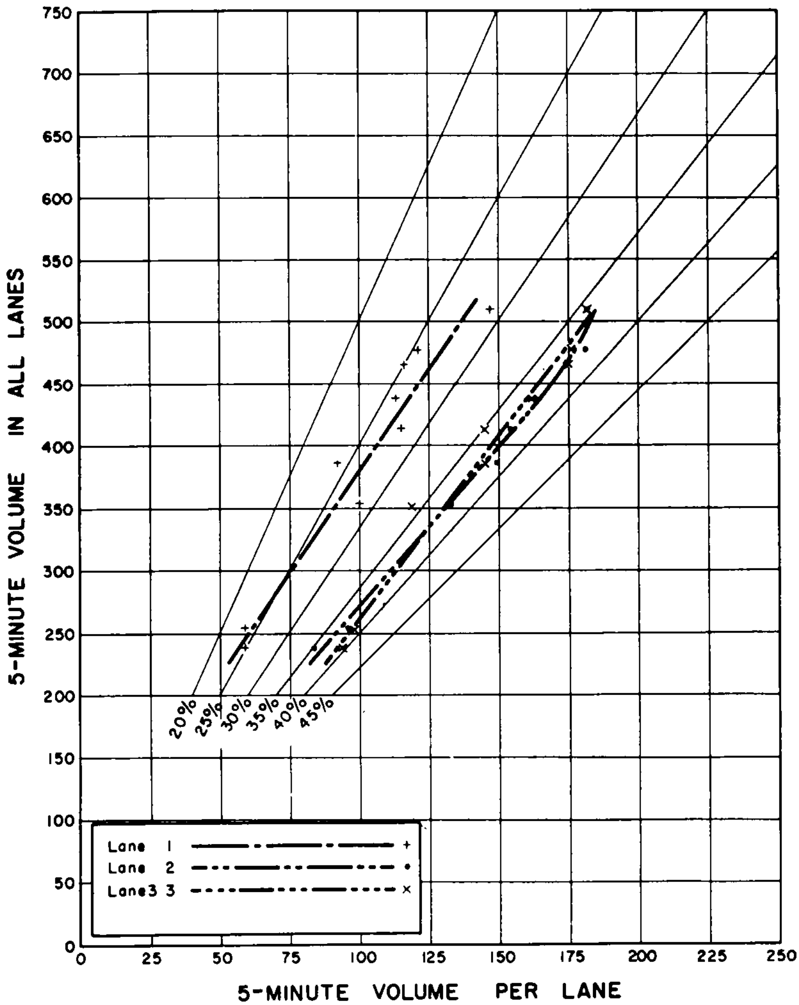


Figure 29(c). Lane distribution, Location 42, Santa Ana Freeway SB at Mott Street.

matter how long the merging area is for determining possible volume, but it should be 600 to 700 ft long for smooth operation at high volumes less than possible capacity.

At many high-volume ramps, the vehicles on the ramp do not come at random intervals as they do on the freeway. Vehicles come in platoons because of signal control on the surface streets, which makes the instantaneous merging rate much higher than the 5-min volumes indicate.

Other random observations regarding merging follow:

At very low volumes, speeds are more or less up to the individual rather than being dictated by traffic conditions. The approach (or merging) speed at Location 25 (Table 2 and Figure 28) is somewhat higher than that at Locations 17 and 18 (Table 3A, see Figure 33 for Location 18). This is a distinct advantage in merging and appears to be because the 7th Street ramp (Location 25) is downhill whereas the others are uphill.

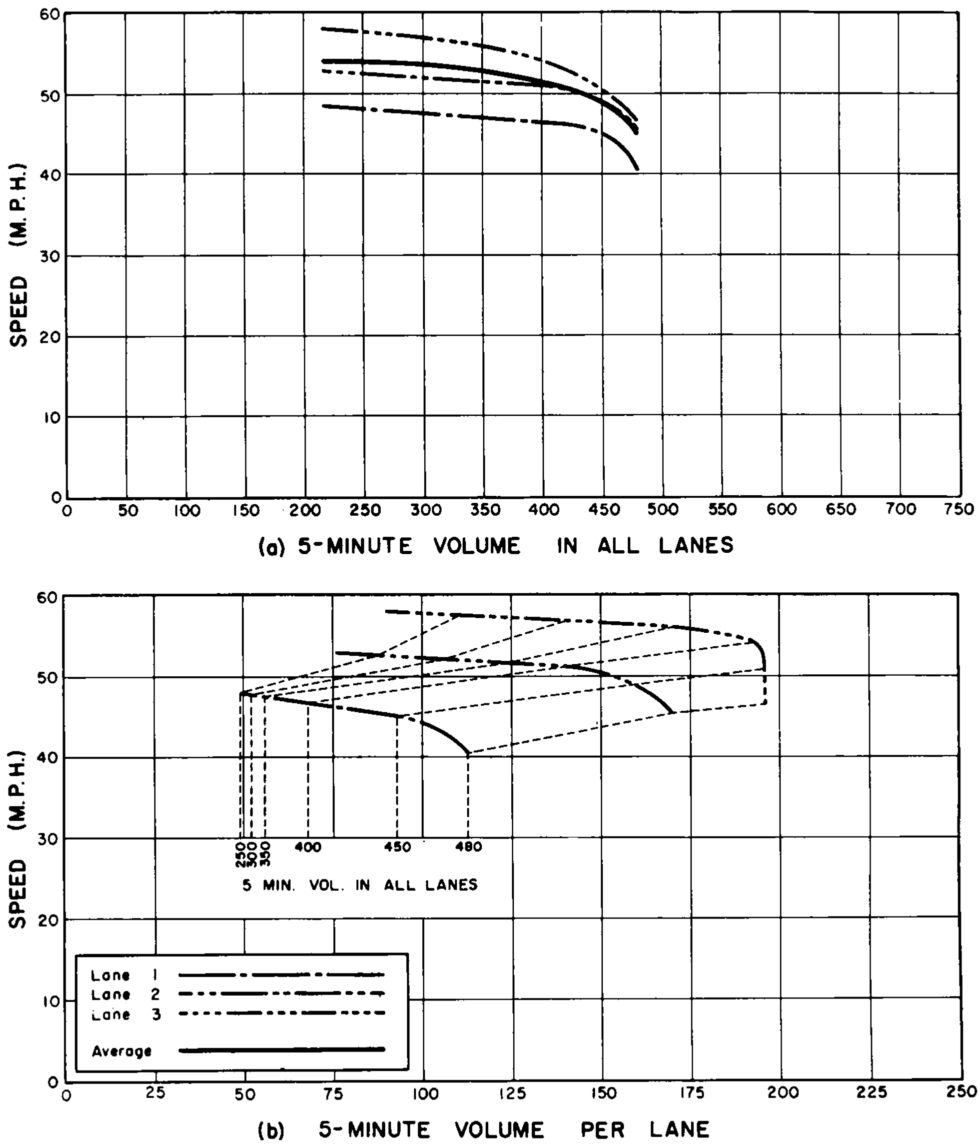


Figure 30. Speed-volume relationship, Location 46, Santa Ana Freeway NB at Long Beach Freeway.

The actual merging area here is only 405 ft long.

The possible capacity of a merge can approach but does not reach the possible capacity of one lane straight away, although operating conditions are not comparable. The highest whole-hour merging volume was 1,956 vehicles and the highest 5-min volume was 185 vehicles (2,220 vph). At acceptable operating volumes, the speed of merging vehicles will be about 30 mph. An acceptable operating volume is about 150 vehicles total for the ramp and lane 1 in a 5-min period. One or more of the six conditions listed in the second paragraph of this

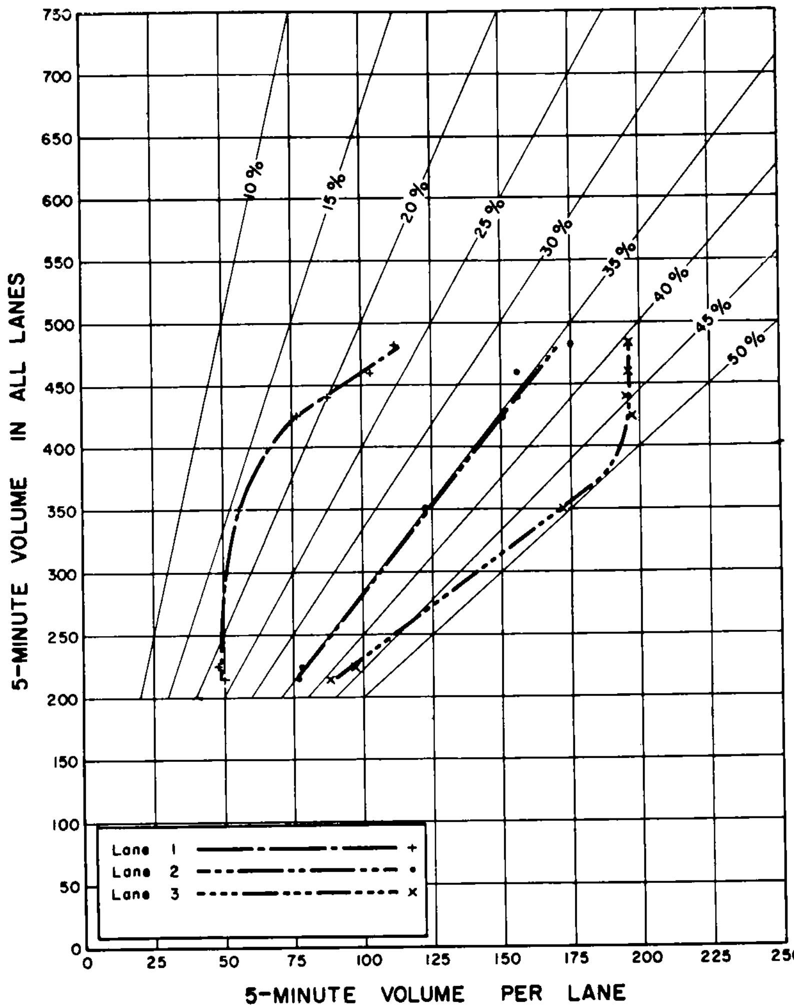


Figure 30(c). Lane distribution, Location 46, Santa Ana Freeway NB at Long Beach Freeway.

section may act to reduce this volume.

When the speed of ramp vehicles drops below 25 mph in the merging area, congestion with stoppages usually occurs. For this reason, steep upgrades on ramps and stop signs at the nose always contribute to poor operation.

Very few left-hand on-ramps have been studied and the ramp volumes were low at all locations. However, from the findings of this study, it can be inferred that left-hand on-ramps are undesirable, particularly those requiring merging with the median lane. Primarily this is because the average headway in the median lane is almost always less than in lane 1 and gaps are shorter and fewer. Slow vehicles in lane 1 usually create gaps large enough to accept entering vehicles. This objection can be overcome by adding a lane to accommodate the ramp traffic. But even if a lane is added, slow-moving vehicles must weave across the faster lanes to travel in lane 1, as the California Vehicle Code requires. If truck volumes

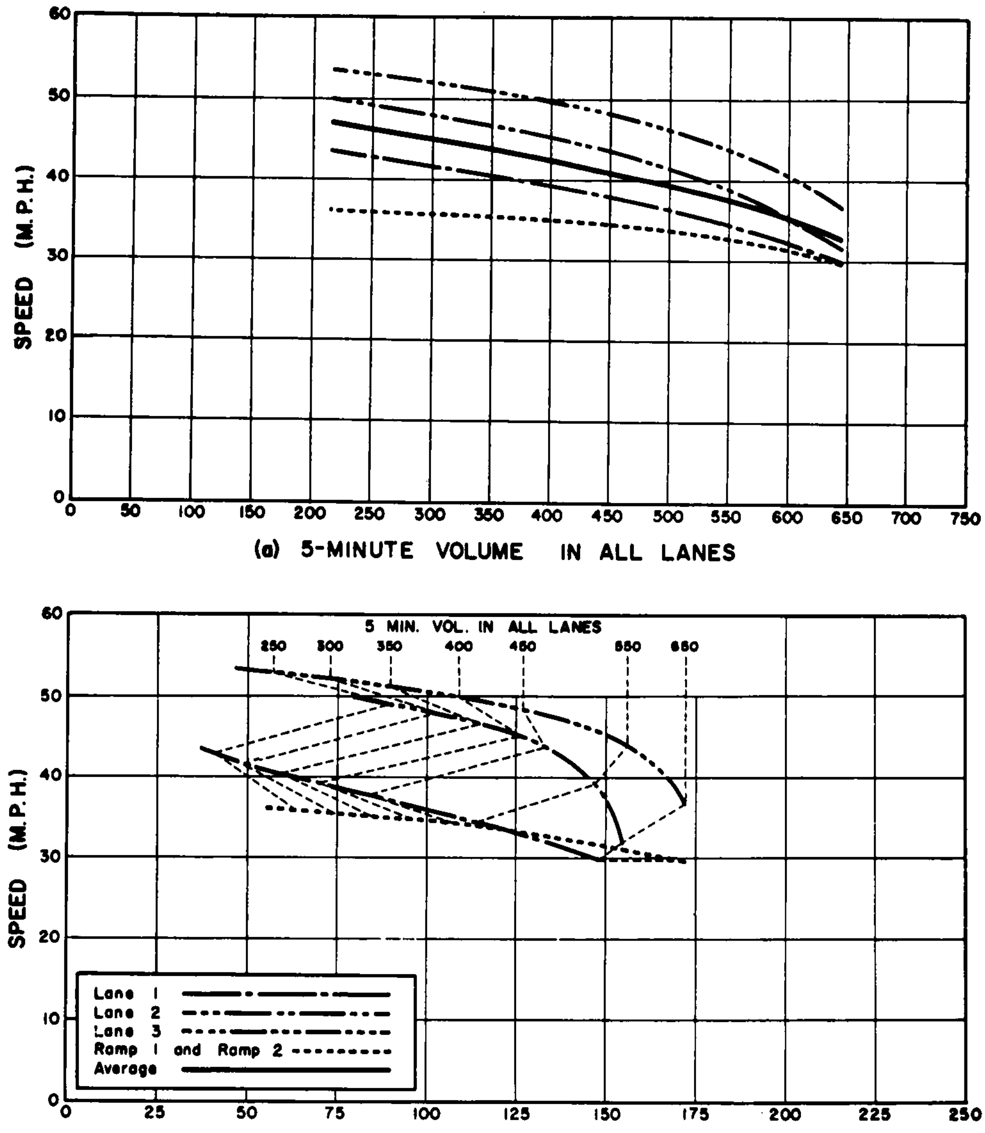


Figure 31. Speed-volume relationship, Location 2, Bayshore Freeway SB at Army Street.

are appreciable, serious congestion could result.

USE OF FREEWAY CHARACTERISTICS CURVES TO DETERMINE ACCEPTABLE VOLUME

The curves in Figures 25 through 37 can be used in determining acceptable operating volume by using speed as a measure of congestion. By entering the graphs at a particular speed, a 5-min volume can be determined which, when expanded to an hour volume by an appropriate factor (developed in a previous section) will be the most congested part of the hour.

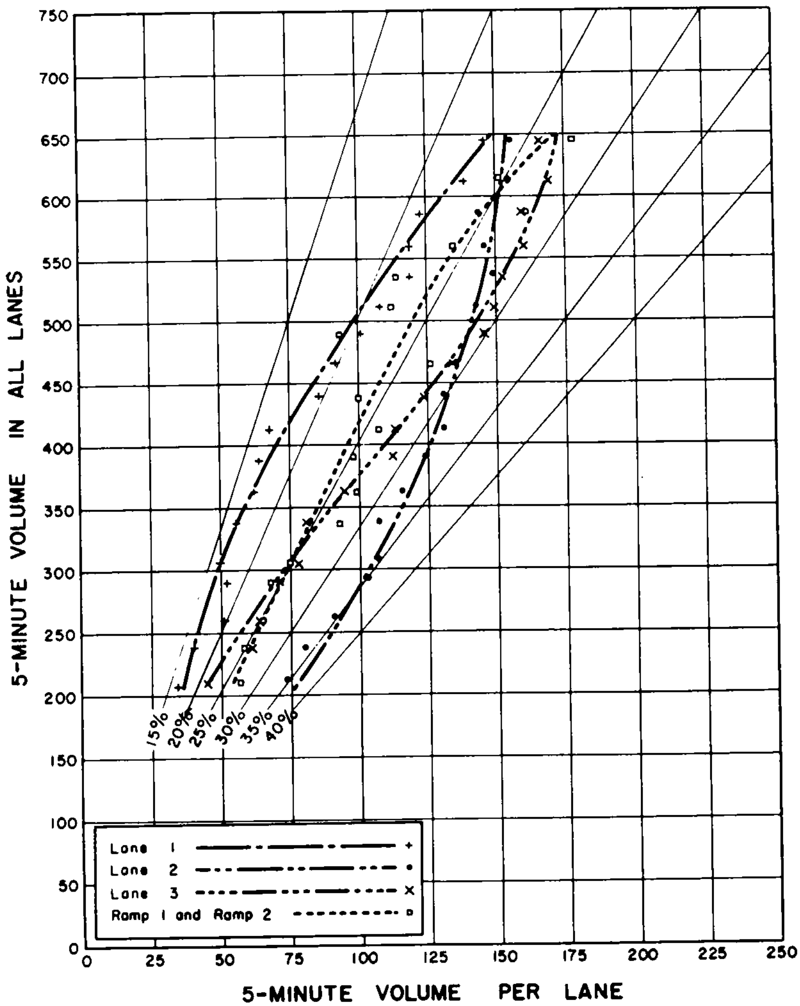


Figure 31(c). Lane distribution, Location 2, Bayshore Freeway SB at Army Street.

It is recommended that capacity be provided such that the average speed during the highest 5-min will not be less than 45 mph. At an average speed of 45 mph, operation is usually very smooth with gaps available for lane changing and no undue strain for urban driving conditions. It has been considered in the past that a freeway speed of 35 mph is tolerable for design purposes. At this speed, traffic is practically bumper to bumper with very few normal gaps available for lane changing and there is quite a bit of driving tension even for urban conditions. In addition to the lack of gaps at this speed, stoppages can occur quickly due to a faulty maneuver on the freeway (such as slow merging or lane changing). Operation which results in average speeds as low as 35 mph is therefore considered undesirable.

Acceptable Operating Volume

The values given in the following table are considered acceptable hourly

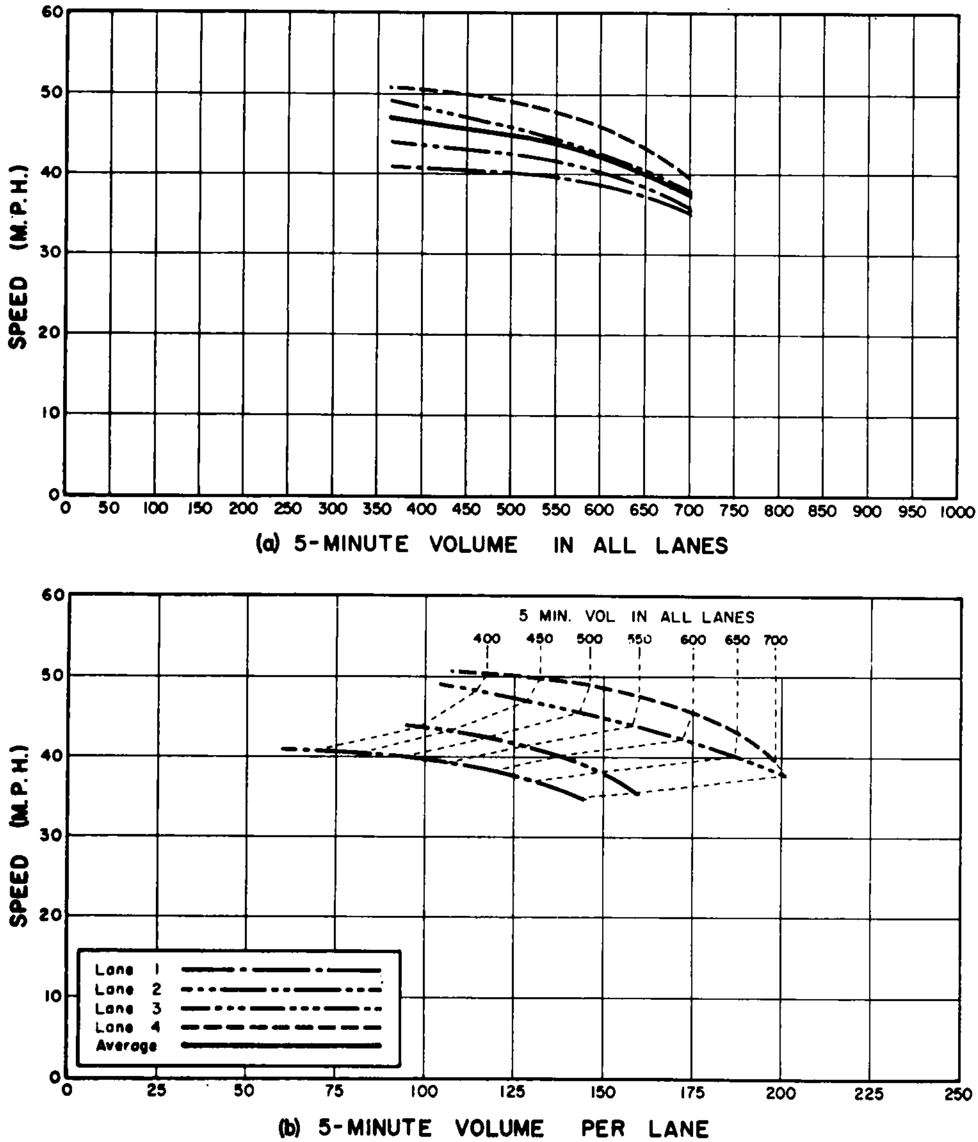


Figure 32. Speed-volume relationship, Location 11, Hollywood Freeway NB at Edgeware Road.

operating volumes under "average" conditions. "Average" conditions are considered to be:

1. Nearly level grade line.
2. About 3 percent trucks.
3. Absence of high-volume ramps within 1 mile.
4. Urban area having more than 1,000,000 population.

These values were determined through careful study of Figures 25 through 36, balanced by experience gained through observation at other locations previously listed.

Acceptable volumes would be higher in the presence of one of the following factors:

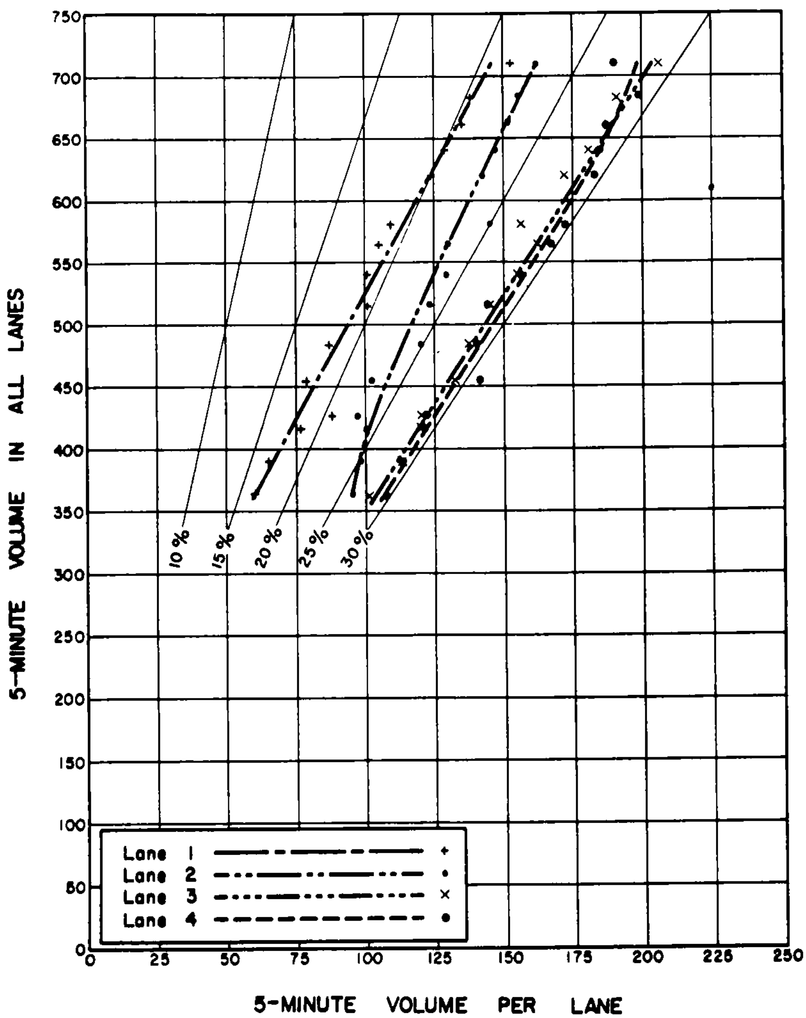


Figure 32(c). Lane distribution, Location 11, Hollywood Freeway NB at Edgeware Road.

Lane	4-Lane Freeway		6-Lane Freeway		8-Lane Freeway	
	Volume, vph	Speed, mph	Volume, vph	Speed, mph	Volume, vph	Speed, mph
1	1,200	40	1,200	40	1,200	39
2	1,800	47	1,700	45	1,500	41
3	—	—	1,800	47	1,800	44
4	—	—	—	—	1,800	47
Total	3,000	—	4,700	—	6,300	—
Avg.	1,500	44	1,565	44	1,575	43

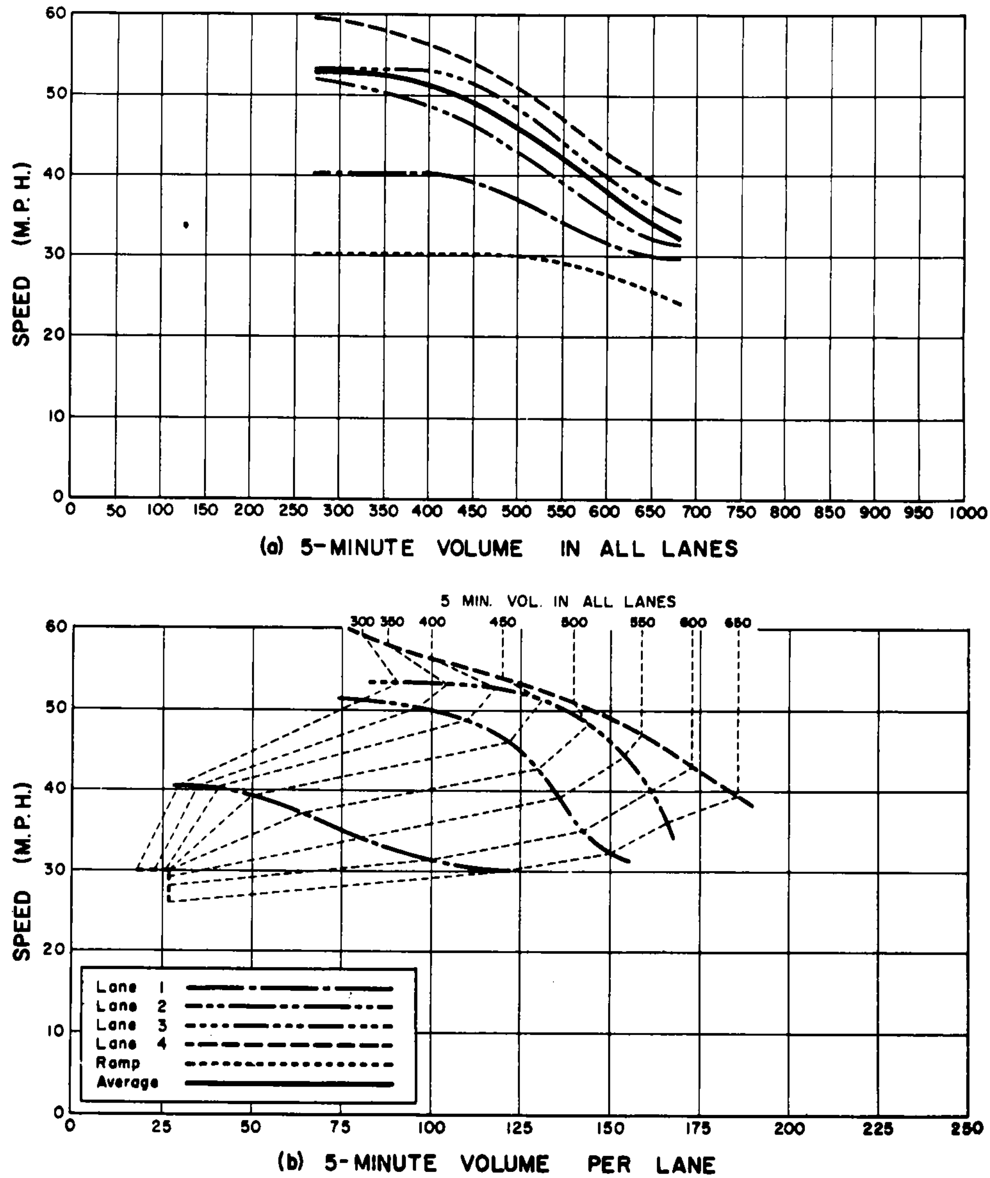


Figure 33. Speed-volume relationship, Location 18, Hollywood Freeway SB between Alvarado Street and Belmont Avenue.

1. Downhill grade line.
2. Less truck volume.
3. An "expanding" situation ahead which could be either the addition of a lane to the freeway, a branch connection where the total number of lanes is increased and both legs have more than adequate capacity, or any other factor providing increased capacity.

Acceptable volumes would be lower in the presence of one of the following:

1. Uphill grade line (this effect is very severe).

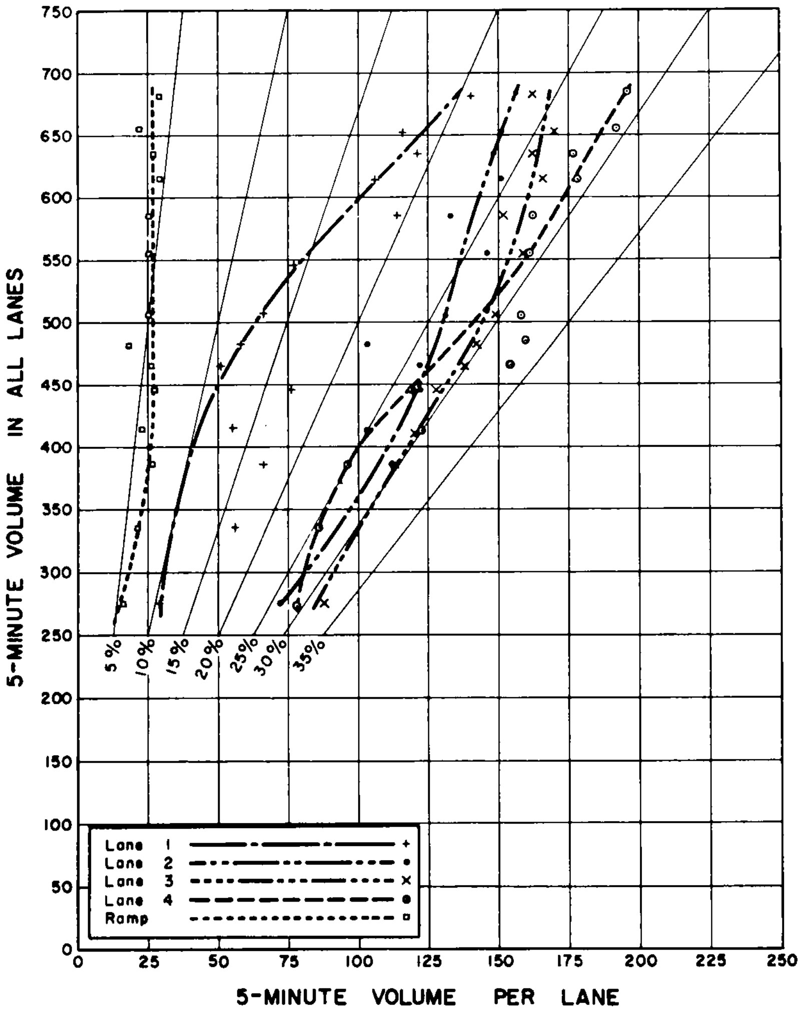


Figure 33(c). Lane distribution, Location 18, Hollywood Freeway SB between Alvarado Street and Belmont Avenue.

2. More truck volume (1 percent would be a lot more).

3. A smaller metropolitan community where the short-term rate-of-flow would be higher because of a lack of metering.

Actually, "average" conditions may be considered hypothetical and acceptable operating conditions are not determined by the average, but rather by the sections of least capacity. For this reason it is important for the engineer to exercise judgment and provide a balanced design. The effectiveness of many miles of excellent design may be lost if adequate capacity is not provided for one or two short lengths.

SUMMARY OF FINDINGS

The following is a summary of general characteristics of freeway operation that have been concluded from these studies:

1. The highest one-way volume observed during one hour was 8,082 vehi-

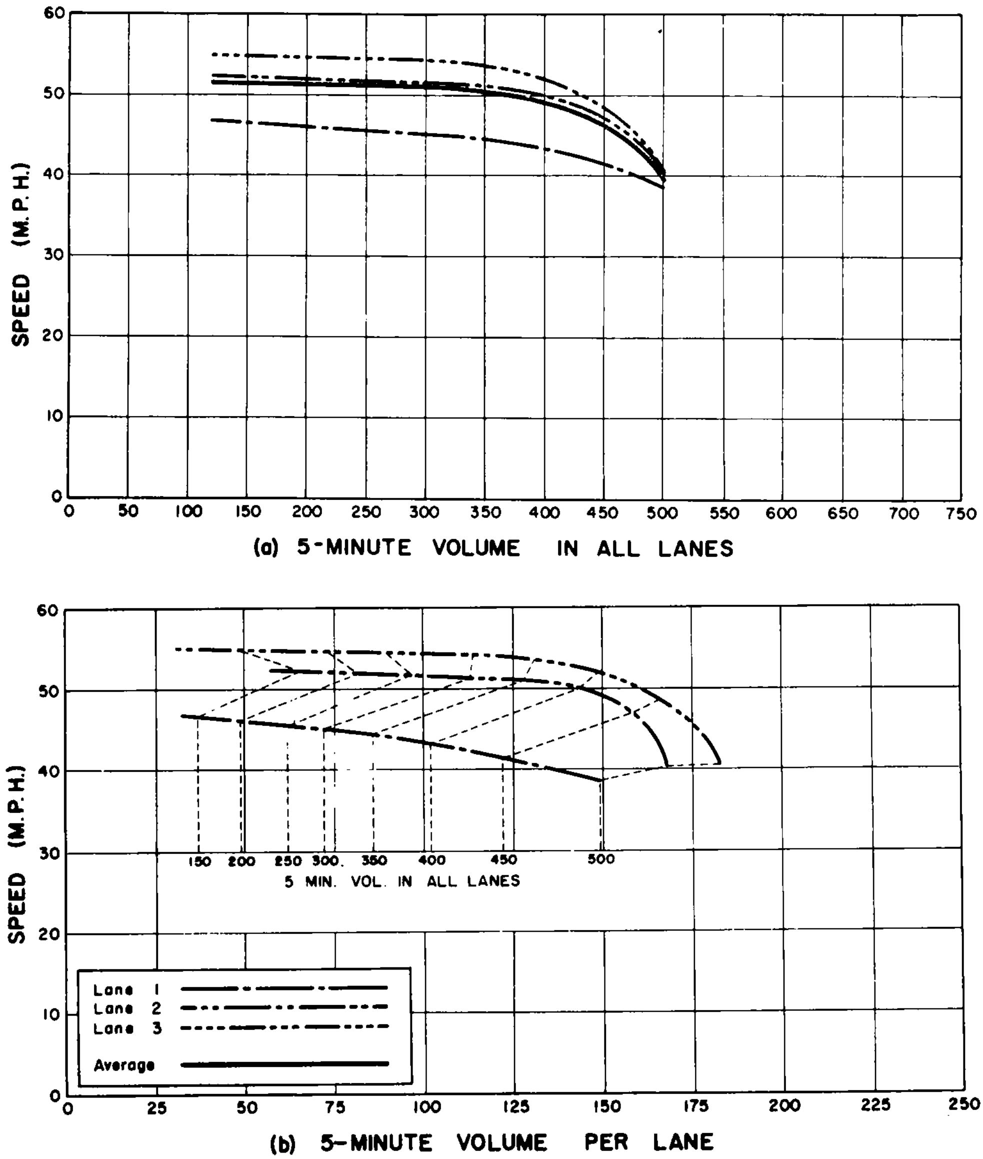


Figure 34. Speed-volume relationship, Location 32, Pasadena Freeway EB at Sycamore Avenue.

cles southbound on the five-lane weaving section of the Harbor Freeway immediately south of the four-level interchange in Los Angeles. The highest lane volume observed during a whole hour was 2,437 vehicles, at an average speed of 45 mph. Some other high hourly volumes were as follows (all figures are one-way traffic in the direction of heavier flow):

Four Lanes One Way (8-Lane Freeways)

Hollywood Freeway NB from 4-level interchange 7,913

Hollywood Freeway NB at Vermont 7,637

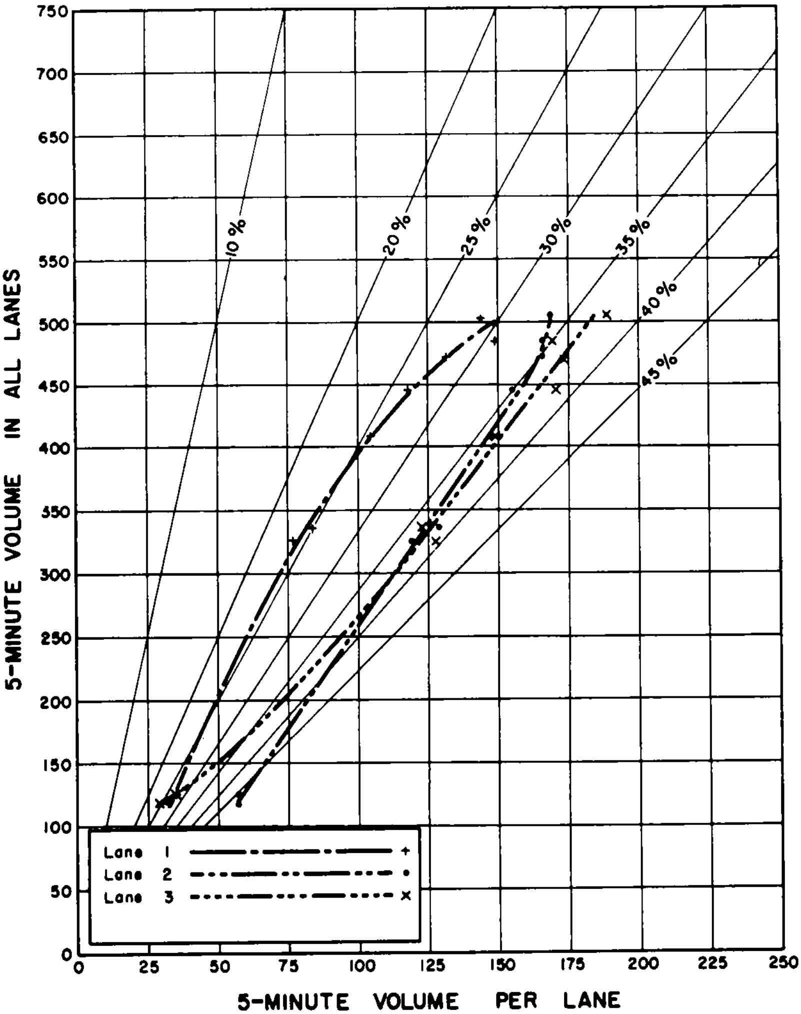


Figure 34(c). Lane distribution, Location 32, Pasadena Freeway EB at Sycamore Avenue.

Hollywood Freeway NB at Mulholland 6,419
Bayshore Freeway SB at 22nd Street 6,002

Three Lanes One Way (6-Lane Freeways)

Hollywood Freeway SB at Highland .... 6,630 (downhill)
Pasadena Freeway NB at Sycamore Avenue 5,665
Eastshore Freeway NB at 19th Street 4,270

Two Lanes One Way (4-Lane Freeways)

Santa Ana Freeway NB at Florence 3,962
Eastshore Freeway SB at Hegenberger 3,164

2. When possible capacity is reached at one location in the freeway system, approaching vehicles have to wait. These waiting vehicles queue up and suffer the symptoms of congestion for long distances behind the point of possible capacity. Observers have to be careful to distinguish between back-up from an-

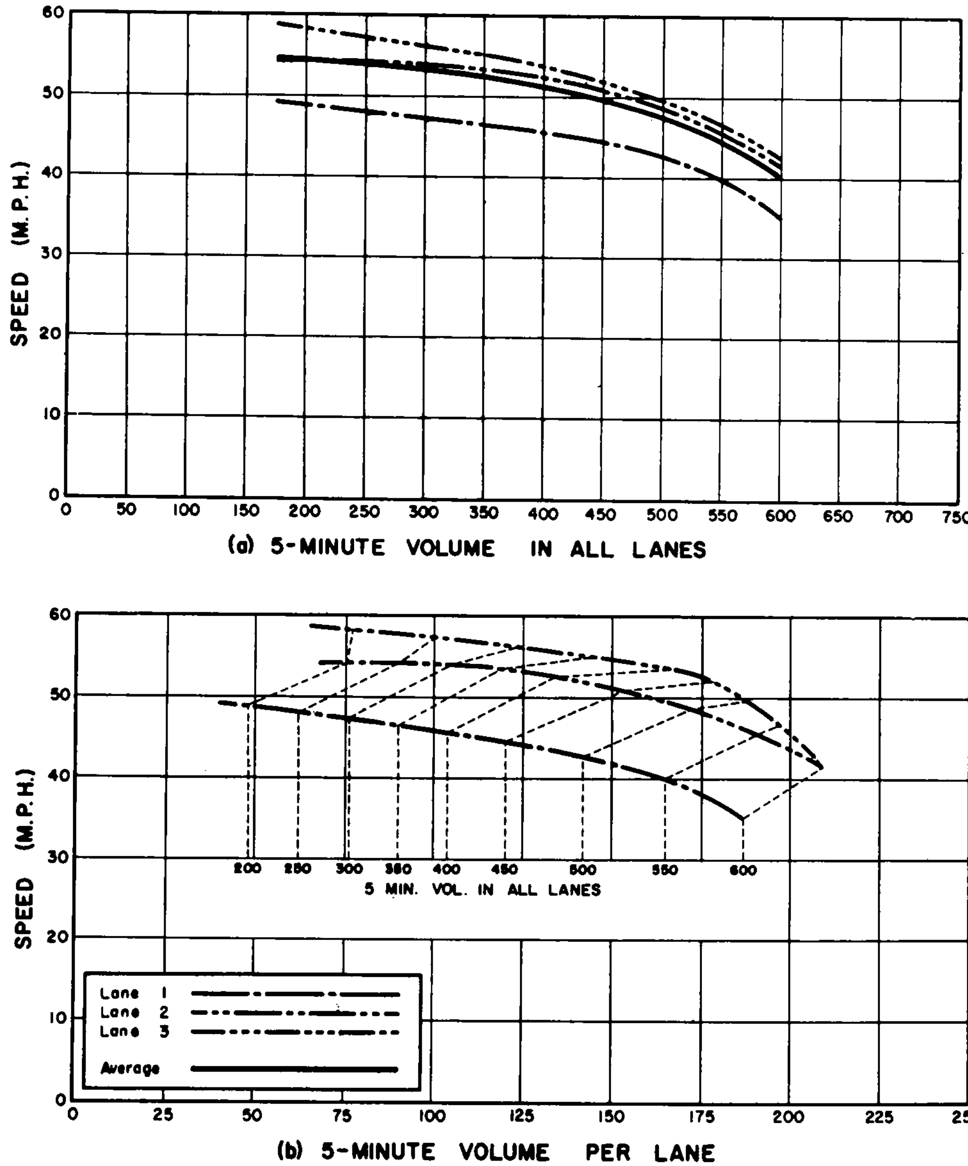


Figure 35. Speed-volume relationship, Location 14, Hollywood Freeway SB at Highland Undercrossing.

other point and restricted operation at the point of observation.

3. To provide acceptable operating conditions, the short-term rate-of-flow may not exceed about 165 vehicles per 5-min interval in the median lane, provided there are no unusual grade or ramp conditions and about 3 percent trucks in the stream. The effect of grades is very pronounced.

4. An hour is too long a unit of time to use in describing a rate-of-flow. In Los Angeles, the hourly volume is about 11 times the highest 5-min volume; in Sacramento the hourly volume is about 9 times the highest 5-min volume. The

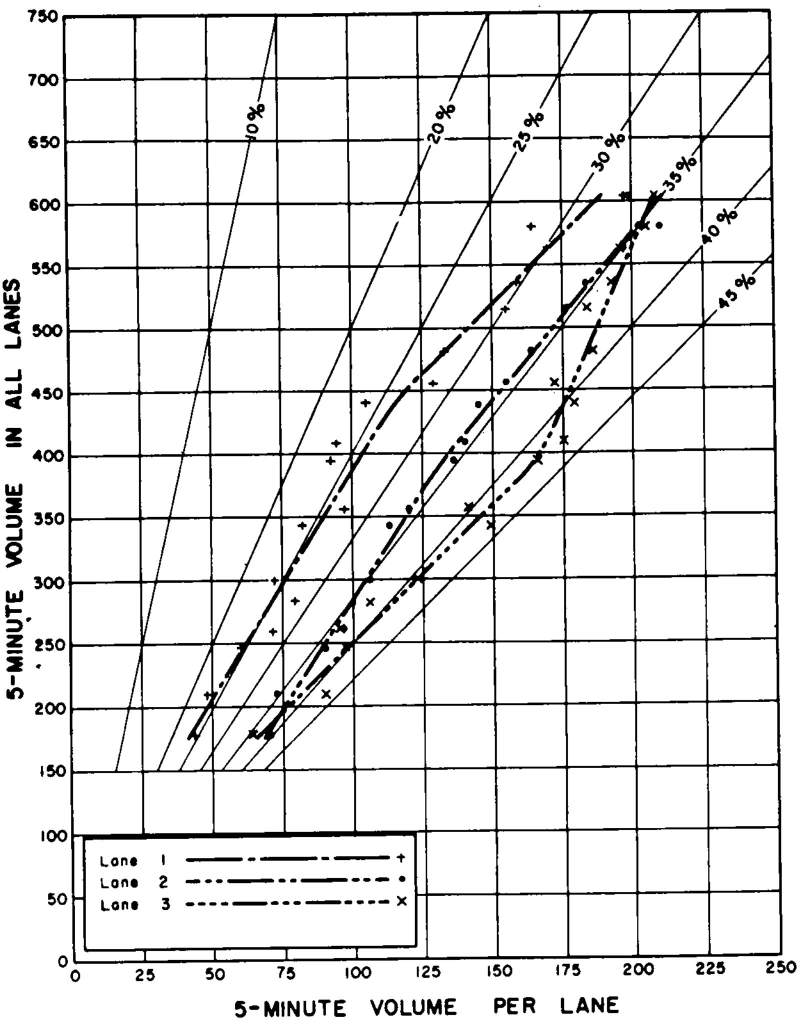


Figure 35(c). Lane distribution, Location 14, Hollywood Freeway SB at Highland Undercrossing.

rate-of-flow cited in the previous paragraph (165 vehicles per 5-min interval) would be associated with an hourly volume of 1,800 vehicles in the median lane in Los Angeles (population of metropolitan area more than 2,000,000), but only 1,500 in Sacramento (population of metropolitan area less than 500,000).

5. Traffic is not evenly distributed by lane. The lanes nearer the median carry much more traffic than the shoulder lane, and at higher speeds than the shoulder lane.

6. Combining the observations of findings 3, 4, and 5, it is seen that even when the maximum practical rate-of-flow is reached for short intervals, an hourly volume that averages 1,500 per lane in one direction on a 4-lane freeway could be considered "practical capacity" only if the traffic is metered by an extensive city street system, and the volume of trucks in lane 1 is very small. On a 6-lane freeway, 1,500-per-lane would be much more practical, and on an 8-lane freeway it would cause no trouble unless there

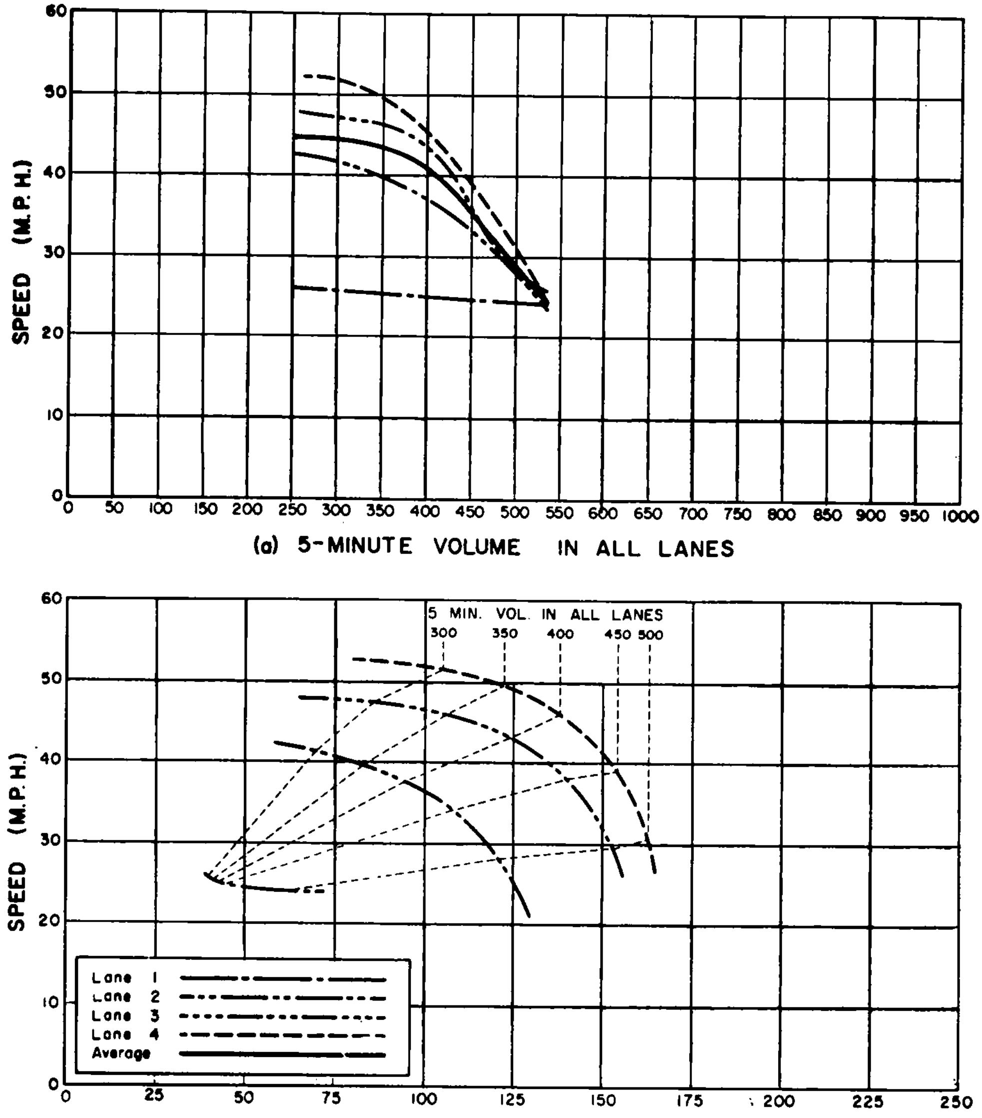


Figure 36. Speed-volume relationship, Location 13, Hollywood Freeway NB at Mulholland Drive.

were sustained up-grades long enough to slow trucks down to speeds of less than 40 mph and thus pre-empt use of lane 1.

7. The drop in speed associated with high volume is slight, unless it is caused by a back-up. At a rate-of-flow of 165 per 5 min, speeds in the median lane are about 50 mph.

8. Undesirable congestion is usually experienced when traffic volumes increase to the point where operating speeds are reduced to 35 mph. At this speed, traffic is practically bumper to bumper; there are few normal gaps available for lane changing, and there is noticeable driving tension even for short rides.

As a matter of fact, the average operating speed never dropped as low as 35

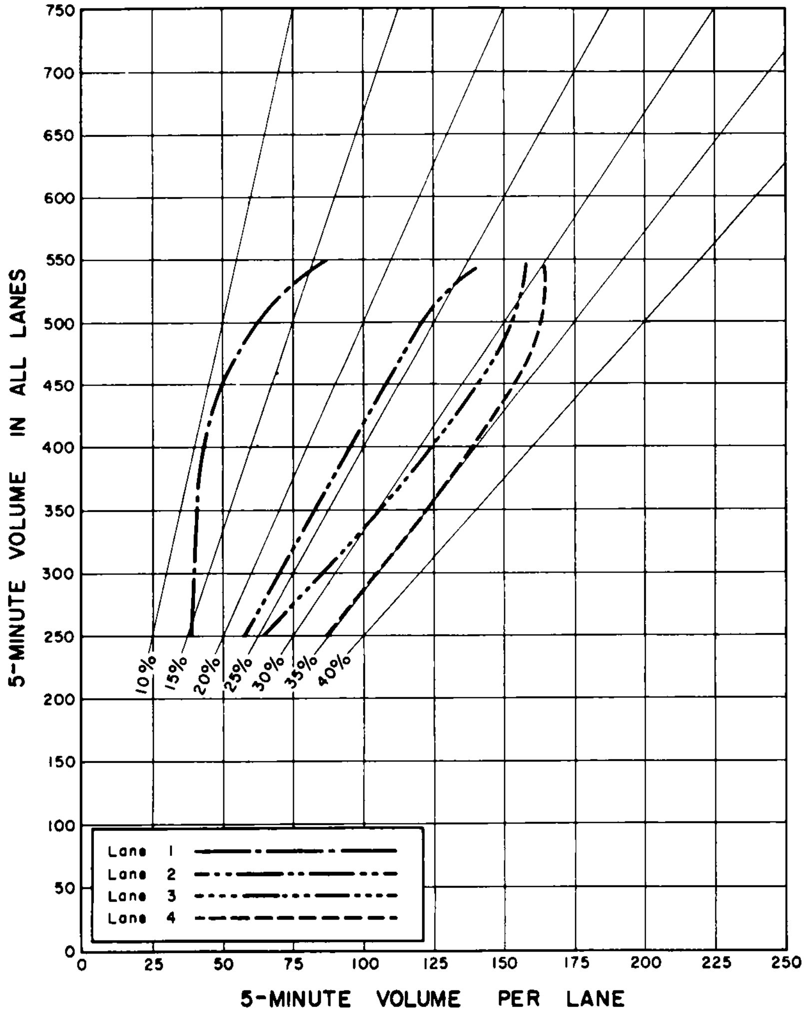


Figure 36(c). Lane distribution, Location 13, Hollywood Freeway NB at Mulholland Drive.

mph at any of the locations observed unless there was a queuing-up of waiting vehicles from a bottleneck (for example, a drop of a lane) ahead. It is believed that volumes which result in an average freeway speed of 45 mph should be considered as the upper limit of practical capacity. At an average speed of 45 mph, the traffic in the shoulder lane will average about 40 mph and traffic in the median lane will average near 50 mph.

9. Speed-volume curves are a little higher than those shown in the "Highway Capacity Manual" of 1950 and appear to be curved downward at the right-hand end.

10. Acceptable hourly operating volumes under "average" conditions in a very large urban area for one roadway of freeways of various widths were shown in the table given under "Acceptable Operating Volume." In a smaller area (less than 2 million) the acceptable volumes would be less.

"Average" conditions for this purpose include: nearly level grade, about 3 percent trucks, and absence of high-volume ramps in the near vicinity.

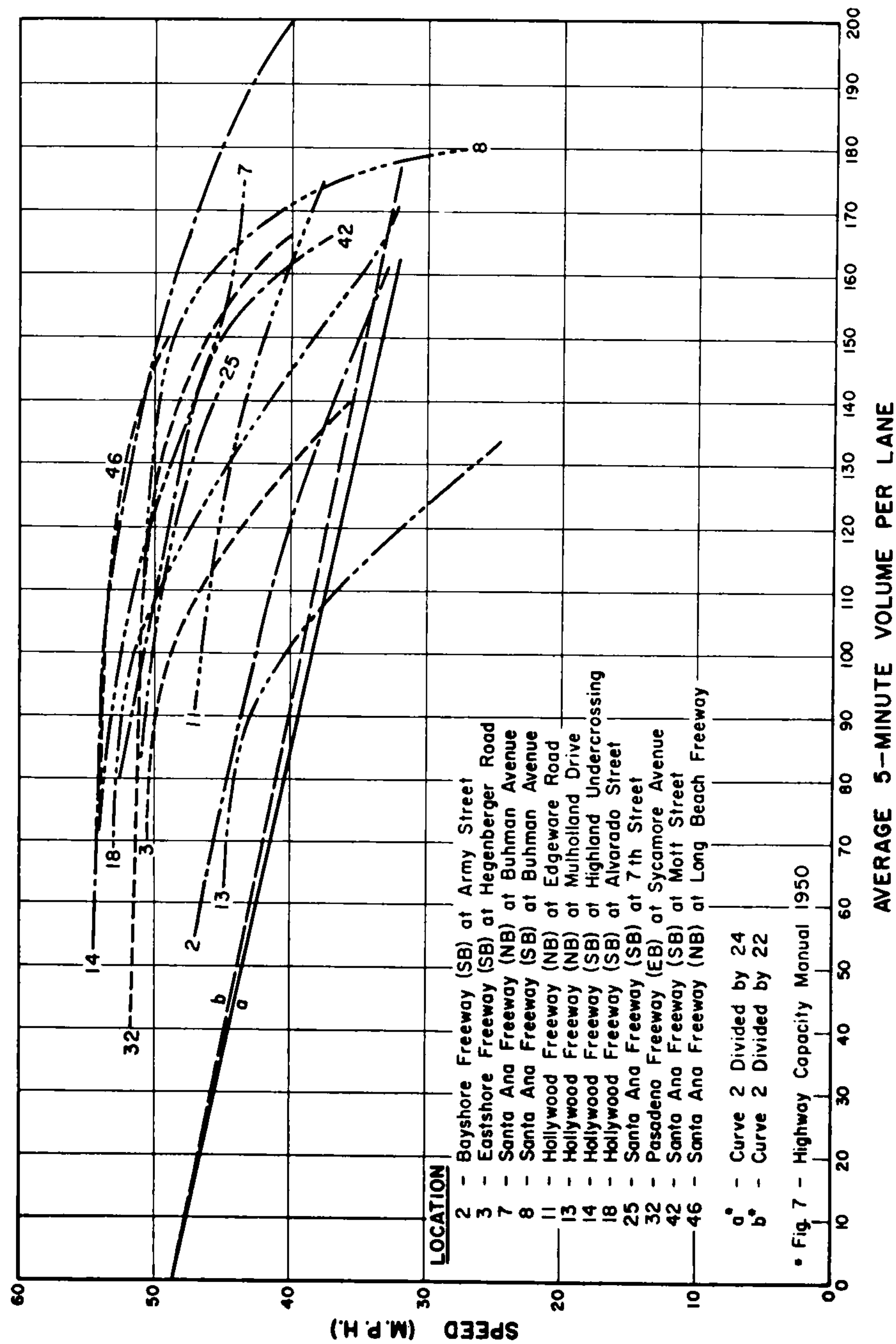


Figure 37. Relation between speed and average lane volume.

11. Plus grades as small as 2 percent significantly reduce capacity when truck volumes are appreciable. On down-grades of significant length, average volumes of 2,000 vehicles per lane per hour can be carried with no congestion.

12. Results obtained to date do not show that long merging areas (more than 500 ft) will handle larger merging volumes than short merging areas. This is contrary to expectation. However, for smooth operation it is essential that the acceleration lane, including the merging area, be long enough for ramp vehicles to reach near-freeway speeds. It is also essential that the merging area portion of the on-ramp be several hundred feet long.

The highest full-hour single-lane on-ramp volume observed was 1,309, merging with 647 to produce 1,956 in lane 1 just beyond the merge. This merging area is 405 ft long, including the taper.

At all locations where merging or weaving operations appeared to break down, the straight-away rate-of-flow per lane exceeded the inverse of a 2-second headway. From this it is tentatively concluded that the correlation of merging or weaving distance and volume is less than previously supposed.

ACKNOWLEDGMENT

The work reported here was done for the California Division of Highways under the supervision of the authors. Henry O. Case and Leonard Newman are responsible for much of the editorial content of the report, as well as collection of the data. D. C. Chenu and George Pluto did most of the work involved in compiling and reducing the data and producing the graphs.

REFERENCE

1. HRB Committee on Highway Capacity, "Highway Capacity Manual." U. S. Govt. Printing Office, Washington, D. C., $1.00 (1950).

APPENDIX

LIST OF OBSERVED LOCATIONS

Location No.	Freeway Name	Location Name
1	Bayshore Frwy SB	22nd Street
2	Bayshore Frwy SB	Army St. on-ramp
3	Eastshore Frwy SB	Hegenberger Road off-ramp
4	Eastshore Frwy NB	19th Street
5	Eastshore Frwy SB	1st Ave. off-ramp
6	Bayshore Frwy NB	Alemany Street on-ramp
7	Santa Ana Frwy NB	Buhman Avenue
8	Santa Ana Frwy SB	Buhman Avenue
9	Santa Ana Frwy NB	Greenwood Avenue
10	Pasadena Frwy EB	Avenue 35
11	Hollywood Frwy NB	Edgeware Road
12	Hollywood Frwy NB	Vermont Avenue off-ramp
13	Hollywood Frwy NB	Mulholland Drive
14	Hollywood Frwy SB	Highland Avenue undercrossing
15	Hollywood Frwy NB	At Pasadena — Harbor merge
16	Hollywood Frwy SB	Barham Blvd. on-ramp
17	Hollywood Frwy SB	Vermont Ave. on-ramp
18	Hollywood Frwy SB	Between Alvarado St. and Belmont Ave.
19	Bayshore Frwy SB	Alemany Street off-ramp
20	Bayshore Frwy NB	Army Street off-ramp
21	Santa Ana Frwy NB	Florence Avenue on-ramp
22	Hollywood Frwy NB	Highland Avenue on-ramp
23	San Bernardino Frwy	Rosemead Boulevard
24	San Bernardino Frwy WB	Marengo Street on-ramp
25	Santa Ana Frwy SB	7th Street on-ramp
26	Harbor Frwy SB	Hollywood — Santa Ana merge
27	Bayshore Frwy NB	Army Street on-ramp
28	No. Sacto. Frwy SB	El Camino Avenue on-ramp
29	No. Sacto. Frwy NB	Marconi Avenue off-ramp
30	Elvas Frwy NB	Arden Way off-ramp
31	No. Sacto. Frwy SB	Arden Way (WB) on-ramp
32	Pasadena Frwy EB	Sycamore Avenue
33	Pasadena Frwy WB	Fair Oaks Avenue on-ramp
34	San Bernardino Frwy WB	Campbell Avenue
35	San Bernardino Frwy WB	Garvey Avenue on-ramp
36	Hollywood Frwy SB	Spring Street
37	Hollywood Frwy NB	Hill Street
38	No. Sacto. Frwy SB	Arden Way — El Camino Avenue
39	Hollywood Frwy SB	Highland Avenue off-ramp
40	Santa Ana Frwy NB	Lakewood Boulevard on-ramp
41	Harbor Frwy NB	Northbound Distributor on-ramp
42	Santa Ana Frwy SB	Mott Street
43	San Bernardino Frwy WB	Del Mar Avenue — Almansor Avenue
44	San Bernardino Frwy EB	Warwick Road
45	San Bernardino Frwy WB	Atlantic Boulevard
46	Santa Ana Frwy NB	Long Beach Frwy
47	Hollywood Frwy SB	Between Highland Ave. and Cahuenga Blvd.
48	Hollywood Frwy SB	Sunset Blvd. on-ramp
49	Hollywood Frwy NB	Sunset Blvd. off-ramp
50	Santa Ana Frwy NB	Between Atlantic St. and 7th St.