# New Approach to Design for Stopping Sight Distance

TIMOTHY R. NEUMAN

**Design for stopping sight distance (SSD) is among the most basic, critical considerations in the total design of a highway. SSD requirements affect all geometric elements—horizontal and vertical alinement and cross section. Despite the importance of SSD, there is continuing, growing dissatisfaction among many design engineers with the current policy and general approach toward SSD. Such dissatisfaction can be attributed to the problems and costs of meeting current design policy, which have changed in recent years, coupled with a lack of evidence of the safety effectiveness of the policy. This paper presents a new approach to SSD design. It involves the abandonment of the concept that a single operational model for SSD is appropriate for all highway types under all conditions. Instead, the approach presented here suggests functional highway classification as the foundation for determining SSD design policy and values. A range of different operational models and driver, vehicle, and roadway parameters would be possible for different classes of highways. This, in turn, allows a range of design values for SSD for a given design speed, rather than just one value for all conditions. The paper presents examples of such models, with assumed values for driver reaction time, pavement friction, and object height. Illustrative calculations of SSD for five different classes of highways are shown. The calculations indicate the potential for SSD design values to vary significantly from those currently shown by the AASHTO policy.**

Design for stopping sight distance (SSD) is among the most basic, critical considerations in the total design of a highway. SSD requirements affect all geometric elements—horizontal and vertical alinement and cross section.

Despite the importance of SSD, there is continuing, growing dissatisfaction among many design engineers with the current policy and general approach to the subject. Such dissatisfaction can be attributed to the problems and costs of meeting current design policy, which have changed in recent years, coupled with a lack of evidence of the safety effectiveness of the policy.

Engineers and researchers have made much progress toward investigating stopping sight distance requirements (*1–3*). Their efforts have been valuable in quantifying important measures of effectiveness and in helping to put SSD in perspective with other design needs. Yet research focus thus far has not addressed the real issue in SSD: the basic model used to determine SSD values for highway design.

This paper is intended to focus the technical debate concerning SSD and to present a new approach to SSD design. This approach represents a major change in policy, yet one that is clearly overdue. In brief, it involves the abandonment of the concept that a single operational model for SSD is appropriate for all highway types under all conditions. Instead, it suggests *functional highway classification* as the foundation for determining SSD design policy and values.

Jack E. Leisch & Associates, 1603 Orrington Avenue, Suite 1200, Evanston, Ill. 60201.

## HISTORICAL REVIEW OF SSD

Current basic design policy for SSD has remained unchanged for almost 50 years. It is summarized (*4–6*) as follows:

> The minimum sight distance available on a highway should be sufficiently long to enable a vehicle traveling at or near the likely top speed to stop before reaching an object in its path. While greater length is desirable, sight distance at every point along the highway should be at least that required for a below average operator or vehicle to stop.

### AASHTO "Object in Road" Model

The American Association of State Highway and Transportation Officials (AASHTO) model for SSD, formalized in 1940, describes design requirements in simple terms, as shown in Figure 1. The parameters of interest in SSD design include eye height, object height, perception-reaction time, pavement-tire coefficient of friction, and speed of operation. What is notable is that design policy as formulated establishes the same operational model (collision avoidance of an object in the road) and the same values for each parameter, regardless of the type of highway.

### Evolution of AASHTO Policy

The AASHTO design policy has changed as the population of vehicles and drivers has changed and as operational and safety research has shed light on safety effectiveness of SSD. Table 1 summarizes the changes in AASHTO policy design

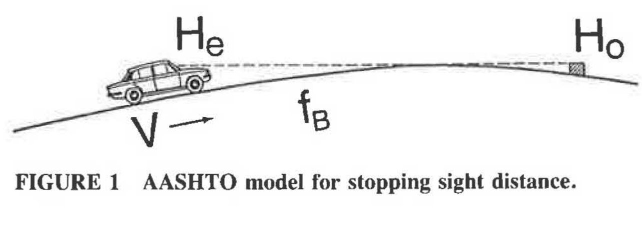


**FIGURE 1 AASHTO model for stopping sight distance.**

TABLE 1 EVALUATION OF AASHTO STOPPING SIGHT DISTANCE POLICY

| | Design Parameters | | | | | |
|---|---|---|---|---|---|---|
| Year | Eye Height (ft) | Object Height (in.) | Perception-Reaction Time (sec) | Assumed Tire-Pavement Coefficient of Friction (*f*) | Assumed Speed for Design | Effective Change from Previous Policy |
| 1940 | 4.5 | 4 | Variable[a] | Dry—from 0.50 at 30 mph to 0.40 at 70 mph | Design speed | |
| 1954 | 4.5 | 4 | 2.5 | Wet—from 0.36 at 30 mph to 0.29 at 70 mph | Lower than design speed (28 mph at 30-mph design speed; 59 mph at 70-mph design speed) | No net change in design distance |
| 1965 | 3.75 | 6 | 2.5 | Wet—from 0.36 at 30 mph to 0.27 at 80 mph | Lower than design speed (28 mph at 30-mph design speed; 64 mph at 80-mph design speed) | No net change in design distance |
| 1970 | 3.75 | 6 | 2.5 | Wet—from 0.35 at 30 mph to 0.27 at 80 mph | Minimum values—same as 1965; desirable values—design speed | Increase in SSD of up to 250 ft at 70 mph |
| 1984 | 3.50 | 6 | 2.5 | Wet—from 0.35 at 30 mph to 0.27 at 80 mph | Minimum values—same as 1965; desirable values—design speed | No net change from 1970 |

[a]3.0 sec at 30 mph to 2.0 sec at 70 mph.

and parameters and the effects of these changes on actual design.

The most recent changes, reflected in the 1984 policy, have the effect of lengthening the required vertical curve and increasing the required horizontal curve offset for a given design speed. These changes, combined with increasing emphasis on reconstruction problems and costs, have highlighted SSD as a major design concern. In many cases of major reconstruction, an existing alinement must be revised if the design agency desires such reconstruction to be compatible with current policy.

Nevertheless, as pointed out in previous work (*7*), blanket alinement reconstruction is clearly not a cost-effective design approach. Other recent research confirms that, in terms of accidents and safety, there is little reason to believe that SSD design is having the kinds of safety effects that designers believed would occur or intended to occur.

## PROPOSED SSD OPERATIONAL MODEL FOR DESIGN OF HIGHWAYS

This paper proposes a revised operational model for stopping sight distance. More precisely, *a series of models* is proposed rather than one single model. This paper outlines the framework for these models and illustrates possible resulting design values for SSD. There are four key elements of the proposed approach:

1. SSD requirements are considered to be related to a number of possible operational events, rather than only one event.
2. There are inherent differences in the operating characteristics and safety experiences of different highway types. The overall design approach should recognize these differences through the use of operating models that relate to each highway type.
3. Human factors and vehicle-roadway parameters also differ with roadway type.
4. SSD requirements differ along the same highway. Demands on drivers and vehicles and probabilities that critical operations will occur are not uniform, but vary according to other physical, geometric, and operating conditions.

### Functional Classification

SSD design models should be based on the functional classification of the highway system. Of primary interest is location (rural or urban), cross section (undivided or divided), general level of traffic volume, and control of access. Solely for the purpose of illustrating the approach here, five distinctly different types of highways are considered—low-volume rural roads, two-lane primary rural highways, multilane urban arterials, rural freeways, and urban freeways.

For each type of highway, there are many critical events that might reasonably serve as the basis for an SSD operational model. Table 2 summarizes these and addresses the concerns of interest—frequency of an occurrence and severity of the consequences of the event. Confronting a large object in the road may be a critical event for design of low-volume, high-speed highways when one considers the lower relative probabilities of vehicle-vehicle conflicts. For other highway types, however, accident and operational experience—as well as common sense—dictate that other more frequent and serious conflicts offer better representations of critical operations. On facilities with uncontrolled access, crossing or rear-end conflicts with stopped vehicles are important. On rural freeways, fewer vehicle-vehicle conflicts occur, making vehicle-object conflicts relatively more important.

For the purpose of discussion, design critical events for the five highway types are presented here. They are

- Low-volume road (LVR)—single-vehicle encounter with a large object (1 ft high);
- Two-lane primary rural highway (2LRP)—vehicle-vehicle conflict involving crossing or stopped vehicle;

TABLE 2 ROADWAY EVENTS RELATED TO SSD

| Type of Event | Frequency of Occurrence | Severity of Conflict/ Impact |
|---|---|---|
| **Two-Lane Rural Highway** | | |
| Object in road | | |
| Large animal | Variable—generally infrequent | Severe |
| Road debris | Infrequent | Minor to moderate |
| Rocks | Infrequent | Minor |
| Small animal | Occasional | Minor to moderate |
| Icepatch | Infrequent | Minor to moderate |
| Pothole, washout | Infrequent | Minor |
| Vehicle in road | | |
| Head-on | Very infrequent | Very severe |
| Rear-end | Frequent | Severe |
| Crossing | Occasional | Severe |
| Pedestrian/bicyclist | Very infrequent | Very severe |
| **Rural Freeway** | | |
| Object in road | | |
| Large animal | Variable—generally infrequent | Severe |
| Road debris | Infrequent | Moderate |
| Rocks | Infrequent | Moderate |
| Small animal | Infrequent | Moderate |
| Icepatch | Infrequent | Minor to moderate |
| Pothole, washout | Infrequent | Minor to moderate |
| Vehicle in road | | |
| Rear-end | Infrequent | Very severe |
| Pedestrian/bicyclist | Infrequent | Very severe |
| **Urban Arterial** | | |
| Object in Road | | |
| Large animal | Very infrequent | Severe |
| Road debris | Infrequent | Minor |
| Rocks | Very infrequent | Minor |
| Small animal | Infrequent | Minor |
| Icepatch | Infrequent to occasional | Moderate |
| Pothole, washout | Occasional | Minor to moderate |
| Vehicle in road | | |
| Head-on | Infrequent | Very severe |
| Rear-end | Frequent | Moderate to severe |
| Crossing | Frequent | Severe |
| Pedestrian/bicyclist | Frequent | Very severe |
| **Urban Freeway** | | |
| Object in road | | |
| Road debris | Frequent | Moderate |
| Small animal | Very infrequent | Moderate |
| Icepatch | Infrequent | Moderate to severe |
| Pothole, washout | Infrequent | Moderate to severe |
| Vehicle in road | | |
| Rear-end | Frequent | Moderate to severe |
| Pedestrian | Very infrequent | Very severe |

- Multilane urban arterial (MUA)—vehicle-vehicle rear-end conflict;
- Rural freeway (RF)—single-vehicle conflict with small (0- to 6-in.) object; and
- Urban freeway (UF)—vehicle-vehicle conflict (rear-end).

Selection of these design critical events represents an attempt to identify events that would (a) occur frequently enough and (b) result in severe enough consequences that a reasonably cost-effective basis for highway design might ensue.

**Driver, Vehicle, and Roadway Characteristics**

Operational model parameters require assumptions concerning driver behavior, vehicles, and roadway characteristics. These might also be expected to vary by highway type. Among the parameters of interest are

- Perception-reaction time, $t_{P/R}$;
- Vehicle type(s);
- Assumed deceleration and braking behavior; and
- Available pavement-tire friction.

*Perception-Reaction Time*

Current design policy assumes 2.5 sec for perception and reaction time and hard braking for collision avoidance with the 6-in. object. Within the framework of functional classification, it is reasonable—in fact desirable—to differentiate in development of model assumptions. Regarding driver behavior, the driver's state of mind has an important effect on performance. Whether the driver is alert or fatigued and what the driver's expectations are for the type of trip and highway should vary by functional classification. A second consideration is the complexity of the driving task, which is strongly related to highway functional type. Uncontrolled-access, high-speed highways present constant decisions to drivers. Rural freeways by their very nature are easy to drive. Urban freeways, because of the density of traffic and frequency of interchanges, are relatively more difficult to drive.

The AASHTO policy discusses driver reaction time in the context of whether information is expected or unexpected and the distribution of driver reaction behavior. The median driver reaction time for responding to unexpected, simple information is about 1.5 sec. More complex decisionmaking and consideration of 85th-percentile versus median drivers result in reaction times of 5 sec or more.

There are clearly differences in the types of decisions, the state of drivers, and the need or desire to design for 85th- versus 50th-percentile behavior. The example below illustrates how a different set of driver assumptions could translate to a range of assumed perception-reaction times for the various highway types studied here.

| | *LVR* | *Two-Lane Primary (Rural)* | *Urban Arterial* | *Rural Freeway* | *Urban Freeway* |
|---|---|---|---|---|---|
| Driver's state | Alert | Fatigued | Alert | Fatigued | Fatigued |
| Complexity of tasks | Low | Moderate | High | Low | High |
| Assumed $t_{P/R}$ (sec) | 1.5 | 3.0 | 2.5 | 2.5 | 3.0 |
| Percent $t_{P/R}$ of AASHTO | 60 | 120 | 100 | 100 | 120 |

*Vehicle Type*

AASHTO SSD requirements are based solely on passenger car characteristics. Some recent research has challenged the AASHTO assumptions that the added height of a truck driver's eye compensates for his vehicle's longer stopping requirements. Furthermore, in terms of design for horizontal SSD requirements, a truck driver's greater eye height offers no advantage. There is evidence, however, that advancing brake technology will soon produce truck stopping distances that are much shorter than those produced by the current fleet.

A revised set of models for SSD policy should fully investigate the truck-passenger car sensitivities. SSD design for rural primary highways and urban highways may need to be based on truck rather than passenger car characteristics.

*Deceleration and Braking*

There are two aspects to an assumed design value for the friction factor. The first is the friction capability of the pavement. To the extent that this tends to vary for different highway types, the operational model's friction chracteristics should vary. The second aspect is the assumed or desired driver action. Is a hard braking response to every event on all highway types a reasonable or desirable model assumption? The model proposed here again differentiates among highway classes. Higher-class facilities could be designed assuming a greater standard of comfort than is assumed for lower classes. The lowest-class facilities, in turn, should probably be designed with minimal consideration for driver comfort. This is consistent with the approach intended by AASHTO in presenting design policy by functional classification.

When a range in assumed friction characteristics and differences in assumed driver braking behavior are used in model development, further SSD variation can be expected. For discussion purposes, the design values for $f$ shown in Figure 2 were used to compute SSD. These values are consistent with the rationale discussed above—that lower-class facilities should be designed with minimal consideration for driver comfort. Note that to simplify the presentation, only passenger car braking is assumed. Truck behavior, as stated previously, may be a better basis for SSD design for some highway types. Analysis of the possible effects of design for trucks was beyond the scope of this paper.

**Stopping Sight Distance Requirements**

Once design models and parameters have been selected, it is possible to calculate SSD requirements by functional highway

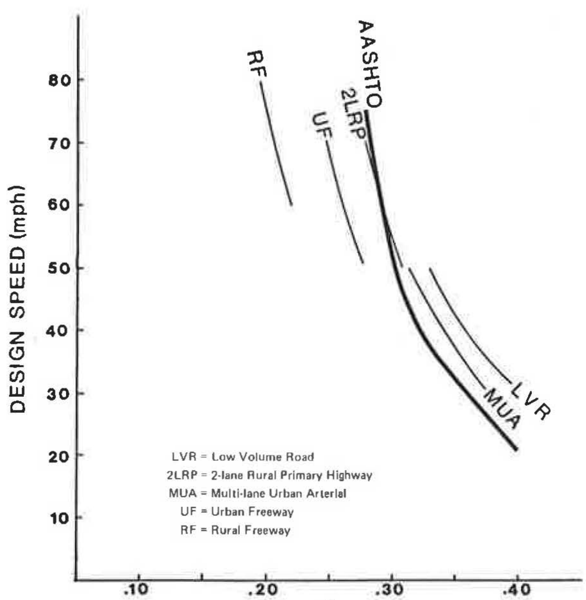


**FIGURE 2 Design values for coefficient of friction by functional class.**

TABLE 3 STOPPING SIGHT DISTANCE REQUIREMENTS BY HIGHWAY TYPE

| Design Speed (mph) | Low-Volume Road[a] | | | Two-Lane Primary Rural Highway[b] | | | Multilane Urban Arterial[c] | | | Urban Freeway[b] | | | Rural Freeway[c] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_{P/R}$ | $d_B$ | SSD | $d_{P/R}$ | $d_B$ | SSD | $d_{P/R}$ | $d_B$ | SSD | $d_{P/R}$ | $d_B$ | SSD | $d_{P/R}$ | $d_B$ | SSD |
| 30 | 66 | 75 | 141 | | | | 110 | 79 | 189 | | | | | | |
| 40 | 88 | 148 | 236 | 176 | 167 | 343 | 147 | 157 | 304 | | | | | | |
| 50 | 110 | 253 | 363 | 220 | 278 | 498 | 183 | 269 | 452 | 220 | 298 | 518 | 183 | 362 | 545 |
| 60 | 132 | 375 | 507 | 264 | 414 | 680 | | | | 264 | 462 | 726 | 220 | 545 | 765 |
| 70 | | | | 308 | 583 | 891 | | | | 308 | 681 | 989 | 257 | 817 | 1,074 |

NOTE: $d_{P/R}$, $d_B$, and SSD values in feet.
[a] $t_{P/R}$ = 1.5 sec.
[b] $t_{P/R}$ = 3.0 sec.
[c] $t_{P/R}$ = 2.5 sec.

type and design speed. The standard equations shown in the AASHTO policy (*6*) are used:

$$SSD = d_{P/R} + d_B$$

$d_{P/R}$ = distance traveled during perception-reaction time (ft)
$d_B$ = distance traveled while braking (ft)
$d_{P/R} = 1.47\ V_{\text{Des}} t_{P/R}$
$d_B = (V_{\text{Des}})^2/30f$
$V_{\text{Des}}$ = design speed (mph)
$t_{P/R}$ = perception-reaction time (sec) (above)
$f$ = design coefficient of friction for braking (Figure 2)

If SSD design values are calculated for each class of highway using the above assumptions, the values shown in Table 3 result. Note that the cumulative effect of varying the parameters results in a range of stopping sight distances from 363 to 545 ft for 50-mph highways. This produces values that are from 79 to 118 percent of current AASHTO policy (see Figure 3).

It is also important to note the relationship between functional class and stopping sight distance. Much lower values than AASHTO recommends are shown for low-volume rural roads. Somewhat *higher* values than AASHTO recommends are called for in the case of two-lane primary rural highways. The greatest values are indicated for rural freeways. Although one might argue with the relative spread or specific parameter values used, the overall results appear logical, and they are consistent with many engineers' views of design. The values illustrate what is considered to be the desired result, that is, a meaningful variation in SSD by functional class.

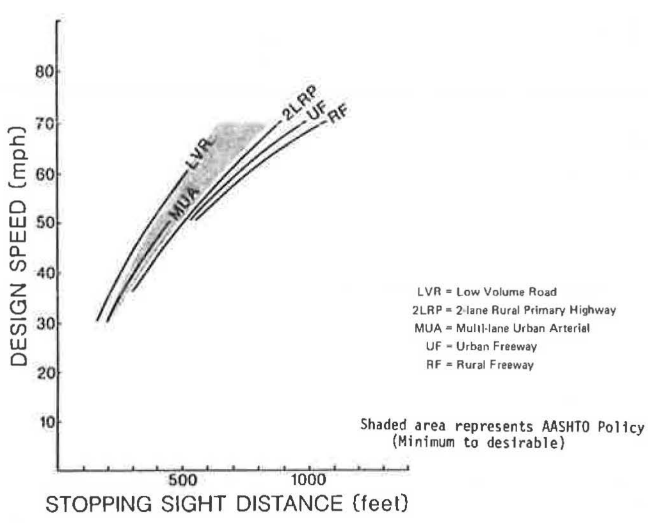


**FIGURE 3 Stopping sight distance design values by highway type.**

## TRANSLATION OF SSD VALUES TO HIGHWAY DESIGN REQUIREMENTS

The final step in the new approach to SSD design is development of design lengths for vertical curves and offsets through horizontal curves. Here again, variations in the functional SSD models may produce variable design results. Such variation reflects the lack of one single object or eye height assumption that is appropriate for all highway types.

### Vertical Curve Design

The functional operational models previously presented imply the eye and object heights shown below. (The author has not evaluated SSD requirements for trucks for this paper. Greater eye heights would be used, along with much longer SSD values. This sensitivity should be investigated, and selection of a rational model made.) Design values of 2.0 ft for tail lights and 1.0 ft for a large object are used.

Vertical curve length requirements are calculated using the following (*6*):

For SSD < $L$

$$L = A\ (\text{SSD})^2/100\ [(2h_1)^{1/2} + (2h_2)^{1/2}]^2$$

For SSD > $L$

$$L = 2(\text{SSD}) - 200\ [(h_1)^{1/2} + (h_2)^{1/2}]^2/A$$

where

$L$ = length of crest vertical curve (ft),
$A$ = algebraic difference in grades,
$h_1$ = height of eye (ft), and
$h_2$ = height of object (ft).

Tables 4–8 show vertical curve length design values for the full range of design speeds. To illustrate the variability in design, consider Figure 4, which shows a plot of crest vertical

TABLE 4 DESIGN LENGTH REQUIREMENTS FOR CREST VERTICAL CURVES ON LOW-VOLUME ROADS—LENGTH OF VERTICAL CURVE IN FEET

| Algebraic Difference in Grades % | Design Speed (mph) 30 (SSD=141 ft.) | 40 (SSD=236 ft.) | 50 (SSD=353 ft.) | 60 (SSD=507 ft.) | 70 (SSD= -- ft.) |
|---|---|---|---|---|---|
| 1 | 90 | 120 | 150 | 180 | - |
| 2 | 90 | 120 | 150 | 190 | - |
| 3 | 90 | 120 | 177 | 465 | - |
| 4 | 90 | 120 | 314 | 624 | - |
| 5 | 90 | 142 | 400 | 760 | - |
| 6 | 90 | 197 | 480 | 936 | - |
| 7 | 90 | 237 | 560 | 1092 | - |
| 8 | 90 | 270 | 640 | 1248 | - |
| 9 | 99 | 304 | 719 | 1404 | - |
| 10 | 117 | 338 | 799 | 1553 | - |

Design assumptions:

Coefficient of braking friction per Figure 2
Perception/reaction time = 3.0 sec.
Height of Object = 2.0 ft.
Height of Eye = 3.5 ft.

Numbers above the line represent minimum curve lengths based on
Length = 3 x $V_{Des}$

TABLE 5 DESIGN LENGTH REQUIREMENTS FOR CREST VERTICAL CURVES ON TWO-LANE RURAL PRIMARY HIGHWAYS—LENGTH OF VERTICAL CURVE IN FEET

| Algebraic Difference in Grades % | Design Speed (mph) 30 (SSD= -- ft.) | 40 (SSD=343 ft.) | 50 (SSD=498 ft.) | 60 (SSD=680 ft.) | 70 (SSD=891 ft.) |
|---|---|---|---|---|---|
| 1 | - | 120 | 150 | 180 | 210 |
| 2 | - | 120 | 150 | 281 | 703 |
| 3 | - | 120 | 277 | 641 | 1103 |
| 4 | - | 146 | 456 | 857 | 1471 |
| 5 | - | 254 | 575 | 1071 | 1639 |
| 6 | - | 326 | 629 | 1285 | 2207 |
| 7 | - | 362 | 804 | 1500 | 2575 |
| 8 | - | 436 | 919 | 1714 | 2943 |
| 9 | - | 491 | 1034 | 1928 | 3310 |
| 10 | - | 545 | 1149 | 2142 | 3678 |

Design assumptions:

Coefficient of braking friction per Figure 2
Perception/reaction time = 3.0 sec.
Height of Object = 2.0 ft.
Height of Eye = 3.5 ft.

Numbers above the line represent minimum curve lengths based on
Length = 3 x $V_{Des}$

curve length design values for the five functional models compared with current AASHTO policy for 50-mph design speed. What is interesting is the great variation in length requirements. For example, for a low-volume road with a *A* of 6 and 50-mph design speed, the vertical curve length requirement is 480 ft, compared with the AASHTO values of 660 ft to 960 ft. Rural freeway vertical curve requirements would be much greater under the model assumptions—1,340 ft. This results from the use of a 6-in. object height for rural freeways rather than a 1.0- or 2.0-ft object height.

TABLE 6 DESIGN LENGTH REQUIREMENTS FOR CREST VERTICAL CURVES ON MULTILANE URBAN ARTERIALS—LENGTH OF VERTICAL CURVE IN FEET

| Algebraic Difference in Grades % | Design Speed (mph) 30 (SSD=189 ft.) | 40 (SSD=304 ft.) | 50 (SSD=452 ft.) | 60 (SSD= -- ft.) | 70 (SSD= -- ft.) |
|---|---|---|---|---|---|
| 1 | 90 | 120 | 150 | - | - |
| 2 | 90 | 120 | 150 | - | - |
| 3 | 90 | 120 | 185 | - | - |
| 4 | 90 | 120 | 364 | - | - |
| 5 | 90 | 176 | 473 | - | - |
| 6 | 90 | 248 | 568 | - | - |
| 7 | 90 | 300 | 663 | - | - |
| 8 | 108 | 343 | 757 | - | - |
| 9 | 138 | 385 | 852 | - | - |
| 10 | 162 | 428 | 947 | - | - |

Design assumptions:

Coefficient of braking friction per Figure 2
Perception/reaction time = 2.5 sec.
Height of Object = 2.0 ft.
Height of Eye = 3.5 ft.

Numbers above the line represent minimum curve lengths based on
Length = 3 x $V_{Des}$

TABLE 7 DESIGN LENGTH REQUIREMENTS FOR CREST VERTICAL CURVES ON URBAN FREEWAYS—LENGTH OF VERTICAL CURVE IN FEET

| Algebraic Difference in Grades % | Design Speed (mph) 30 (SSD= -- ft.) | 40 (SSD= -- ft.) | 50 (SSD=518 ft.) | 60 (SSD=725 ft.) | 70 (SSD=989 ft.) |
|---|---|---|---|---|---|
| 1 | - | - | 150 | 180 | 210 |
| 2 | - | - | 150 | 373 | 899 |
| 3 | - | - | 317 | 733 | 1360 |
| 4 | - | - | 496 | 977 | 1813 |
| 5 | - | - | 622 | 1221 | 2266 |
| 6 | - | - | 746 | 1465 | 2719 |
| 7 | - | - | 870 | 1709 | 3172 |
| 8 | - | - | 995 | 1954 | 3626 |
| 9 | - | - | 1119 | 2198 | 4079 |
| 10 | - | - | 1243 | 2442 | 4532 |

Design assumptions:

Coefficient of braking friction per Figure 2
Perception/reaction time = 3.0 sec.
Height of Object = 2.0 ft.
Height of Eye = 3.5 ft.

Numbers above the line represent minimum curve lengths based on
Length = 3 x $V_{Des}$

### Horizontal Offsets

The minimum offset from the outside lane to a roadside obstruction to provide horizontal SSD is given by the following from the AASHTO policy (*6*):

$$M = (5730/D)\,[1 - \cos(\text{SSD} \times D/200)]$$

where $M$ = offset from center of lane to obstruction (feet) and D = degree of horizontal curve. Design values here are solely a function of SSD values (Table 3) and not eye and

TABLE 8 DESIGN LENGTH REQUIREMENTS FOR CREST VERTICAL CURVES ON RURAL FREEWAYS—LENGTH OF VERTICAL CURVE IN FEET

| Algebraic Difference in Grades % | Design Speed (mph) 30 (SSD= -- ft.) | 40 (SSD= -- ft.) | 50 (SSD=545 ft.) | 60 (SSD=765 ft.) | 70 (SSD=1074 ft.) |
|---|---|---|---|---|---|
| 1 | - | - | 150 | 201 | 819 |
| 2 | - | - | 425 | 881 | 1736 |
| 3 | - | - | 670 | 1321 | 2603 |
| 4 | - | - | 894 | 1761 | 3471 |
| 5 | - | - | 1117 | 2202 | 4339 |
| 6 | - | - | 1341 | 2642 | 5207 |
| 7 | - | - | 1564 | 3082 | 6075 |
| 8 | - | - | 1788 | 3522 | 6943 |
| 9 | - | - | 2011 | 3963 | 7810 |
| 10 | - | - | 2235 | 4403 | 8678 |

Design assumptions:

Coefficient of braking friction per Figure 2
Perception/reaction time = 2.5 sec.
Height of Object = 0.5 ft.
Height of Eye = 3.5 ft.

Numbers above the line represent minimum curve lengths based on Length = 3 x $V_{Des}$

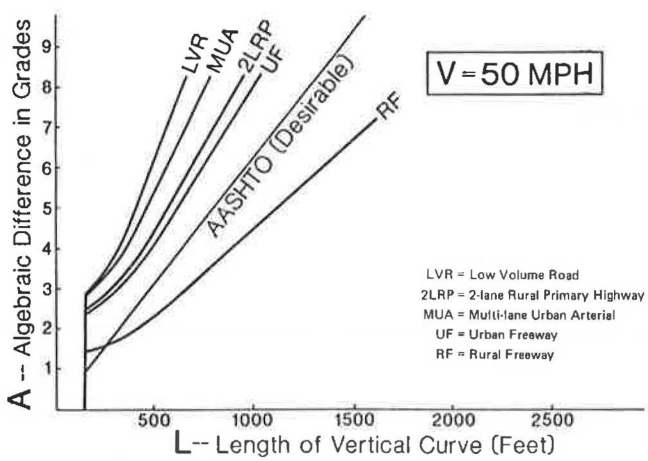


**FIGURE 4 Comparison of crest vertical curve design requirements for 50-mph design speed.**

object height parameters. The resulting values for the range of design speeds are shown in Table 9.

## REFINEMENTS AND ADJUSTMENTS TO REFLECT SPECIAL GEOMETRY OR CONDITIONS

Current design policy for SSD does not account for any of the operational variations in safe stopping requirements that actually occur along a highway. The present policy produces designs that are inconsistent operationally and inevitably not cost effective. The inclusion of a range of values to reflect operational variations is suggested as an important element of the recommended new approach to SSD.

There are two aspects to be considered. The first is the effect of confounding geometry or unusual conditions within the influence of the area of limited sight distance. Examples include the presence of intersections, diverges, horizontal curvature, changes in cross section, and the like. At these locations, additional sight distance should be routinely provided. Alternative design values to the base values presented earlier should be derived on the basis of rationally derived alternative values for the particular operational parameters of different highway types. To illustrate, consider the following possible adjustments (NC indicates no change over values recommended previously):

| *Highway Type* | *Condition with SSD Constraint* | *Adjustments to Operational Model Parameters* $t_{P/R}$ *(sec)* | $h_1$ *(ft)* | $h_2$ *(ft)* | $f$ |
|---|---|---|---|---|---|
| Low-volume road | Intersection, sharp horizontal curve | 4.0 | 3.5 | 0 | NC |
| Two-lane primary | Major intersection, sharp curve | 5.0 | 3.5 | 0 | NC |
| Urban arterial | Change in cross section, major intersection, sharp horizontal curve | 6.0 | 3.5 | 0 | NC |
| Rural freeway | Interchange | 7.0 | 3.5 | 0 | NC |
| Urban freeway | System or major interchange | 7.0 | 3.5 | 0 | NC |

TABLE 9 HORIZONTAL CURVE OFFSETS (*M*) REQUIRED FOR SSD

| Design Speed (mph) | AASHTO Model Min. SSD[a] | *M* | Des. SSD[b] | *M* | Low-Volume Road SSD | *M* | Two-Lane Primary Rural Highway SSD | *M* | Multilane Urban Arterial SSD | *M* | Urban Freeway SSD | *M* | Rural Freeway SSD | *M* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | — | — | 200 | 21.3 | 141 | 10.7 | | | 189 | 19.1 | | | | |
| 40 | 275 | 21.5 | 325 | 30.0 | 236 | 15.9 | 343 | 33.3 | 304 | 26.2 | | | | |
| 50 | 400 | 25.0 | 475 | 39.7 | 363 | 23.3 | 498 | 43.6 | 452 | 36.0 | 518 | 47.2 | 545 | 52.1 |
| 60 | 525 | 30.8 | 650 | 47.1 | 507 | 28.8 | 680 | 51.5 | | | 726 | 58.7 | 765 | 65.1 |
| 70 | 625 | 31.5 | 850 | 58.0 | | | 891 | 63.7 | | | 989 | 78.4 | 1,074 | 92.3 |

NOTE: SSD and *M* values are in feet.
[a]Min. SSD = minimum SSD based on assumed running speeds for wet pavement lower than full design speed (*6*).
[b]Des. SSD = desirable SSD based on assumed full design speed (*6*).

TABLE 10 STOPPING SIGHT DISTANCE REQUIREMENTS FOR LOCATIONS WITH SPECIAL GEOMETRY OR CONDITIONS

| Design Speed (mph) | Low-Volume Road[a] | | | Two-Lane Primary Rural Highway | | | Multilane Urban Arterial | | | Urban Freeway | | | Rural Freeway | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_{P/R}$ | $d_B$ | *SSD* | $d_{P/R}$ | $d_B$ | *SSD* | $d_{P/R}$ | $d_B$ | *SSD* | $d_{P/R}$ | $d_B$ | *SSD* | $d_{P/R}$ | $d_B$ | *SSD* |
| 30 | 176 | 75 | 251 | | | | 265 | 79 | 344 | | | | | | |
| 40 | 235 | 148 | 383 | 294 | 167 | 461 | 353 | 157 | 510 | | | | | | |
| 50 | 294 | 253 | 547 | 368 | 278 | 646 | 441 | 269 | 710 | 514 | 298 | 812 | 514 | 362 | 876 |
| 60 | 352 | 375 | 727 | 441 | 414 | 855 | | | | 617 | 462 | 1,079 | 617 | 545 | 1,162 |
| 70 | | | | 514 | 583 | 1,097 | | | | 720 | 681 | 1,401 | 720 | 817 | 1,537 |

NOTE: $d_{P/R}$, $d_B$, and *SSD* values in feet.

The longer perception-reaction times are consistent with the unexpected and more complex driver decisions produced by the special condition. Similarly, an object height of 0 ft represents a rational requirement to see the pavement or geometry that contributes to the special condition. When these adjustments are used in the calculation of stopping sight distance requirements, the results shown in Table 10 would apply to design.

The implications of these adjustments are clear. In certain locations, regardless of the type of highway, stopping sight distance requirements are greater. This is because of special circumstances that may require additional time for drivers to make decisions or react. Why not formulate design policy to explicitly recognize these additional needs? On the other hand, it is undoubtedly costly, difficult, and, in the long run, counterproductive to formulate SSD design policy around a single most critical model. In most locations the long SSD values produced by the above parameters would clearly not be justified by the costs of achieving such values.

Other adjustments should also be made to reflect the dynamic requirements of braking on a curve or stopping on a downgrade. These adjustments would apply whenever the segment of restricted stopping sight distance coincides with moderate to severe horizontal or vertical alinement. Here, revised design values for the coefficient of braking friction can rationally produce adjusted design values.

## RECONSTRUCTION VERSUS NEW CONSTRUCTION

The SSD issue cannot be completely addressed without mention of problems associated with reconstruction. The current AASHTO policy specifies that "this publication is intended to provide guidance in the design of new and major reconstruction projects." The design profession is thus faced with a dilemma that seriously affects design, budgeting, and programming functions. Given the changes in design policy previously described, every time a major reconstruction project occurs, one of three difficult choices must be made:

1. Redesign the alinement to upgrade it to current SSD policy;
2. Ignore any deficiencies in SSD (as measured against current policy) and reconstruct on existing alinement; or
3. Evaluate each segment of alinement and either reconstruct or request a "design exception."

The first approach is extremely costly. The second inevitably produces problems with tort liability. The third, undoubtedly the best approach, is time-consuming. Moreover, when engineers evaluate existing SSD-deficient locations, most often there is no safety problem identified. A rational decision based on such analysis is to request a design exception. Design exceptions have unfortunately become routine in 4R projects, rather than special or unusual cases. This is not the fault of location and design engineers, but rather the inevitable result of a flawed design policy.

The solution to this dilemma is to treat new construction SSD design differently from reconstruction within the framework of the policy. A rational decision, backed up by analysis of site conditions and actual safety, should not have to be labeled as a design exception. Instead, design values and procedures should be determined in a manner that is sensitive to the particular difficulties and aspects of major reconstruction.

## SUMMARY

This paper was intended to provide the design profession with a fresh approach to stopping sight distance. Example parameter and design volumes were presented to illustrate the model concepts and to demonstrate the sensitivities that should be a part of stopping sight distance design policy. At this stage, the exact values cannot be fixed, but should be extensively tested through further research. Rather than focus on these values, the author urges researchers and designers to address the following concepts:

1. The existing AASHTO operational model for stopping sight distance is not reflective of reasonably frequent occurrences of critical events for all highway types.
2. There are inherent differences in sight distance requirements among highway types defined by their location, traffic volume, cross section, and access control. Such differences should be part of any operational model or models for SSD.
3. Differences among highway types are also reflected in differences in assumed driver behavior and dynamic vehicle characteristics. Basic design parameters should vary for the range of highway types.
4. Design for horizontal and vertical SSD should reflect additional operational needs imposed by confounding geometry.
5. SSD design values should be separately derived for major reconstruction versus new construction.

The most recent edition of the AASHTO policy provides an ideal framework for presenting a functionally classification-based SSD design policy. Concepts related to operational models, driver-vehicle design, parameters, and other basics

can be presented in Chapter II. Each individual chapter could then contain separately derived design tables and charts for SSD.

Should the approach presented here be adopted for highway design, there would be much greater flexibility within the presentation of standard values. Much more cost-effective designs would result, providing additional sight distance where it is most needed. Such cost-effectiveness would be achieved *within* the framework and values rather than through design exceptions in the policy.

## REFERENCES


1. P. L. Olson, et al. *NCHRP Report 270: Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics*. HRB, National Research Council, Washington, D.C., 1984.
2. T. R. Neuman and J. C. Glennon. Cost-Effectiveness of Improvements to Stopping Sight Distance Safety Problems. In *Transportation Research Record 923*, TRB, National Research Council, Washington, D.C., 1983.
3. T. J. Foody and M. D. Long. *The Identification of Relationships Between Safety and Roadside Obstructions*. Ohio Department of Transportation, 1974.
4. *A Policy on Geometric Design of Rural Highways*, AASHO, Washington, D.C., 1954.
5. *A Policy on Geometric Design of Rural Highways*. AASHO, Washington, D.C., 1965.
6. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 1984.
7. *Special Report 214: Designing Safer Roads: Practices for Resurfacing, Restoration and Rehabilitation*. TRB, National Research Council, 1987.


*Publication of this paper sponsored by Committee on Geometric Design and Committee on Operational Effects of Geometrics.*