

# Traffic Behavior and Off-Ramp Design

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• OFF-RAMP terminals on California Freeways are designed according to the direct angular take-off principle, as contrasted with the parallel deceleration lane principle. This design is a modification stemming from the off-ramp design of the added full lane preceded by a taper which was at one time standard. It was observed that almost no drivers actually drove the reverse curve alignment that this design called for, and this led to the statewide use of the direct type of off-ramps. Some of the reverse-curve types of off-ramps at major interchanges were reconstructed as directional-type ramps.

The shape of the direct type of off-ramp as it leaves the freeway is considered generally satisfactory, but the damage to guardrails and markers, the tire scuffs on curbs, and some reported accidents indicate that the deceleration distance to the ramp curve beyond the curb nose may be inadequate. This study was made to obtain factual data on the operating characteristics of the traffic as it leaves the freeway on various existing off-ramps. The objective was to determine whether the length of the ramp tangent approaching the ramp curve has any effect on ramp speed, and if it does, what the optimum length of such a tangent is.

## METHODS

To obtain this objective, the speeds at various locations along the ramp were observed.

### Off-Ramps Studied

For the purpose of this study 8 existing off-ramps were observed. Three were in the San Francisco Bay area (sites 11, 21 and 31), four in the Los Angeles area (sites 41, 51, 61, and 71), and one in Sacramento (site 81). Exit speeds were not posted at the ramps and the prima facie speed limit at the time of the study was 55 mph.

The description of these ramps follows:

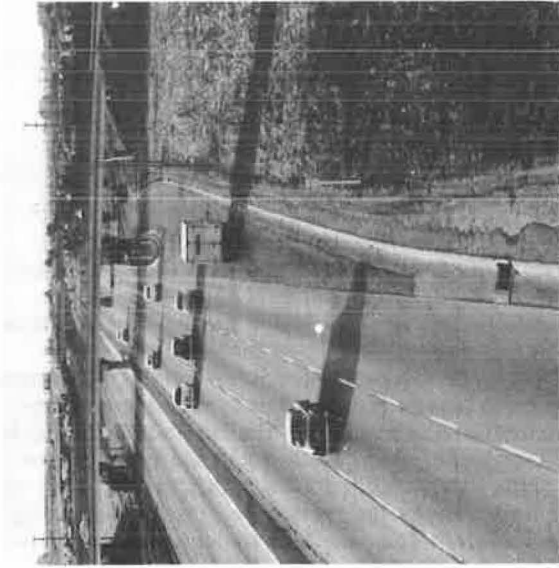
Site 11.—Northbound off-ramp to First Avenue on the Eastshore Freeway in Oakland (Fig. 1). The ramp connects to a loop of a two-quadrant cloverleaf interchange. The reversing curve of the off-ramp appears to slow traffic on the ramp. The distance from the curb nose of the ramp to the B.C. of the 250-ft radius curve is 167 ft. It is an additional 121 ft to the PCC of the 150-ft radius curve. The off-ramp passes under the First Avenue overcrossing.

Site 21.—Southbound off-ramp to Winton Avenue on the Eastshore Freeway in Hayward (Fig. 2). The distance from the curb nose to the B.C. of the 400-ft radius curve is 490 ft.

Site 31.—Northbound off-ramp to Gilman Avenue on the Eastshore Freeway in Berkeley (Fig. 3). The ramp widens to two lanes 350 ft beyond the curb nose. The distance from curb nose to "Stop" sign at end of this diamond-type off-ramp is 990 ft.

Site 32.—Approach to "Stop" sign at end of diamond-type off-ramp to Gilman Street (Fig. 4).

Site 41.—Southbound off-ramp to Lakewood Boulevard on the Santa Ana Freeway (Fig. 5). The B.C. of the 250-ft radius curve is at the nose of the off-ramp. The free-



way at this point is on a +2.30 percent grade. The crest of the vertical curve on the ramp is 110 ft beyond the nose.

**Site 51.**—Westbound off-ramp to Rosemead Boulevard on the San Bernardino Freeway. The interchange is a full cloverleaf-type design with a collector road for turning traffic (Fig. 6). The distance from the curb nose to the dividing point where the northbound on Rosemead enters a 200-ft radius curve to the right and the southbound on Rosemead travels straight ahead is 350 ft. Sight distance is no problem. The freeway is on a +0.96 percent grade. The off-ramp gore is striped as shown.

**Site 61.**—Westbound off-ramp to Temple City Boulevard on the San Bernardino Freeway (Fig. 7). The B.C. of the 130-ft radius curve is 100 ft beyond the curb nose of the ramp. The freeway is on a sag vertical curve with the grade at the beginning of the ramp approximately -1.4 percent. The off-ramp gore is striped.

**Site 71.**—Eastbound off-ramp to Vincent Avenue on the San Bernardino Freeway (Fig. 8). The freeway is on +0.94 percent grade. The distance from curb nose to B.C. of the 141-ft radius curve is 82 ft. The off-ramp gore is striped.

**Site 81.**—Northbound off-ramp to Arden Way on the Elvas Freeway in North Sacramento (Fig. 9). At this location the freeway is on a 2,000-ft radius curve and the off-ramp is also on a 2,000-ft radius curve. Sight distance is not a problem. The ramp merges with an off-ramp from the North

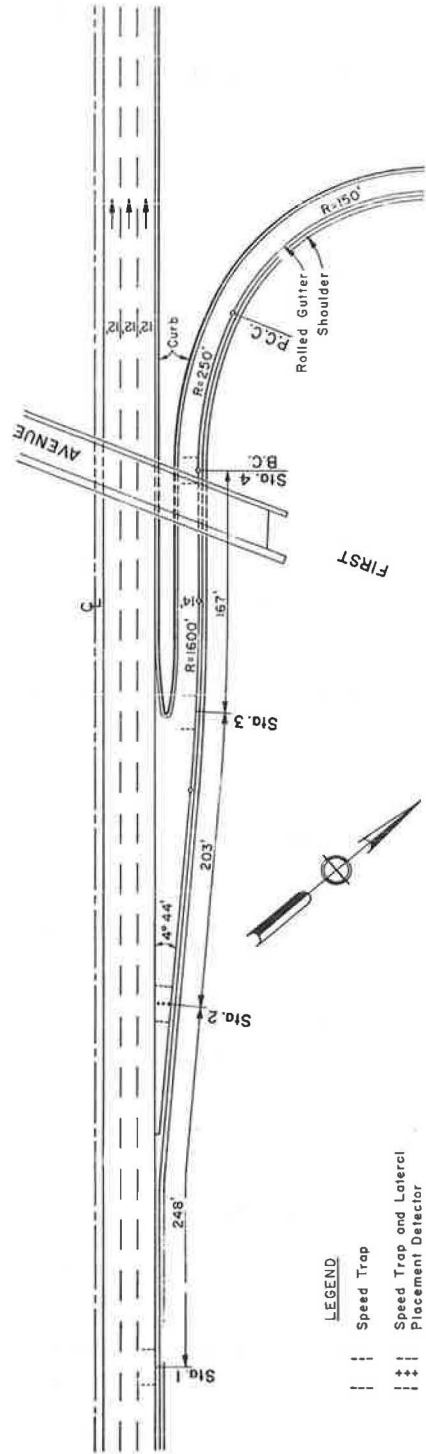
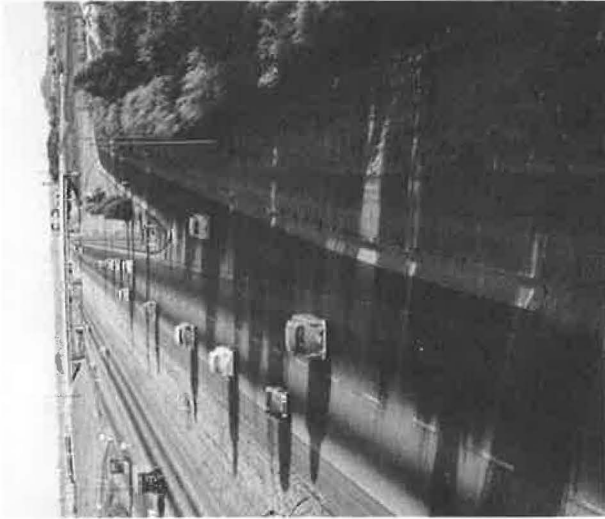


Figure 1. Study site 11, northbound exit ramp to First Ave., Eastshore Freeway, Oakland, Calif.



Sacramento Freeway (US 40) 1,700 ft from the curb nose, and the controlling 250-ft radius curve is 1,200 ft beyond this point. Due to its length, the ramp was split into two sites: site 81 at the location where vehicles leave the freeway, and site 82, the location where vehicles entering Arden Way pass through the controlling 250-ft radius curve.

Site 82.—Location at the end of the Arden Way ramp (Fig. 10).

Data Collecting

The data were obtained with the aid of Traffic Analyzer equipment furnished and operated by personnel of the U. S. Bureau of Public Roads. Four separate units permitted the study of four locations along the ramp simultaneously. Each unit, when actuated by road tubes placed at predetermined locations, recorded on an adding machine tape the time of day to ten-thousandths of an hour and time in hundredths of a second to travel a set speed trap. In addition, operators were present to punch a code into each unit for classifying the type of vehicle.

The stations for study along the ramp were situated as shown in the figures of the various off-ramps. In each study, station 1 was located on the freeway preceding the beginning of the off-ramp. At this station, the operator was required to segregate by code each vehicle that entered the off-ramp. Station 2 was placed where the tapered off-ramp was 12 ft wide. Here, in addition to the speed trap, a placement detector was put in the roadway and the lateral placement of the vehicles leaving the freeway was recorded.

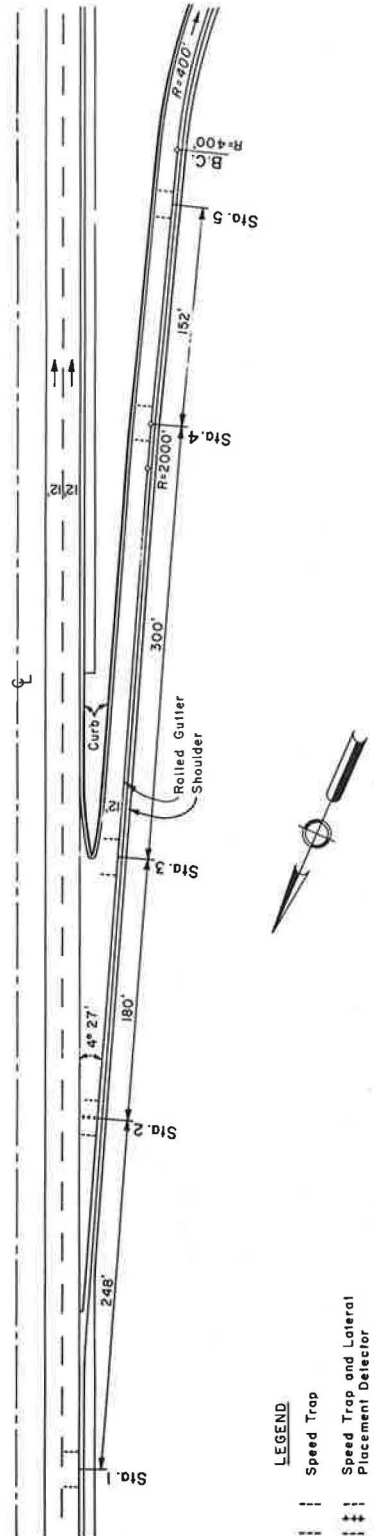
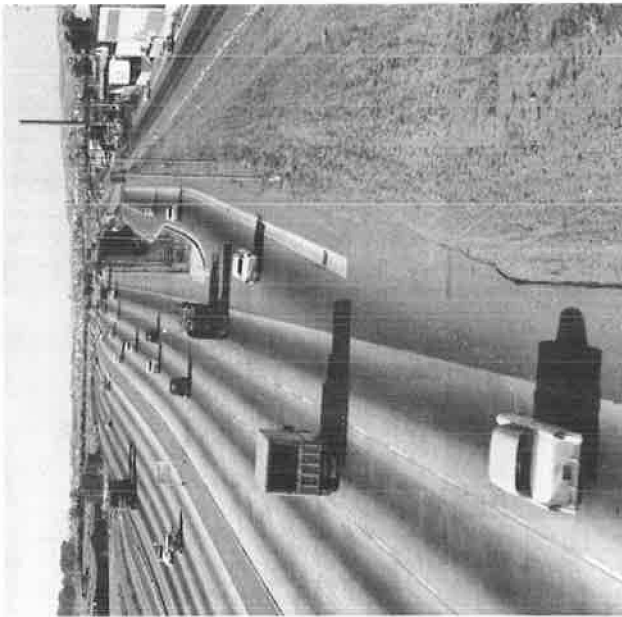


Figure 2. Study site 21, southbound ramp to Winton Ave., Eastshore Freeway, Hayward, Calif.



Station 3 was always placed at the nose of the off-ramp. Additional stations were located on the ramps as the geometrics of the off-ramp warranted.

**DATA ANALYSIS**

The data collected consisted primarily of speeds of all vehicles as they passed the various observation stations.

Observation in the field and preliminary analysis of the data showed that ramp traffic behavior was greatly influenced by the characteristics of the traffic flow on the main freeway, especially during periods of congestion on the freeway.

For the purpose of comparing behavior of ramp vehicles at one site with that at another site, it was desirable to eliminate as far as possible the effect of traffic itself. A primary breakdown was therefore made of all data in the following manner:

For every six-minute observation period, the average speed of traffic in lane 1 on the freeway was computed. All data regarding ramp vehicles were then divided into groups, depending on the freeway speed in lane 1.

The groups were in 5-mph increments:

| Group | Speed (mph) | Group | Speed (mph) |
|-------|-------------|-------|-------------|
| 6     | > 50        | 3     | 35 - 40     |
| 5     | 45 - 50     | 2     | 30 - 35     |
| 4     | 40 - 45     | 1     | < 30        |

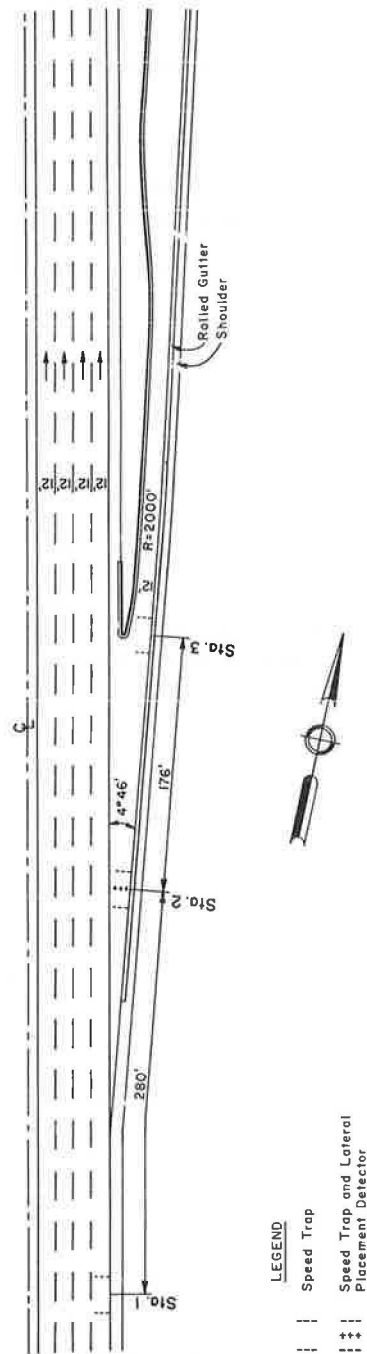
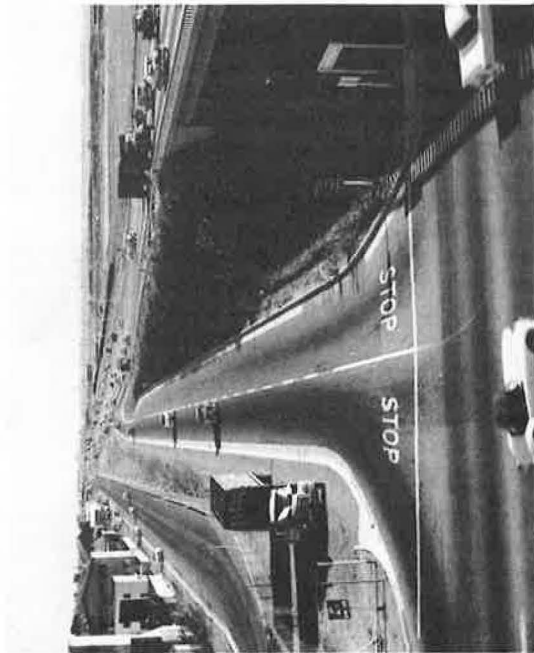


Figure 3. Study site 3L, northbound exit ramp to Gilman St., Eastshore Freeway, Berkeley, Calif.



The speed and deceleration rates of ramp vehicles observed during periods when freeway traffic was congested, would not give the type of data on the operating characteristics of free-running vehicles which must be used as a basis for design and comparison between the various off-ramps.

For this reason, it was decided to base the study on speed group 5 with average speeds between 45 and 50 mph. Except for site 41 where the speeds did not get as high as 45 mph, and at site 81 where speeds were greater than 50 mph, sufficient samples are available in this speed group to indicate a trend in the operating characteristics of the various off-ramps. Table 1 gives the number of vehicles observed.

Placement of the vehicles at station 2, where the off-ramp taper is 12 ft wide, was obtained to compare the lateral placements on the various ramps and the effectiveness of the gore striping.

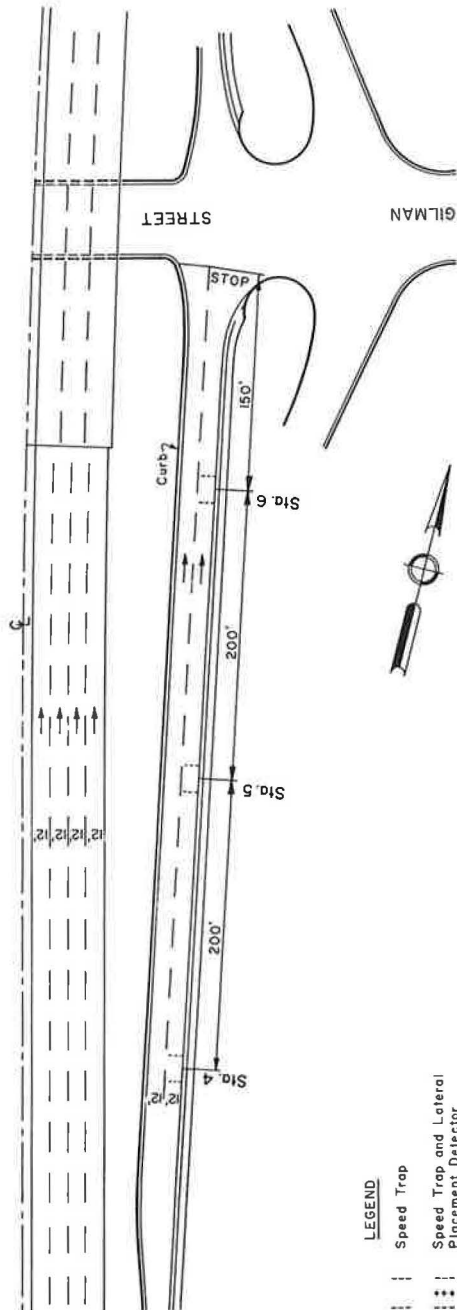


Figure 4. Site 32, terminal condition northbound exit ramp to Gilman St., Eastshore Freeway, Berkeley, Calif.

## RESULTS

### Speeds Along Tangent Portion of Off-Ramps

Table 2 gives ramp speeds at various locations. Speeds along the tangent portion of the off-ramps were roughly proportional to the length of the ramp tangent; the longer the tangent, the higher the ramp speed. However, where very long tangents are available and alignment is not a control, it appears that there is a psychological maximum of about 46 mph. On these long straight ramps, the speeds at which the vehicles left the freeway were no longer a function of ramp length but of the speed in the outside freeway lane.

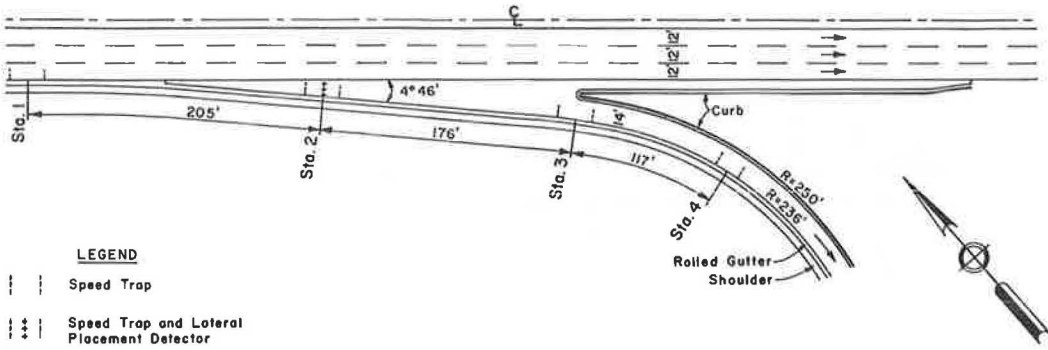


Figure 5. Study site 41, eastbound exit ramp to Lakewood Blvd., Santa Ana Freeway.

TABLE 1  
NUMBER OF VEHICLES OBSERVED  
IN EACH SPEED GROUP

| Site | Freeway Speed Group | Number of Vehicles |
|------|---------------------|--------------------|
| 11   | 3                   | 495 <sup>1</sup>   |
|      | 4                   | 410                |
|      | 5                   | 203                |
| 21   | 4                   | 156                |
|      | 5                   | 269                |
| 31   | 4                   | 212                |
|      | 5                   | 321                |
| 41   | 2                   | 187                |
|      | 3                   | 382                |
|      | 4                   | 593                |
| 51   | 2                   | 454                |
|      | 3                   | 115                |
|      | 4                   | 329                |
| 61   | 5                   | 295                |
|      | 4                   | 60 <sup>2</sup>    |
|      | 5                   | 56 <sup>2</sup>    |
| 71   | 4                   | 345                |
|      | 5                   | 301                |
| 81   | 6                   | 206                |

<sup>1</sup>Due to congestion on freeway.

<sup>2</sup>Number of samples limited due to counter being out of order.

The table shows that the difference of speed between sites 31 and 81 at the point where the ramp widens to 12 ft is only 0.7 mph and at the curb nose, 0.4 mph. The difference at the beginning of the ramp is 2.5 mph because the through vehicle speed on lane 1 of site 31 is 46.9 mph, as compared to 51.3 mph at site 81. Also, long tangents encouraged vehicles on the off-ramp to accelerate after they left the freeway.

Four speed-distance diagrams for the various off-ramps were plotted. Each diagram shows all study sites, but datum (or station 0) is different for each diagram:

1. Figure 11 uses the curb nose as the distance control. It shows that the speed at the curb nose is related to the distance to the control curve of the ramp.

It also indicates that for a curve having a 400-ft radius, a tangent length of 490 ft beyond the nose is not required for deceleration. However, the long tangent length does result in vehicles leaving the freeway at speeds greater than for shorter lengths.

2. Figure 12 shows speed on the ramp with the distance control at the point where the ramp widens to 12 ft. This can be considered as the location at which the full lane of the ramp becomes available. Here, as in Figure 11, speed is related to the tangent distance to the beginning of the ramp curve with a maximum speed of about 46 mph for high-speed off-ramps.

The speed at the 12-ft point (station 0, Fig. 12) is nearly equal for all tangent distances between 180 and 360 ft. This speed was between 38 and 39 mph, when freeway speeds in the right-hand lane of the freeway were 46 to 47 mph.

It appears that varying the tangent distance between limits of 180 ft (site 41) to 310 ft (site 61) from this point to the ramp curve has little effect on the speed at the beginning of the ramp. Also, when the distance from the 12-ft point to the ramp curve was increased from 310 ft at site 61 to 370 ft at site 11, the deceleration rate decreased. At

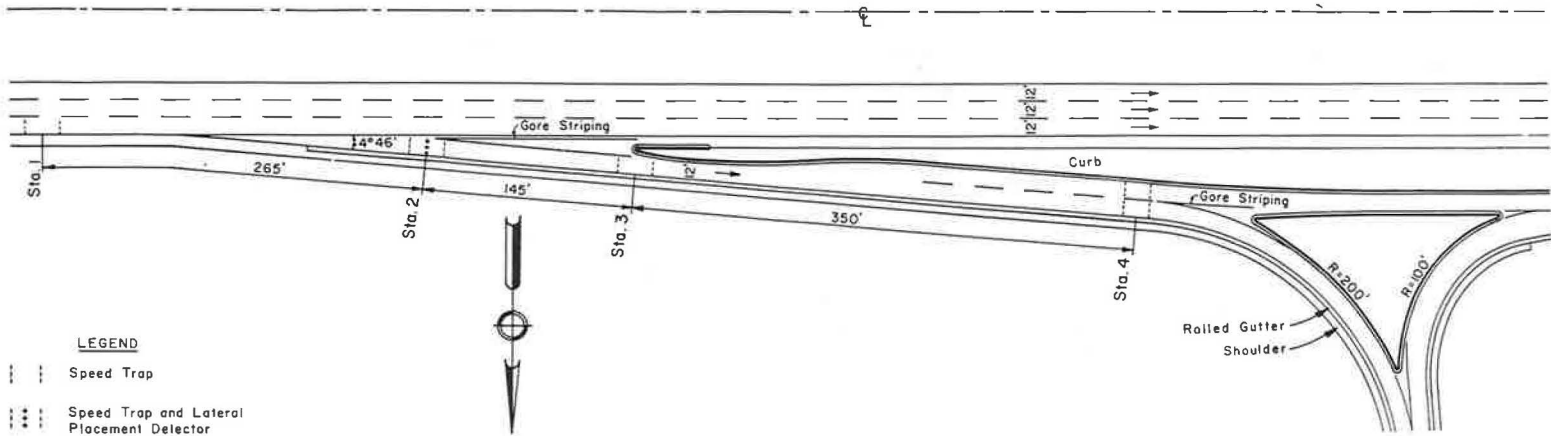


Figure 6. Study site 51, westbound exit ramp to Rosemead Blvd., San Bernardino Freeway.

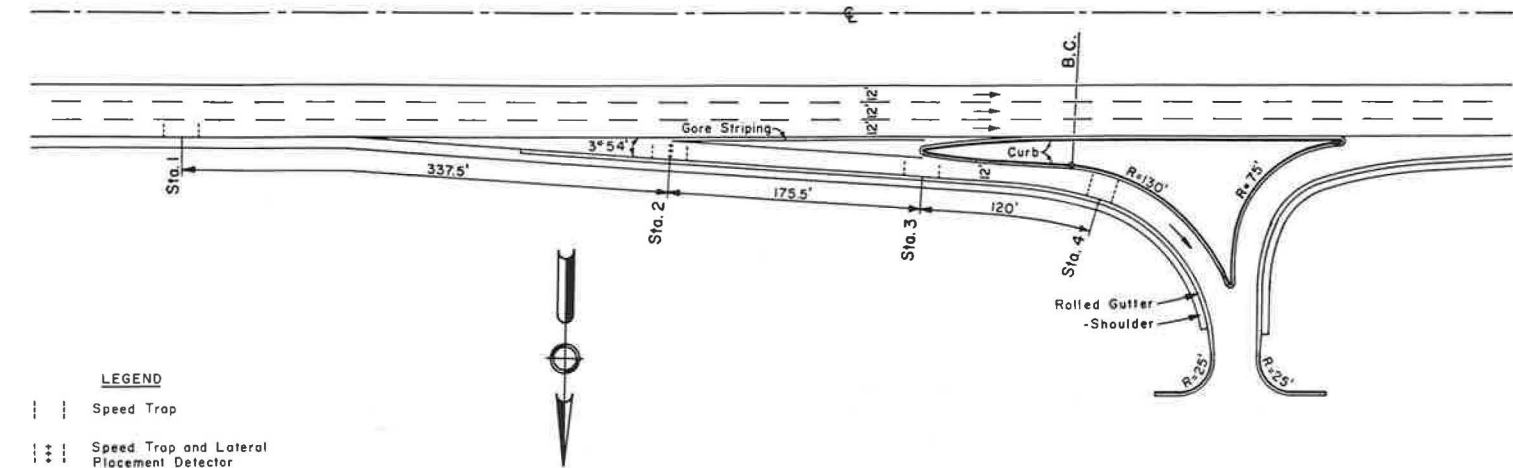
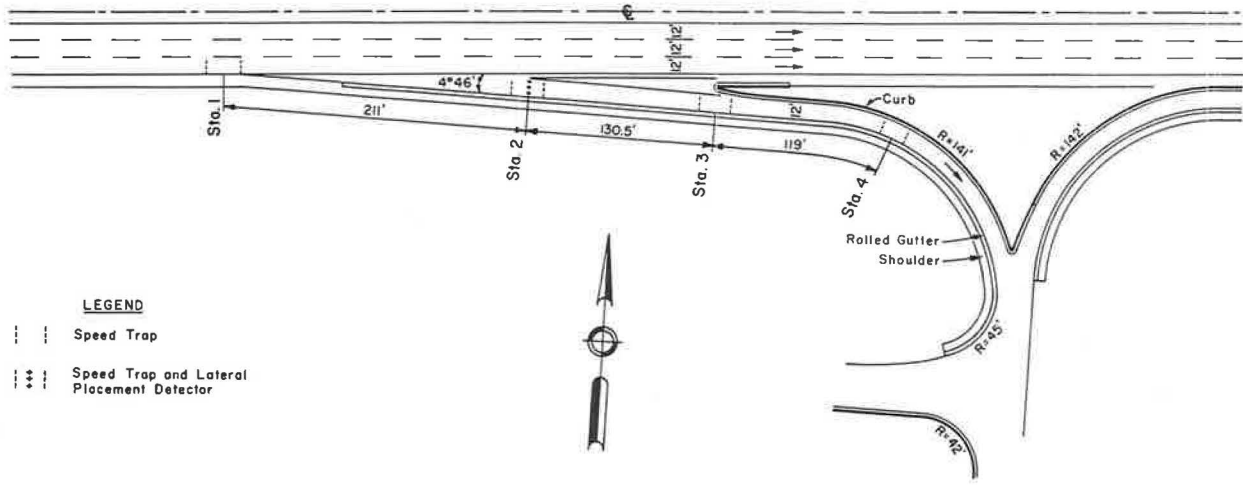
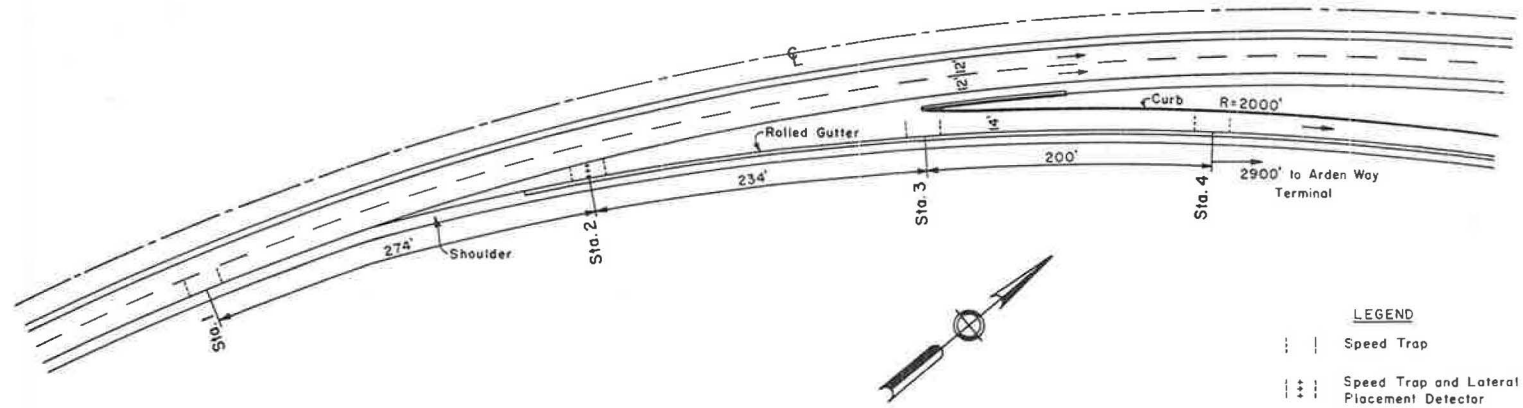


Figure 7. Study site 61, westbound exit to Temple City, San Bernardino Freeway.



**LEGEND**  
 --- Speed Trap  
 --- Speed Trap and Lateral Placement Detector

Figure 8. Study site 71, eastbound exit ramp to Vincent Ave., San Bernardino Freeway.



**LEGEND**  
 --- Speed Trap  
 --- Speed Trap and Lateral Placement Detector

Figure 9. Study site 81, northbound exit ramp to Arden Way, Elvas Freeway, North Sacramento, Calif.



site 11, the average of the higher speed groups at the 200-ft point is 35 mph and at site 61 is 33 mph.

3. Figure 13 shows speed along the ramp with the beginning of the off-ramp taper as the distance control. It also shows that vehicles leaving the freeway begin their deceleration on the freeway between 135 and 220 ft before the beginning of the ramp. This condition prevails without regard to the length of tangent beyond the curb nose. Even on the high-speed Arden Way off-ramp (site 81), there was some decelerating on the freeway.

Ramp speed between the beginning of the taper and the controlling ramp curve is affected by the length of tangent. In addition, the geometry of the ramp, both horizontal and vertical, and the speed of through vehicles on freeway lane 1 have definite effects.

Speed of vehicles leaving the freeway at sites 81 and 41 are definitely affected by the speed of through vehicles on lane 1 of the freeway. By the time the vehicles reach the point where the pavement widens to 12 ft, this effect is not significant.

At site 61, the speed at the beginning of the taper is affected by the downgrade of the freeway. The freeway is on a sag vertical curve from -2.5 percent to level grade. At the beginning of the ramp, it is -1.4 percent. This downgrade results in a higher speed leaving the freeway, and, as a consequence, requires a higher deceleration rate.

At site 11, the geometry of the ramp appears to affect the off-ramp speed. The shape of this ramp is reverse curves, separated by a tangent, and even with a 167-ft tangent length beyond the curb nose, it had the lowest speed for the group at the beginning of the ramp (Fig. 1).

Speed at Ramp Curve

Figure 14 which was plotted with the end of the ramp tangent as the distance control, indicates that drivers do not differentiate between curves having radii varying from 130 to 250 ft. From approximately 150 to 80 ft ahead of these ramp curves, the speeds at sites 11, 61, 71, and 82 vary only about 1.5 mph. Yet, the radius of the curve at end varies from 130 to 250 ft. The high speeds going into the 130- and 141-ft radius curves at sites 61 and 71 are due to the short tangent distance as compared to sites 11, 51, and 82 with larger radius curves and also longer distances to the curves.

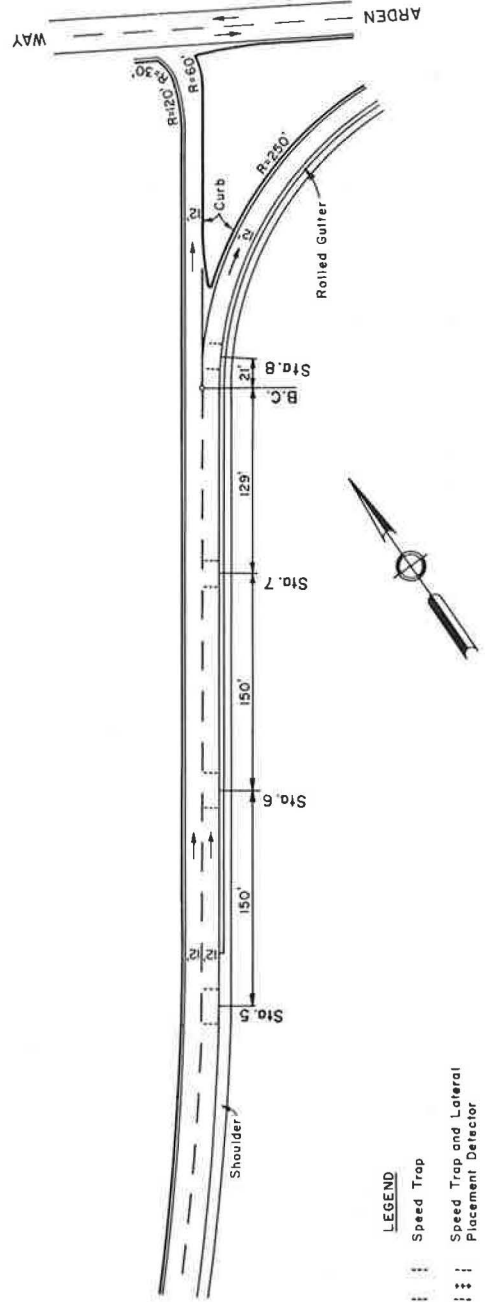


Figure 10. Study site 82, terminal condition northbound exit ramp to Arden Way from Elvas Freeway.

TABLE 2  
RAMP SPEEDS AT VARIOUS LOCATIONS

| Site | Average Speed (mph) |                         |                      |           |                     | Control at Ramp Terminal  |
|------|---------------------|-------------------------|----------------------|-----------|---------------------|---|
|      | Lane 1 of Freeway   | Begin Ramp <sup>1</sup> | Ramp Widens to 12 ft | Curb Nose | B.C. of Ramp Curves |   |
| 11   | 46.6                | 41.8                    | 39.2                 | 35.4      | 29.8                | R = 250 ft  |
| 21   | 46.6                | 45.4                    | 43.8                 | 41.2      | 36.0                | R = 400 ft  |
| 31   | 46.9                | 45.4                    | 46.2                 | 44.4      | ---                 | 1,000 ft of ramp still available from nose to stop sign                 |
| 41   | 41.6                | 39.7                    | 38.2                 | 32.8      | 32.8                | R = 250-ft B.C. at curb nose  |
| 51N  | 45.8                | 43.3                    | 41.3                 | 38.2      | 26.6                | R = 200 ft  |
| 51S  | 45.8                | 43.3                    | 41.3                 | 39.2      | ---                 | 600-ft tangent still available  |
| 61   | 45.4                | 44.5                    | 38.7                 | 32.7      | 31.9                | R = 130 ft  |
| 71   | 46.6                | 42.2                    | 38.4                 | 32.2      | 30.7                | R = 141 ft  |
| 81   | 51.3                | 48.0                    | 45.5                 | 44.0      | ---                 | 3,000 ft of high-speed ramp still available from nose to 250-ft R curve |

<sup>1</sup>For purpose of comparison, estimated speed at beginning of ramp listed in lieu of station 1 on freeway, which was variable distance from beginning of each off-ramp.

The speeds of 31.9 and 30.7 mph for 130- and 141-ft radius curves, respectively, cannot be considered in the safe speed range; therefore, these designs should be considered inadequate.

Site 41 and its 250-ft radius curve does not appear to conform with the others. The explanation is that the freeway at this point is on a +2.3 percent grade and drivers are approaching the curve at a higher speed and utilizing the grade for deceleration. The B.C. of the 250-ft radius curve is located at the curb nose and therefore the shorter tangent length results in the higher speed going into the curve.

Site 82 has the highest deceleration rate approaching the ramp curve. At this site, which has a 250-ft radius curve, the vehicles have been traveling at about 42 mph for at least 1,000 ft and are not affected by the deceleration from the freeway or the length of tangent.

Site 32 in Figure 14 indicates the distance required to come to a complete stop at the end of an off-ramp at a diamond-type interchange. From this observation, it is concluded that a vehicle driver traveling at 33 mph can comfortably decelerate to a stop in 300 ft, if he is aware of the stop requirement. It also indicates that it is comfortable to stop from 28 mph in 150 ft.

#### Lateral Placement at Station 2

Figure 15 shows the location of the left tire at station 2 where the ramp widens to 12 ft. The range of samples used was in the 10-90 percentile group of all vehicles using the off-ramp during the study. Gore striping, as used, does tend to guide the vehicles as indicated by sites 51, 61, and 71, where the decelerating vehicles make full use of the ramp as designed. The other sites did not have gore striping at the time of the study.

Figure 11 shows that gore striping at sites 61 and 71 results in an increased rate of deceleration where there is a ramp curve a short distance beyond the curb nose. On

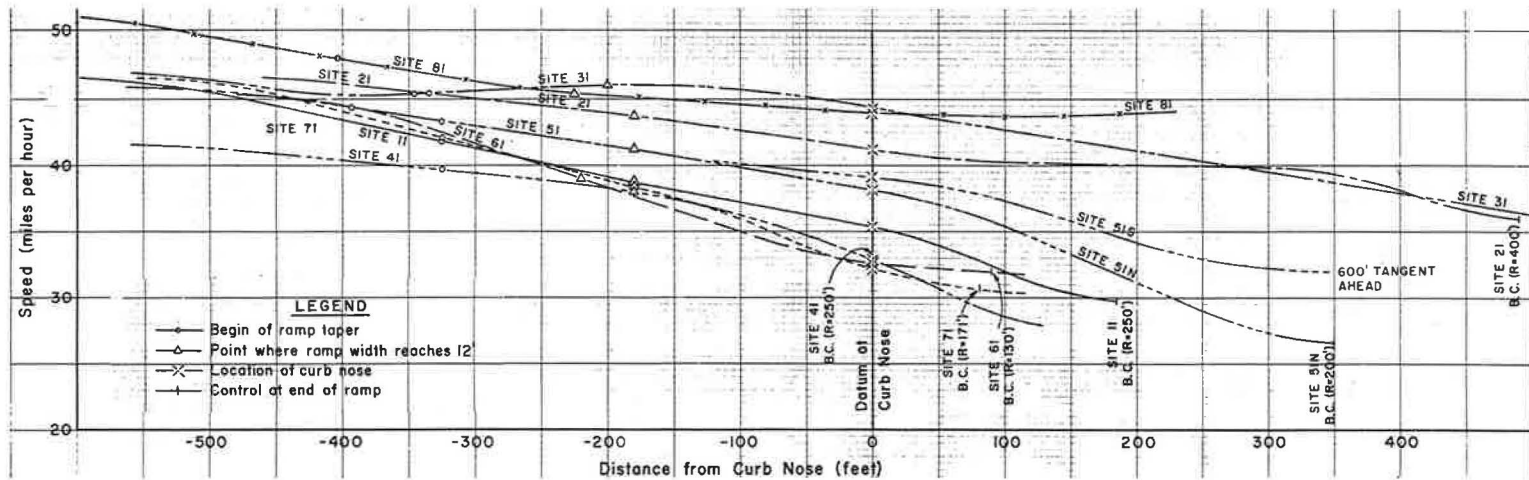


Figure 11. Speed along off-ramp related to distance from curb nose.

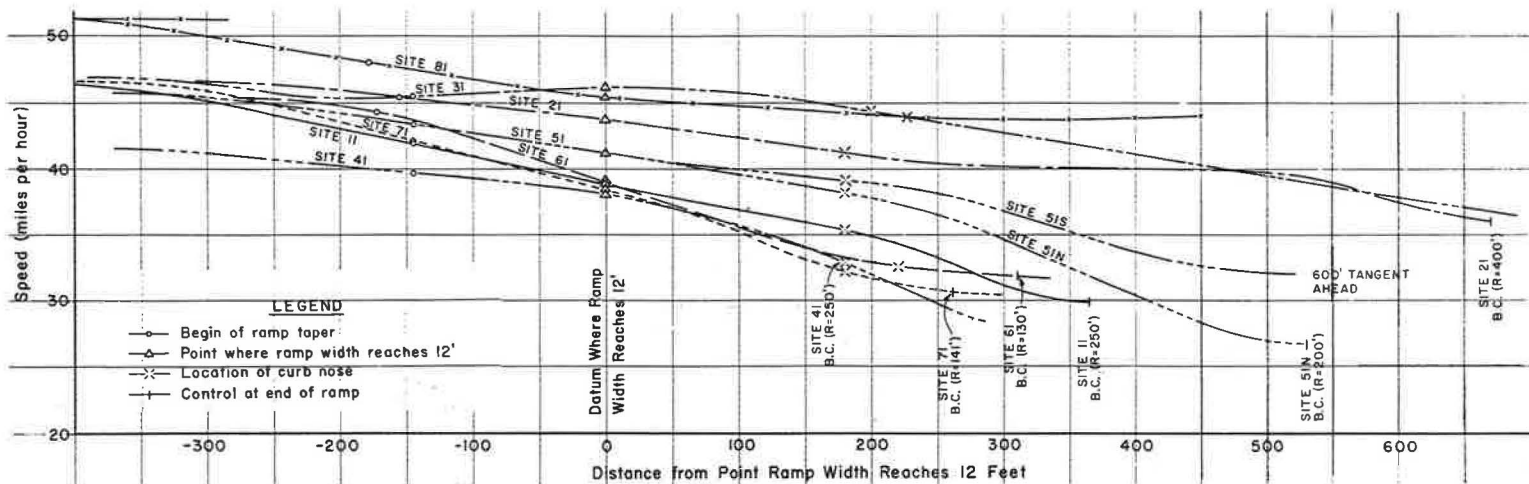


Figure 12. Speed along off-ramp related to location where ramp widens to 12 ft.

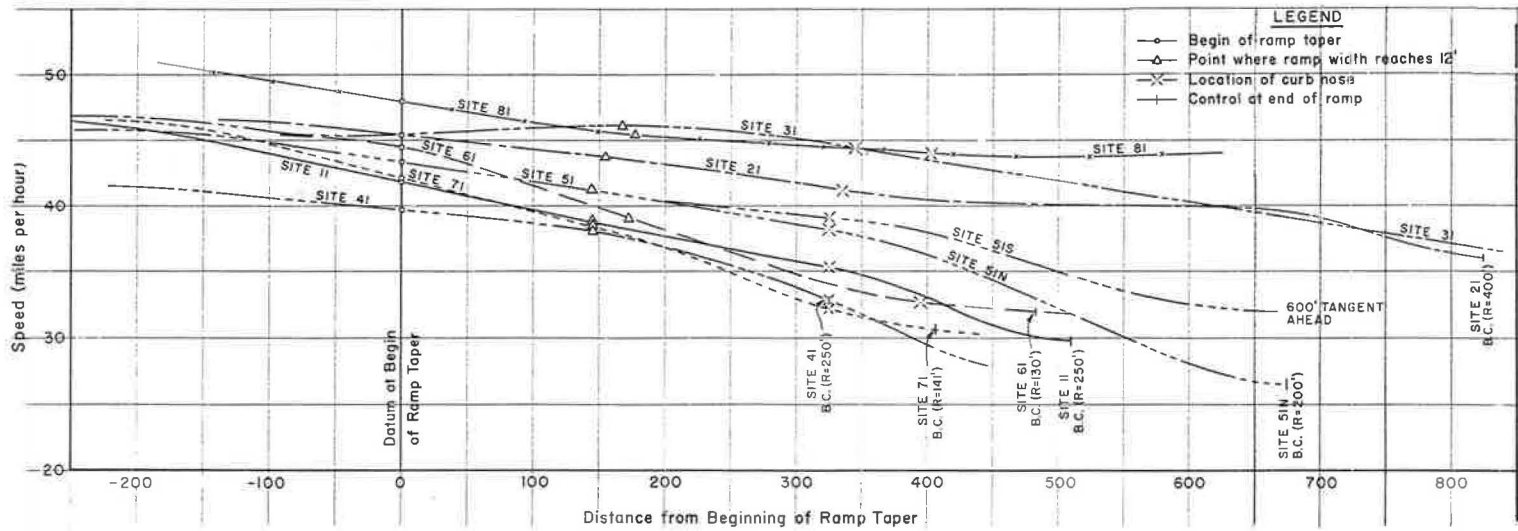


Figure 13. Speed along off-ramp related to distance from beginning of ramp taper.

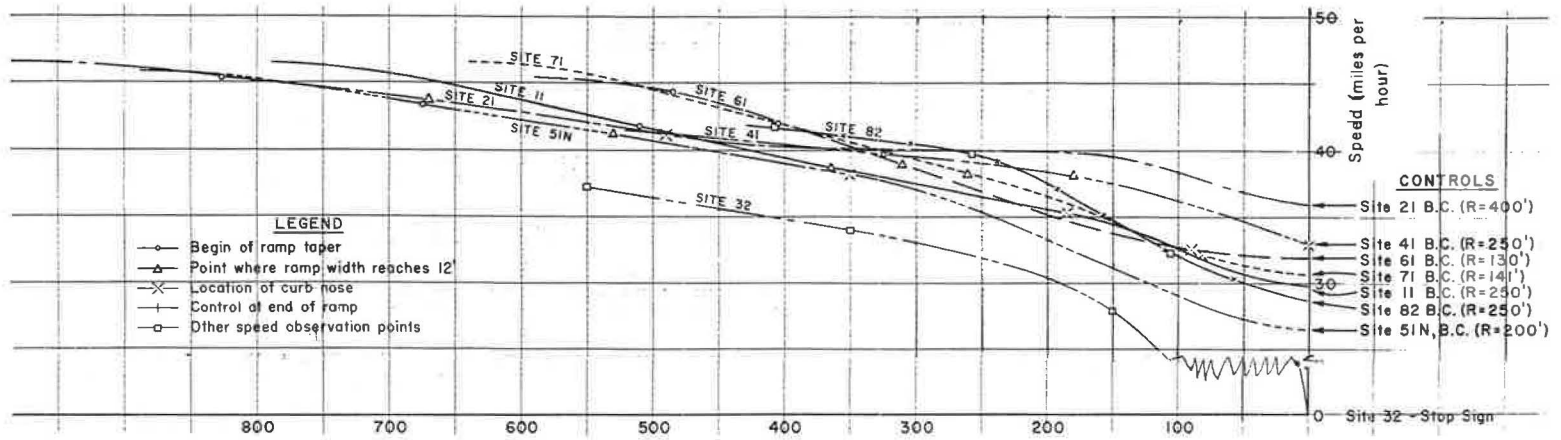


Figure 14. Speed along off-ramp related to distance from end of ramp tangent.

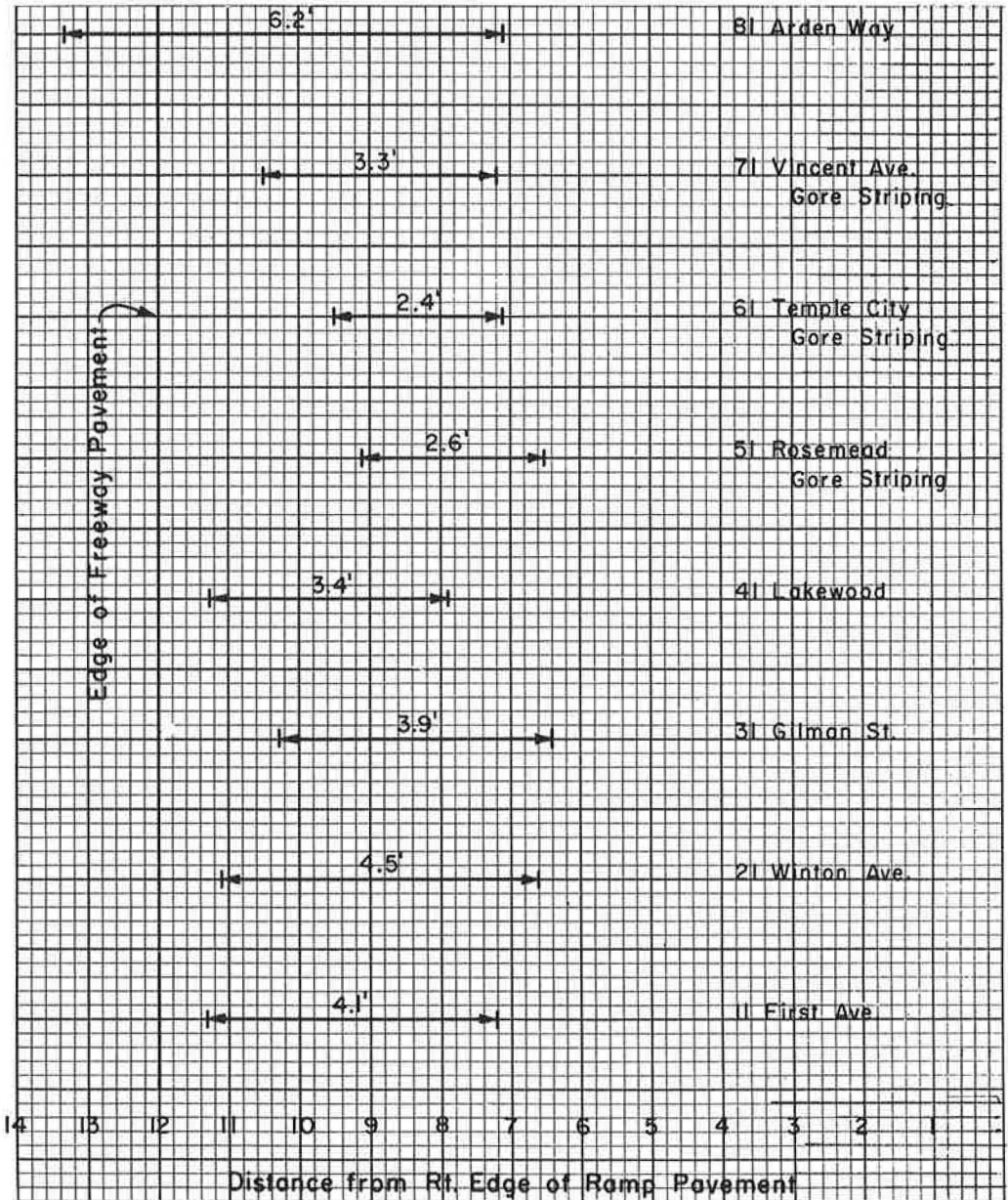


Figure 15. Ramp placement, range of left tire 10-90 percentile.

diamond-type off-ramps and long tangent off-ramps, gore striping does not appear to affect the decelerating rate.

### CONCLUSIONS

The following conclusions and recommendations were drawn from this study and observation of other off-ramps.

The speed of vehicles using the deceleration lane is determined by three factors in combination: (a) the speed of vehicles in the outside lane of the freeway, which influ-

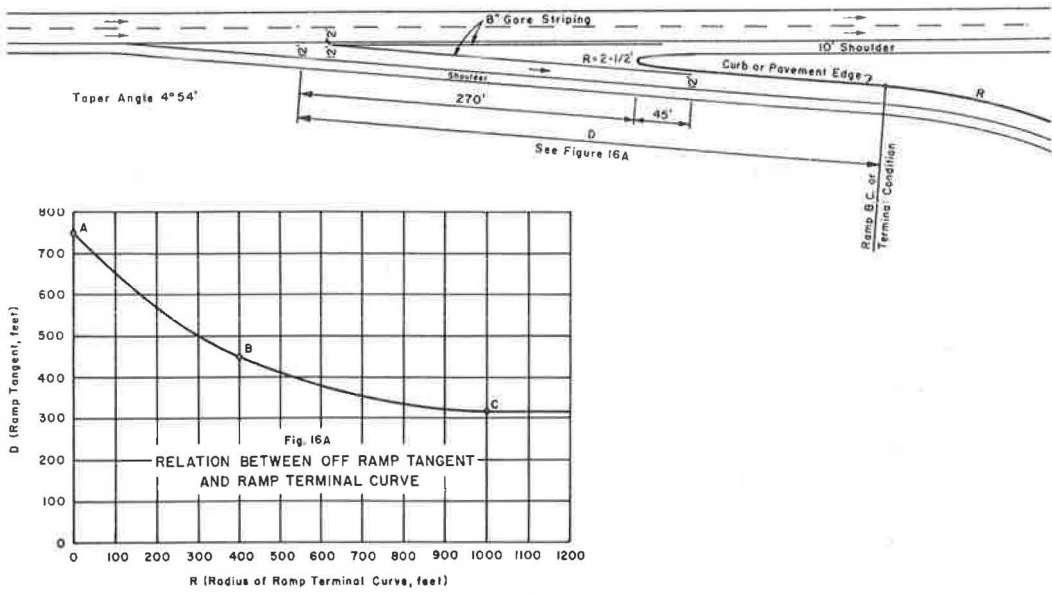


Figure 16. Suggested exit ramp.

ences the exit speed, (b) the length of tangent available to decelerate, and (c) the ramp curve or terminal which determines the speed to which the ramp traffic must decelerate.

The ideal off-ramp design is the arrangement of the diverging area to provide the least interference to through traffic and a length of tangent to encourage high-speed exit. In this regard, because the average driver decelerates before entering the off-ramp, relative speed of the vehicle leaving the freeway from lane 1 and the through vehicle on lane 1 is an important criterion for judging the design. Every effort should be made to provide a high-speed design, but it must be kept in mind that this is not a branch connection, and the geometrics should not entice through vehicles onto the ramp. A definite cue must be retained to indicate that this is an off-ramp. This cue is provided by the angle of deflection of the ramp.

On leaving the freeway, the driver should be provided with a length of tangent sufficient to decelerate to the speed of the terminal control. It was found that if this length is exceeded, vehicles will assume a steady speed, and accomplish the necessary deceleration in the last few hundred feet preceding the curve or "Stop." The length of tangent is controlled by the ramp terminal curve. The driver does not discriminate between a 130- and a 250-ft radius curve. He is just as likely to enter a 130-ft radius curve at a higher rate of speed than a 200- or a 250-ft radius curve (Table 2).

Figure 12 shows that the longer the tangent distance, the higher the ramp speed. Also, a ramp tangent length up to 310 ft does not increase vehicular speeds on the ramp (sites 61, 71, 41). Tangent length of 365 ft (site 11) just begins to indicate an increase in ramp speed.

The curve for site 21 indicates that when 670 ft of tangent precedes a 400-ft radius curve, a steady speed is maintained for more than 200 ft; in other words, this is more distance than would be used for deceleration. Considering that 200 ft was not used in decelerating, a length of 470 ft would appear to be adequate.

#### SUGGESTED STANDARD OFF-RAMP

From the preceding, it is seen that the length of tangent from the 12-ft point should be at least 450 ft when the ramp curve has a radius of 400 ft. Shorter distances are found to result in significantly lower speeds at the curb nose, which are reflected



in interference with freeway traffic as the ramp vehicles leave the freeway. It may also be assumed that distances less than this amount result in unnaturally high rates of deceleration. This would have a significant effect on the unfamiliar driver who is more likely to overrun the curve if he is required to use an unnatural rate of deceleration than if natural deceleration could be obtained. In making a traffic behavior study, almost all of the vehicles observed are "familiar" drivers and a certain amount of rationalization is necessary to interpret this behavior in terms of accident-producing situations.

The observed data provided a foundation for determining a natural deceleration distance for curves with a 400-ft radius; namely, 450 ft for decelerating to 37 mph after leaving the main line. They also provide a foundation for determining a natural deceleration distance; namely, 300 ft for decelerating from 33 mph to a stop (site 32). The curve for site 32 in Figure 14 does not show what the natural distance for decelerating from 37 mph to a stop would be, because the faster group of drivers were only going 33 mph when they really started to decelerate. It is believed that the 300-ft distance is more significant in determining where the drivers decide to start coming to a stop than the 4-mph difference between 37 and 33 mph. It is known, of course, from many other studies, that braking distance under forced conditions is much less than this amount; the objective of this study is to try to ascertain a "natural" distance which should result in fewer misjudgments and accidents than some lesser distance.

Having established 450 ft as the natural distance for a 400-ft radius and 750 ft as the natural distance for a stop, it follows that for curves between 130 and 400 ft in radius, some in-between distance is required. (To fit topographic controls, diamond-type interchanges usually provide tangent length in excess of the 750-ft requirement.)

It is also recognized that for curves with a 1,000-ft radius or flatter, no distance is needed for deceleration, and the minimum distance is, therefore, the distance required to cue the driver that he is approaching an off-ramp. This can be accomplished by retaining a standard geometric design for all off-ramps. This design should be common to a point 45 ft beyond the curbed nose to include the curb offset flare.

In Figure 16, Point A (the natural distance for a stop), Point B (the natural deceleration distance for a 400-ft radius curve), and Point C (when deceleration distance is not required) were plotted. A curve was passed through these points from which the ramp tangent, D, can be selected for any ramp terminal curve, R.

In the design of ramp terminal curve, R, it is recommended that 400-ft be held as a minimum for all exterior ramps of interchanges. It is also recommended that radii less than 130 ft be considered a channelizing turn at a stop sign, and treated as a "stop" situation.

A combination of the preceding recommendations has resulted in the off-ramp suggested in Figure 16. The deflection angle of the ramp is controlled by the width necessary in the gore for ground-mounted guide signs. Pavement marking ahead of the curb nose is recommended to delineate the left-hand edge of the ramp, while providing a traversable target for vehicles leaving the freeway. In addition to the horizontal geometrics, it is also very important that the driver has a good view of the ramp and, if possible, the ramp terminal control.

The suggested off-ramp is being recommended as a standard design for all conditions. Although quantitative observations were not made on traffic behavior at higher freeway speeds, general observations indicate the exiting vehicles generally decelerate to the 50-mph range before leaving the freeway, and this is believed to be unavoidable as well as unobjectionable. This was partially observed at site 81 (Table 2). Lane 1 of the freeway at site 81 averaged 51.3 mph, approximately 4.7 mph faster than at a similar high speed at site 31. However, at the location where the ramp widens to 12 ft the vehicles at site 81 were 0.7 mph slower. It therefore seems that the off-ramp design will be adequate at the higher speeds found on some rural freeways.

Off-ramps are not as subject to variation in design as entrance ramps, but standardization to a high type of design would result in the use of the ramps as the designer intended, would eliminate doubt on the part of the motorist, and would simplify engineering.