Abridgment

Passing Requirements for Two-Lane Highways in Mountainous Areas

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ABSTRACT

The Virginia Department of Highways and Transportation uses a special centerline marking designated mountain pavement marking on two-lane highways in mountainous regions. This marking consists of a single broken line supplemented by PASS WITH CAUTION signs. This marking has been criticized because it does not prohibit passing on sections of highways with inadequate sight distances. Consequently, a study was conducted to determine if this marking system should be replaced with the Manual on Uniform Traffic Control Devices (MUTCD) standard marking pattern and to develop guidelines for minimum lengths of passing zones and minimum sight distances for safe passes on two-lane mountain roads. In this paper the results of that part of the study that dealt with the development of minimum passing criteria are presented. Passing maneuvers were recorded at five sites with a 16-mm movie camera. Relevant data were then extracted from the film and used to develop a regression model for the minimum length of passing zone based on the passing speed and the difference in speeds of the passing and impeding vehicles. A minimum passing sight distance for a safe pass or a comfortable aborting of the pass was then developed using the concepts of critical position and comfortable deceleration. The results indicate that the minimum values suggested in the MUTCD are inadequate and that there are no significant differences in traffic characteristics between roads with the special marking and those with standard MUTCD marking. The results also indicate that, although speed is the major factor affecting the passing distance on two-lane highways in mountainous regions, other factors such as the difference between the speeds of the passing and impeding vehicles and grade, in that order, also have some effect.

FIGURE 1 Mountain pavement marking.

The long-standing policy of the Virginia Department of Highways and Transportation is to use the centerline marking standards outlined in the Manual on Uniform Traffic Control Devices (MUTCD) (1). The department, however, uses a special type of marking on two-lane highways in mountainous regions. This special marking, designated mountain pavement marking, consists of a single, broken, yellow line supplemented by PASS WITH CAUTION signs (Figure 1). Passing maneuvers are not prohibited by the solid yellow line, even when sight distances are inadequate for prevailing speeds, so the decision to pass is left entirely to the motorist. The argument in favor of this marking pattern is that it allows motorists to legally pass slow-moving vehicles where it would not be possible to do so for long distances if these roads were marked in compliance with the MUTCD standards.

In response to criticism of this practice of marking two-lane highways in mountainous regions, a study was undertaken to evaluate the marking and to determine minimum lengths of passing zones and sight distances for these highways.

In this paper the minimum criteria developed for passing zones and sight distances are documented in terms of

1. A description of the regression model developed for minimum passing sight distances and minimum lengths of passing zones;
2. Recommended guidelines for establishing passing and no-passing zones; and
3. Results of a comparison of the before and after data, with the focus on the driver's interpretation of and compliance with the MUTCD pavement marking pattern and the evaluation of the proposed passing zone lengths.

PURPOSE AND OBJECTIVES

The primary purpose of this portion of the study was to develop guidelines that can be used to delineate passing and no-passing zones on two-lane highways in mountainous regions using the MUTCD standard pavement marking pattern. The objectives were

1. To determine safe and acceptable passing distances for this type of roadway,
2. To determine minimum sight distances for safe passing, and
3. To recommend means of determining appropriate marking patterns for the roads.

STUDY APPROACH

The research was designed as a before-and-after study. The before phase investigated traffic operational characteristics and passing maneuvers at selected sites striped with the mountain pavement marking. The data taken at these sites were subsequently used in developing pass models that, in turn, were used to formulate guidelines for minimum passing zone lengths and minimum passing sight distances. Two of the sites used in the before phase and one other site were then selected for the after phase. The mountain pavement marking at these three sites was replaced with the standard MUTCD marking patterns for passing and no-passing zones in conformity with the guidelines developed. During the after phase, motorists' interpretation of the MUTCD marking patterns and compliance with them, and the adequacy of the proposed minimum passing zone lengths, were evaluated. Data on traffic operational characteristics were also collected during this phase.

From an inventory of the roadways striped with the mountain pavement marking, five sites were selected for study based on the criterion that traffic volume, operating speed, and passing maneuvers at the selected sites be representative of the range that exists on mountainous roads striped with mountain pavement markings.

DATA COLLECTION

The data collection consisted of two major tasks: the collection of traffic flow data with an electronic traffic data acquisition system and the filming of passing maneuvers with a 16-mm movie camera.

A traffic data recorder (TDR) system developed by Leupold & Stevens, Inc., was used for the first task. Traffic operational data such as volume, vehicle speeds, headways, traffic queues, and vehicle classifications were collected during a period of at least 24 continuous hours on Tuesday through Thursday.

For the second task, a Canon Scoopic 16 MS 16-mm movie camera was used. The camera was placed at a point from which the centerline pavement marking was clearly visible. A film speed of 24 frames per second was used throughout the study. Kodak Ektachrome film 7241EE (ASA 80), on 100-ft rolls was used throughout the study. Data on passing maneuvers were collected from a total of 85 passing maneuvers filmed.

Figure 2 is a schematic presentation of the passing maneuver. Among the distance elements shown in the figure, PD, D_3, D_9, G_2, and X' were extracted from the passes filmed with the 16-mm camera. The distance elements are defined as

P = passing vehicle;
I = impeding vehicle;
O = oncoming vehicle;
PD = passing distance denoting the distance traveled by the passing vehicle while it is on the left lane;
D_3 = distance traveled by the passing vehicle from the head and tail position, where the passing vehicle catches up with the impeding vehicle, to completion of the pass;
D_9 = distance traveled by the passing vehicle from the abreast position to the completion of the pass;
X' = space headway retained by the passing vehicle just before it encroaches onto the left lane, before spacing;
G_2 = space headway left for the impeding vehicle by the passing vehicle when it completes the pass, after spacing;
C = clearance distance between the passing and oncoming vehicle at completion of passing maneuver;
D_{cp} = distance traveled by the passing vehicle between the critical position and the position of completion of a pass; and
D_4 = distance traveled by the oncoming vehicle while the passing vehicle travels from the critical position to completion of pass.

DATA REDUCTION AND ANALYSIS

Traffic Operating Characteristics

Operating Speed

Eighty-fifth percentile speeds observed were between approximately 40 and 50 mph, and mean speeds were between 35 and 45 mph. The difference in speeds between opposing lanes was found to be significant at 95 percent confidence for grades greater than 5 percent. The maximum speed difference observed between the opposing lanes was 7.0 mph.

Speed Difference Between Passing and Impeding Vehicles

The speeds of impeding vehicles varied from 15 to 45 mph, whereas those of passing vehicles ranged from 30 to 64 mph.

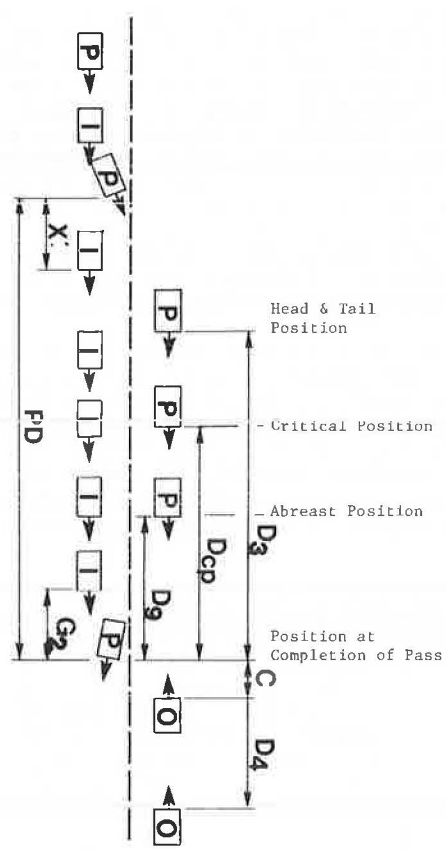

FIGURE 2 Distance elements of passing maneuvers.

Passing Speed Versus Off-Peak 85th Percentile Speed

The MUTCD employs the prevailing off-peak 85th percentile speed as the independent variable to compute minimum passing sight distances. The accuracy of this for the roads in this study was checked by comparing the mean speed of the passing vehicles with the off-peak 85th percentile speed at the appropriate sites, and it was found that in all cases the mean passing speeds were approximately equal to the off-peak 85th percentile speeds.

Regression Analysis

A stepwise multiple linear regression analysis was performed using the software package BMDP (2) with the passing distance as the dependent variable and passing speed, available sight distance, speed difference between passing and impeding vehicles, and grade as independent variables. The analysis showed that passing speed had the greatest impact on passing distance. Passing speed was followed by available sight distance, then speed difference, with grade having the least impact. This analysis, however, also showed that multicollinearity exists between sight distance and speed (i.e., speed is related to sight distance). Further analysis also showed that, for speeds less than 50 mph and grades less than 10 percent, the effect of grade on passing distance is minimal. Therefore, the regression equation was developed using the two major variables, speed and speed difference. The equation thus obtained is

$$PD = 266.397 + 9.689\ V - 12.448\ m \qquad (1)$$

where

PD = passing distance in feet,
V = passing speed (off-peak 85th percentile speed) in mph, and
m = speed difference in mph.

Minimum Lengths of Passing Zones

In this study a passing zone is analogous to the passing distance. It is the distance traveled by the passing vehicle on the left lane in a passing maneuver. Within this distance, the passing vehicle encroaches onto the left lane, passes the impeding vehicle, and returns to the right lane on completion of the passing maneuver.

In developing the proposed minimum lengths of passing zones, two factors were taken into consideration. First, the speed difference (m) used in the regression model was 12 mph. This assures that the lengths of passing zones suggested will be equal to or greater than the actual passing distances of 85 percent of all passing maneuvers. Second, to provide for passing maneuvers that do not commence at the beginning of the passing zone, the 95 percent confidence level upper limit of the obtained regression model was used. The proposed minimum lengths of passing zones for different 85th percentile speeds were, therefore, obtained from this model and are given in Table 1. It can be seen that the proposed minimum lengths are greater than 400 ft, which is the minimum suggested in the MUTCD for all speeds. This suggests that the minimum length of 400 ft suggested in the MUTCD may be inadequate for two-lane, two-way highways in mountainous regions, even at the low speed of 30 mph.

TABLE 1 Suggested Minimum Lengths of Passing Zones for Two-Lane Highways in Mountainous Regions

85th Percentile Speed (mph)	Proposed (ft)	MUTCD (ft)
30	560	400
35	610	400
40	660	400
45	710	400
50	750	400

PASSING SIGHT DISTANCE REQUIREMENTS

In this study, the passing sight distance was defined as the sum of the distance between the critical position (CP) and the position at completion of a pass, the clearance distance between the passing and oncoming vehicles at completion of a pass (C), and the distance traveled by an oncoming vehicle while the passing vehicle travels from the critical position and completely returns to the right lane (D_4). This relation is shown in Figure 2.

To compute the passing sight distances for different passing speeds it was first necessary to locate the critical position of a passing maneuver. The critical position was defined by Lieberman as the point where "the decision by the passing vehicle to complete the pass will afford it the same clearance relative to an oncoming vehicle, as will the decision to abort the pass" (3). As the deceleration rate decreases, the passing motorist must decide earlier to abort.

In order to determine the critical position in this study, the deceleration rates (d) necessary for an abort maneuver starting at a point with a clearance distance (C') equal to the clearance distance (C) for a pass maneuver starting at the same point were calculated for different passing speeds.

The deceleration rates computed for the different positions were then compared with acceptable deceleration rates. It was determined that acceleration rates for the critical position located at 2/3 PD are within acceptable limits, whereas those for critical positions located at less than 2/3 PD tend to exceed comfortable limits when passing speeds are greater than 40 mph. It was, therefore, decided to select 2/3 PD as the critical position, and this position was used to determine the sight distance requirements given in Table 2. The suggested minimum passing sight distances given in Table 2 were computed for equal upgrade and downgrade speeds by the equation

$$PSD = (4/3\ PD) + C$$

where

PD = passing distance, in feet, from regression model m = 12, and
C = clearance distance estimated from AASHTO.

and for different speeds between upgrade and downgrade by the equation

$$PSD' = (2/3\ PD) + C_h + D_h$$

where

PSD' = adjusted passing sight distance, in feet,
C_h = clearance distance for higher speed, in feet, and
D_h = distance traveled by oncoming vehicle at

TABLE 2 Comparison of Minimum Passing Sight Distance Requirements

Upgrade 85th Percentile Speed (V_l) (mph)	Minimum Passing Sight Distance (ft)			
	Equal Upgrade and Downgrade Speeds		Different Speeds Between Upgrade and Downgrade (this study)	
	This Study	MUTCD	$(V_l < V_h < (V_l + 5.0)$	$(V_l + 5.0) < V_h < (V_l + 10.0)$
30	645	500	700	800
35	735	550[a]	800	870
40	825	600	885	950
45	910	700[a]	970	1,070
50	1,000	800	1,095	1,190
55	1,115	900[a]	1,200	—[b]

[a] Interpolated.

[b] Passing sight distances were computed only for passing speeds up to 55 mph because grade may significantly affect passing distance when passing speeds are higher than 55 mph.

higher velocity during time passing vehicle travels from critical point to completion of pass.

A comparison of the minimum sight distances obtained from this study with the corresponding values suggested in the MUTCD indicates that the MUTCD values are inadequate for two-lane, two-way highways in mountainous regions.

EVALUATION OF PROPOSED GUIDELINES

The adequacy of the proposed guidelines when used to provide passing zones marked with the MUTCD standard patterns was evaluated by conducting an after study at two of the five sites selected for the before study and a new site. Only two of the original five sites were used for the after study because only at these sites do the traffic and geometric characteristics conform to the proposed guidelines.

The results indicate that when passing zones were provided based on the guidelines developed, 80 percent of passing motorists returned to the right lane without intruding into the passing zone of the opposing lane. This indicates that the majority of motorists correctly interpreted the MUTCD passing and no-passing zone marking patterns.

At sections where the mountain pavement marking was replaced with the double solid yellow line for the no-passing zone, it was found from the data taken with the electronic data acquisition system that very few passing maneuvers occurred. This indicates that motorists correctly interpreted the marking and complied with it.

The results also indicate that at passing zones based on the guidelines developed, a minimum of 88 percent of the passing maneuvers at each site were completed within the proposed minimum length of passing zone for the 85th percentile speed at the site. These figures suggest that the proposed minimum lengths for passing zones are adequate.

CONCLUSIONS

The results of this study indicate that although speed is the major factor affecting the passing distance on two-lane, two-way highways in mountainous regions, other factors such as the speed difference between the passing and impeding vehicles and grade, in that order, also have some effect. Grade is, however, not a major factor if the passing speed is less than 50 mph.

The results also indicate that the MUTCD specified requirements for marking no-passing zones are not adequate to ensure safe passing maneuvers on mountainous highways. The minimum length of 400 ft for a passing zone specified by the MUTCD may not be adequate for passing vehicles to safely complete a pass, even at a 30 mph passing speed.

RECOMMENDATIONS

It is recommended that a review of the guidelines given in the MUTCD for marking passing and no-passing zones be undertaken with the objective of updating these guidelines using results of this and other recent studies.

REFERENCES

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