DESIGN AND STRIPING FOR SAFE PASSING OPERATIONS

Graeme D. Weaver and John C. Glennon, Texas Transportation Institute,
Texas A&M University

ABRIDGMENT

•THE passing maneuver is one of the most hazardous operations on 2-lane highways. It is one of the few situations in which a driver may legally operate in the left lane of a 2-lane highway and, in so doing, may create a potential head-on collision. Yet, faster vehicles should be able to safely pass slower vehicles if efficient highway operations are to be maintained.

To provide the passing driver adequate sight distance and passing distance, we must assess the elements of the maneuver from a safety viewpoint and combine the critical elements in a compatible design. What is the critical condition in a passing maneuver? Is it a completed pass or an aborted pass? What distances are traveled during the perception-reaction time by the passing vehicle that occupies the left lane or by an opposing vehicle? At what point in the maneuver does the passing driver need the greatest sight distance? What "design speed" should be used? The answers to these questions are the inputs for formulating design and striping standards for safe passing sight distance.

The goals of this study were to examine passing behavior on rural 2-lane highways; to compare study parameters with the current passing sight distance design standards; and to develop, where appropriate, design and striping standards compatible with current operating conditions. Of primary concern were passing maneuvers on highways with operating speeds of 50 to 80 mph.

Current standards for designing passing sight distance and for striping rural 2-lane highways to restrict passing are based on different criteria. Passing sight distance is designed by using "A Policy on Geometric Design of Rural Highways," whereas no-passing zones are set by using the "Manual on Uniform Traffic Control Devices for Streets and Highways" (MUTCD). Unfortunately, the striping operation is done after the highway is constructed, when alignment changes are economically unfeasible.

The current standards for design and striping were critically evaluated with particular emphasis given to the inequities between design and operations. From this evaluation, and based on the operating characteristics of the passing maneuvers observed in the field studies, a new concept was developed that integrates design and striping to accommodate the safety and operational aspects of the passing maneuver.

SIGHT DISTANCE REQUIREMENTS

Current design standards are based on studies conducted from 1938 to 1941. The minimum passing sight distances for 2-lane highways were determined as the sum of 4 elements. From these studies of actual passing maneuvers on rural highways, distance values were established for the 4 elements of the maneuver: the perception-reaction distance, d_1; the left-lane distance, d_2; the clearance distance, d_3; and the distance traveled by an opposing vehicle, d_4.

Once he has started a passing maneuver, the driver has only 2 options: complete the maneuver or abort the maneuver. If the passed vehicle maintains a constant speed, there is a point where the time to complete the maneuver is equal to the time to pull back.

Sponsored by Committee on Geometric Highway Design.

This critical condition occurs about when the 2 vehicles are abreast. If at this point an opposing vehicle appears, the passing driver is forced to make a decision that affects the safety of the remaining portion of the maneuver.

The objective of passing sight distance design is to provide passing zones where maneuvers may be safely completed rather than aborted. Therefore, the critical completion distance is one of the elements to be included in the design. The distance required to complete the maneuver from the critical position is about $2/3d_2$. If the speed of the opposing vehicle and the passing vehicle are equal, the opposing vehicle also travels $2/3d_2$. If adequate clearance distance, d_3, is included, the minimum sight distance required for safe operations is $4/3d_2 + d_3$.

The hazard associated with the passing maneuver arises when there is insufficient distance to complete the maneuver if an opposing vehicle is perceived at the critical position. The critical position can occur anywhere throughout the passing zone. To provide a safe "recovery zone" for the passing driver who faces the critical condition at the end of a passing zone, we must provide the minimum sight distance, $4/3d_2 + d_3$, throughout the passing zone. This philosophy approaches the long-zone passing concept because it provides a safe recovery area in a no-passing zone but does not encourage drivers to initiate an illegal passing maneuver.

DESIGN SPEED

A basic inequity between design and operations is that speeds lower than the design speed are used to compute the distance elements. For design speeds greater than 50 mph, the passing speed is assumed to be less than the design speed; this difference increases as the design speed increases.

New stopping sight distance standards are determined by assuming that the vehicle travels at the design speed. This approach is compatible with the "design" concept in engineering practice. Designing is more critical for the passing maneuver than for the stopping maneuver because the passing driver is maintaining a relatively high speed or accelerating. Yet, in the design of passing sight distance, the passing vehicle is assumed to be traveling at a speed less than the design speed.

Because the passing maneuver represents one of the most hazardous operations on a 2-lane highway, it is logical, from a critical design standpoint, that the sight distance elements be computed for a passing vehicle traveling at design speed. Also, so that all elements of the maneuver are placed on a common basis, the opposing vehicle should also be considered to be traveling at design speed.

PASSING ZONE LENGTHS

Passing sight distance design is determined on the basis of sight distance between 2 vehicles approaching each other at opposite sides of a crest vertical curve. A more common situation occurs when sight distance on one crest is limited by the next successive crest in rolling terrain. Often, the driver experiences a series of short passing zones through the sags and is immediately faced with a no-passing zone as he approaches each crest. No provision is made in the current design standards to prohibit this occurrence. These standards specify that certain sight distances be provided for particular design speeds but do not specify the length over which that sight distance must be made available. In other words, a section of highway could have the required sight distance at the crest of a vertical curve, and very shortly thereafter the available sight distance could decrease to less than the design requirement.

Currently, the length of passing zones or the minimum distance between successive no-passing zones is specified as 400 ft in the MUTCD. This distance is not sufficient for modern high-speed passing maneuvers. Limited studies of short passing sections on main rural highways have shown that most drivers do not complete a pass even within an 800-ft section. Actually, the drivers who passed in those short sections were often in the critical position beyond the passing zone where sight distance was less than minimum. A desirable minimum length of passing zone includes the perception-reaction distance, d_1, and the left-lane distance, d_2. If the maneuver is initiated at the beginning of the zone, this distance permits the driver to abort the maneuver if an opposing vehicle is perceived before reaching the critical position. This length also permits the completion of a maneuver within the passing zone if the opposing vehicle is perceived past the critical position.

FIELD STUDIES

A movie camera mounted in an observation box on the bed of a pickup truck was used to photograph passing maneuvers at 3 study sites. Passing situations were created with an impeding vehicle traveling at a predetermined speed. The observation vehicle moved in behind a subject vehicle about 2 miles upstream from the study site. As the 2 vehicles approached, the impeding vehicle stationed on the shoulder near the beginning of the no-passing zone preceding the study site moved out and impeded the subject vehicle. Filming was initiated as the 3 vehicles reached the study site. Approximately 3,000 subjects were tested. Of this number, about 500 completed passing maneuvers were filmed. Impeding speeds were 50, 55, 60, and 65 mph.

Each study site was marked with stripes placed perpendicular to the centerline at 40-ft intervals. This reference system allowed the determination of the speed and distance elements of the passing maneuver by analyzing the film on a Vanguard motion analyzer. Cumulative percentiles of measured speed differentials were plotted for each impeding speed. The 15th percentile was selected as the critical condition. This critical differential was found to decrease as impeding speed increased, ranging from about an 11-mph differential at 50 mph to a 7-mph differential at 65 mph.

Eight best-fit relations were obtained by plotting passing speed against the distance elements d_1 and d_2 for each of the 4 impeding speeds. The relations between each of these distance elements and design speed were then obtained by a best-fit plot through the 4 points representing the distance element at the passing speed equal to the impeding speed plus the speed differential. Those relations were similar to those used in current passing sight distance standards.

IMPLEMENTATION

Table 1 gives the proposed passing sight distance and passing zone length standards for designing and striping passing zones. These values are based on the analysis of the field measurements using the proposed design concept. Examination of the proposed standards reveals several important factors to consider for passing sight distance design. For every design speed, the passing sight distance at the beginning of the zone exceeds the current AASHO standard. The available sight distance at the beginning of a zone is determined by establishing the end of the passing zone, and that is done by finding the point on the profile where sight distance is limited to $4/3d_2 + d_3$; then the beginning of the passing zone is located upstream from this point a distance equal to or greater than the minimum passing zone length of $d_1 + d_2$. The sight distance at the beginning of the zone must, therefore, be at least the sum of these 2 distances, or $d_1 + 2.33d_2 + d_3$.

The 70-mph design speed is used to illustrate another design consideration given in Table 1. If the spacing between successive crests is greater than 3,310 ft, adequate

Table 1. Proposed standard for design and striping passing zones.

Design Speed (mph)	Minimum Sight Distance Throughout Zone (ft)	Minimum Desirable Length of Passing Zone (ft)	Minimum Sight Distance at Beginning of Zone (ft)	Design Speed (mph)	Minimum Sight Distance Throughout Zone (ft)	Minimum Desirable Length of Passing Zone (ft)	Minimum Sight Distance at Beginning of Zone (ft)
50	1,135	885	2,020	70	1,825	1,485	3,310
60	1,480	1,185	2,665	75	2,000	1,785	3,635
65	1,655	1,335	2,990	80	2,170	1,935	3,955

sight distance and passing zone length are automatically provided in the sag. If, however, the distance is slightly less than 3,310 ft, and neither crest affords 1,825 ft of sight distance, an adequate passing zone does not exist. In this case, a passing zone can be provided by minor adjustments to the grade lines.

Historically, vertical profiles have been established by the economic considerations of earthwork. Although the balance of cut and fill is important in establishing profile, it is possible that a substantial improvement in traffic efficiency may be attained by minor adjustments in grade. Flattening grade lines in a sag, in effect, moves both crests outward.

From these considerations, proper passing sight distance in gently rolling terrain is clearly influenced by profile establishment. Computer programs are used widely to establish profile. Cost-effectiveness techniques can be incorporated to determine the benefits derived from grade adjustments for reasons other than earthwork balance.

Another consideration in design is the determination of optimum lengths of passing zones. Limited studies have indicated that utilization is very low for passing zones shorter than about 900 ft based on the current MUTCD standard of 1,200-ft sight distance. Obviously, there exists a passing zone length that many drivers will consider too short for a safe passing maneuver. Additional research is obviously warranted to provide the necessary data for cost-effectiveness evaluations.