

Discussion Paper No. 8.A

**STOPPING SIGHT DISTANCE
AND DECISION SIGHT DISTANCE**

prepared for

Oregon Department of Transportation
Salem, Oregon

by the

The Kiewit Center for Infrastructure and Transportation
Oregon State University
Corvallis, Oregon 97331-2302

September 2004

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

DISCLAIMER

This background paper represents the viewpoints of the authors. Although prepared for the Oregon Department of Transportation (ODOT), it does not represent ODOT policies, standards, practices nor procedures.

GENERAL GOAL

This and other background papers were prepared to provide background, enhance understanding and stimulate discussion among individuals representing a variety of groups, agencies and interests who have concern in Oregon's highways.

SPECIFIC OBJECTIVES

The specific objectives of this discussion paper are to:

1. Summarize the literature and traditional knowledge regarding stopping sight distance and decision sight distance.
2. Summarize research and the current state of the art on the factors and elements of driver behavior and traffic operations that affect stopping and decision sight distance.
3. Review current criteria on stopping sight distance and decision sight distance within the context of access management.
4. Identify questions and issues regarding the appropriate criteria and use of stopping and decision sight distance.

ACKNOWLEDGMENTS AND CREDITS

Mr. Del Huntington was project manager for ODOT, Dr. Robert Layton, Professor of Civil Engineering at Oregon State University, was project director for the Transportation Research Institute, OSU. Dr. Vergil Stover was consultant to TRI on this project. This paper was prepared by Dr. Robert D. Layton.

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

OVERVIEW

Background

The safe operation of all highway facilities, including intersections, requires the consideration of three primary elements for safe roadway operations: the driver, the vehicle, and the roadway. An understanding and consideration of each of these elements is necessary to define appropriate sight distance criteria. Human factors associated with the driver's performance must take account of both physical abilities and psychological influences. The size, weight, and braking ability of vehicles are of particular importance for the safe operation and stopping of vehicles. The roadway geometric design features, obstacles to sight at the roadsides, pavement surface condition, and climatic conditions impact the safety on the roadway and sight distance requirements. Each of these elements and their interactions govern the development and specifications of sight distance criteria and standards.

The determination of stopping sight distance requires the definition and consideration of seven design variables:

Primary Stopping Sight Distance Factors

- Perception-reaction time
 - Driver eye height
 - Object height
 - Vehicle operating speed
 - Pavement coefficient of friction
 - Deceleration rates
 - Roadway grade
-

An important study on stopping sight distance was published as NCHRP Report 400, "Determination of Stopping Sight Distance." This reference presents recommended revisions to the AASHTO "Policy on Geometric Design" for the 2001 Edition.

Most of the recommended changes from NCHRP Report were included in the 2001 AASHTO "Policy on Geometric Design" (i.e., 2001 Greenbook). However, a number of state DOTs have opted to retain some criteria from the 1990 and 1994 AASHTO Policies (1990 and 1994 Greenbooks), rather than accept the significant changes in height of objects, from 150 mm (0.5 ft.) to 600 mm (2.0 ft.), for stopping sight distance.

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OVERVIEW (Continued)

Content

This background paper summarizes the literature, standards and traditional knowledge on stopping and decision sight distance. The primary emphasis of this discussion is on the driver behavior and traffic operation conditions that influence the distance required for drivers to stop or maneuver their vehicles safely.

The discussion includes information drawn from policies, standards and current research. The primary sources of the policies and standards are the AASHTO Policy on Geometric Design, 1990 Edition (English Units), 1994 Edition (Metric units) and 2001 Edition (both units), and the Oregon Highway Design Manual. The standards and criteria for stopping sight distance have evolved since the 1920s. The changes in vehicle sizes and operating characteristics, driver experience and behavior, and highway technology cause a continued evolution of sight distance policies and standards.

Issues

Sight distance criteria have impact on virtually all elements of highway design and many elements of the operation/control. The roadway geometric design features, presence of obstacles to sight at the roadsides and the pavement surface condition are fixed by sight distance requirements. The nature of traffic controls and their placement must take account of sight distance requirements. At times, the effects of traffic stream conditions, such as traffic queues, must be viewed from adequate distance to stop.

Adequate stopping sight distance must be provided on 100% of the street and highway system so a driver with the standard eye height can see an object of standard height with sufficient time to stop safely. This assumes a certain level of alertness on the part of the driver and no influence on a driver's perception and reaction due to added complexity of traffic, control and local environmental conditions. Some research has indicated that driver behavior, expectations and alertness change with the type of area and with the operating conditions on the roadway.

The determination of stopping sight distance requires the definition of six of the seven primary design variables. It is not necessary to specify both deceleration rate and a design coefficient of friction because they both measure the required rate of slowing for the vehicle.

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

OVERVIEW (Continued)

**Issues
(Continued)**

Under some conditions the added complexity of traffic, local activities and driver expectancy may require longer times to accommodate long perception-reaction times due to situation complexity, expectations and alertness, as well as longer distance for normal vehicle maneuvers of lane changing, speed changes and path changes, or for stopping.

These increased perception-reaction times and longer maneuvering distances are accommodated by decision sight distance. Decision sight distance is applied where numerous conflicts, pedestrians, various vehicle types, design features, complex control, intense land use, and topographic conditions must be addressed by the driver. Stopping sight distance is applied where only one obstacle must be seen in the roadway and dealt with. Decision sight distance is different for urban versus rural conditions, and also for maneuvers ranging from stopping to speed, path or direction change within the traffic stream. Consequently, there are five different cases for decision sight distance.

Decision Sight Distance Cases

- Rural Stopping
 - Urban Stopping
 - Rural Speed/Path/Direction Change
 - Suburban Speed/Path/Direction Change
 - Urban Speed/Path/Direction Change
-

Stopping in the context of decision sight distance, as distinct from stopping sight distance, may be necessary to avoid a vehicle that is forced to stop for some traffic condition, such as a queue of vehicles, rather than an object in the roadway.

In view of the complexity and variations in drivers' expectancy for situations associated with access management, decision sight distance is a more logical requirement for many access management situations than stopping sight distance.

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OVERVIEW (Continued)

Sight Distance as an Access Management Measure

Stopping sight distance is required at all locations along the highway, to see an object in the roadway with enough distance to stop. The stopping sight distance is typically required at all intersections and approaches.

The decision sight distance is the control for many access management situations where:

1. driver workload is heavy, driver expectations vary or drivers are likely to be misled, such as in the vicinity of interchange ramp terminals or where continuous two-way left turn lanes are present.
2. complex operations or design features exist, such as unsignalized intersections or approaches on multilane highways.

The decision sight distance may be applied:

1. to control vehicles that must perceive and react with time to stop behind queuing vehicles.
 2. to assure adequate time for a speed, path or direction change, as would occur where vehicles must weave to a left turn lane or to an approach on the right.
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Questions to be Answered

The selection and application of a sight distance criteria require that a number of questions be answered. The most important questions are identified as follows:

1. Should a safe coefficient of friction or acceptable deceleration rate be used to define the deceleration of vehicles? What deceleration rates are implied by the coefficient of friction used for design? What deceleration rates are typical and comfortable for drivers?
2. What height of eye should be used for sight distance? What proportion of the drivers should the height of eye criterion represent?
3. Is a 600 mm (2 ft.) object reasonable? Should the height of the object be different for decision sight distance? Should the height of the object be different for some situations?

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OVERVIEW (Continued)

**Questions to
be Answered
(Continued)**

4. Should trucks be treated specifically or should the higher eye height be assumed to offset the longer stopping distance required?
5. Should the stopping sight distance and decision sight distance be based on design speed, running speed or vary according to conditions?
6. Should the perception-reaction times specified in the AASHTO Green Book be accepted, or should they be specified according to the situation?

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PERCEPTION-REACTION TIMES (cont.)

Reaction Time Research	Recent studies have checked the validity of 2.5 seconds as the design perception reaction time. Four recent studies have shown maximums of 1.9 seconds as the perception-reaction time for an 85th percentile time and about 2.5 seconds as the 95th percentile time.	Brake Reaction Times Studies		
			85th	95th
		Gazis et al. (1)	1.48	1.75
		Wortman et al. (2)	1.80	2.35
		Chang et al. (3)	1.90	2.50
		Sivak et al. (4)	1.78	2.40

Perception-Reaction Times by Road Type

Some researchers have suggested that the perception-reaction should reflect the complexity of traffic conditions, expectancy of drivers and the driver's state. They suggest that the perception reaction times may be altered accordingly, as shown in Table 1 (4).

Table 1. Perception-Reaction Times Considering Complexity and Driver State

	Driver's State	Complexity	Perception-Reaction Time
Low Volume Road	Alert	Low	1.5 s
Two-Lane Primary Rural Road	Fatigued	Moderate	3.0 s
Urban Arterial	Alert	High	2.5 s
Rural Freeway	Fatigued	Low	2.5 s
Urban Freeway	Fatigued	High	3.0 s

An appreciation and understanding of human factors, driver behavior and abilities are needed to determine the sight distance criteria. The physical abilities and psychological limitations of drivers impact these criteria, and should be reviewed here to obtain perspective.

(1) Gazis, D.R., et al., "The Problem of the Amber Signal in Traffic Flow," Operations Research 8, March-April 1960.

(2) Wortman, R.H., and J.S. Matthias, "Evaluation of Driver Behavior at Signalized Intersections," Transportation Research Record 904, T.R.B, Washington, D.C., 1983.

(3) Chang, M.S, et al., "Timing Traffic Signal Change Intervals Based on Driver Behavior," T.R. Record 1027, T.R.B, Washington, D.C., 1985

(4) Sivak, M., et al, "Radar Measured Reaction Times of Unalerted Drivers to Brake Signals," Perceptual Motor Skills 55, 1982.

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HUMAN FACTORS

Visual Acuity

The primary stimulus for operation and safe control of vehicles is eye sight. The physical composition of the eye and its functioning constitute limits that must be considered when developing sight distance criteria.

Visual Acuity

3-4° cone	best vision – can see texture, shape, size, color, etc.
10° cone	clear vision – critical traffic control devices must be in this cone
20° cone	satisfactory vision – regulatory and warning traffic control devices should be this cone of vision
~ 90° cone	peripheral vision – only movement can be seen with this vision

Drivers focus their attention down the roadway in the cone of clear vision at 3 to 4 times the stopping distance. They then shift their vision to the right and left to keep track of traffic conditions, pedestrians and local activities. The eye movement time includes the time required for a driver to shift their eyes and to focus on an object.

Eye Movement Time

Shift to New Position	0.15-0.33 sec
Fix or Focus on Object	0.1-0.3 sec

It takes roughly 0.5 second for a driver to shift his eyes and focus. Thus, a full cycle to right and back to the left takes about 1 second. If there is glare, it takes 3 seconds to recover full visual acuity and 6 seconds to recover from bright to dim conditions.

Human Mind is Single Channel

Humans are sequential processors; that is, drivers sample, select and process information one element at a time, though very quickly. Therefore, complex situations create unsafe or inefficient operations because it takes so long for drivers to sample, select and process the information. This means that as complexity increases a longer perception-reaction time should be available. The visual acuity limitations, visibility constraints of glare/dimness recovery and complexity of traffic conditions, when taken together, require much longer perception-reaction times or decision times.

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HUMAN FACTORS (Continued)

Driver Expectancy Drivers are led to expect a particular operation condition based on the information presented to them. They use both formal and informal information.

- Formal information – this includes the traffic-control devices and primary geometric design features of the roadway, but does not include the roadside features such as ditch lines, guardrail, and other street furniture.
- Informal information – this includes roadside features and also land use features, such as brush lines, tree lines, fences and information signing. It includes all information that is not formal.

Drivers develop expectations on how to drive a roadway through experience, training and habit. At times these expectations are in error because they use inappropriate informal information, or the formal information provided is not proper or gives mixed messages. Often, the information at a location is conflicting, and drivers who are familiar with the location will read traffic conditions differently than unfamiliar drivers. For example, driver error due to driver expectancy can occur where the location of pavement joints (informal information) conflict with lane markings (formal information). A driver may see and follow the pavement joints rather than the pavement striping, particularly on dark, wet nights.

Increased perception reaction time is needed to allow time for drivers to make the proper decision when information conflicts and driver expectancy may be in error.

Traffic conditions vary dramatically on major facilities; consequently, the information that drivers receive from other vehicles and traffic conditions is constantly changing. Therefore, high volume and high speed conditions with the added complexity and heavier driver workloads require longer decision times and compound any problems arising from driver expectancy.

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DRIVER EYE HEIGHT

The height of eye for design has decreased with time as the vehicle sizes and dimensions changed. The design height of eye up to the year 2000 was 1070 mm (3.5 ft.) (1,2). This has reduced from 1680 mm (5.5 ft.) in the 1920s to 1150 mm (3.75 ft.) in 1965. A moderate change in driver's eye height results in a small change in stopping sight distance and in the required length of vertical curves (4). Driver eye height for trucks is not normally of concern because they are significantly higher than passenger cars. The higher height of eye for trucks is assumed to compensate for their longer stopping sight distance. However, truck eye height may be an issue where the stopping sight distance is controlled by horizontal alignment, such as cut slopes, or other vertical sight obstructions, such as a hedge, overhanging limbs or signs. Typical values for height of eye for trucks are from 1820 mm (71.5 in.) to 2860 mm (112.5 in.) with an average eye height of 2360 mm (93 in.). A height of eye of 2400 mm (8.0 ft.) has been used for design (7,8) for trucks.

The NCHRP Report 400 presented the results of some measurements made on height of eye for various vehicles. These results are shown in Table 2.

Table 2. Current Height of Eye Statistics

	Passenger Cars	Multipurpose Vehicles*	Heavy Trucks
	mm (ft)	mm (ft)	mm (ft)
Mean	1149 (3.77)	1482 (4.86)	2447 (8.03)
Standard Deviation	55 (0.18)	130 (0.43)	107 (0.35)
5 th Percentile	1060 (3.48)	1264 (4.15)	2304 (7.56)
10 th Percentile	1082 (3.55)	1306 (4.28)	2329 (7.64)
15 th Percentile	1094 (3.59)	1331 (4.37)	2341 (7.68)

*These include pickups, utility vehicles, vans, etc.

Source: NCHRP Report 400, Transportation Research Board, Washington, DC, 1997.

There was some indication that the height of eye adopted by AASHTO would be reduced to 1 meter, or 3.28 ft., since the passenger car fleet has continued to decrease in height. However, the increased use of pick-ups, SUVs and vans has caused the overall driver's eye height to increase. The NCHRP Report 400 has recommended a height of eye of 1080 mm (3.54 ft.).

This change of height of eye of 1080 mm (3.54 ft.) has been adopted in the new 2001 AASHTO Greenbook; also the new Greenbook adopted an eye height for trucks of 2330 mm (7.6 ft.), with a stated range of 1800 mm to 2600 mm (6-8 ft.). CALTRANS retained an eye height of 1070 mm (3.5 ft.).

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OBJECT HEIGHT

The object height that has been used for stopping sight distance has been 150 mm (6 in.) since 1965. The standards have required that a driver should be able to see and stop before hitting an object of 150 mm (6 in.) in height everywhere on the roadway. This arbitrary value recognized the hazard an object of that height or larger would represent, since 30% of the compact and sub-compact vehicles could not clear a 150 mm (6 in.) object (5). It also suggested that the 150 mm (6 in.) object height was a rational trade-off between the need to see the pavement and the cost to provide that sight distance. Under some circumstances the height of the tail-light at 450 mm (1.5 ft.) to 600 mm (2.0 ft.) were recognized as a more appropriate object to be viewed, in particular at under-crossings, where a truck would be the design vehicle with its height of eye. A study undertaken by CALTRANS for sight distance on HOV lanes found an 85% tail-light height of 760 mm (2.5 ft.).

The new AASHTO standard for object height in the new 2001 AASHTO Greenbook has been increased to 600 mm (2.0 ft.) based on a car's tail-light. CALTRANS, ODOT and WSDOT retained the 150 mm (0.5 ft.) object height for both stopping sight distance and decision sight distance, recognizing all of the aspects of safe highway design and visibility that are provided by this lower height of object of 150 mm (0.5 ft.). Discussion of the safety implications of the use of a 600 mm (2.0 ft.) height of object is given in Appendix A.

The object height at intersections has been 1300 mm (4.25 ft.), which is the same required for passing sight distance (1). This criterion assumes that being able to see the top or roof of a passenger car is adequate as the object for intersection sight distance (6). This ignores the difficulty in distinguishing the thin splinter of the car roof from other objects, particularly if the car is of an earth tone color. It also ignores the difficulty in seeing the car at night with the headlights at about 600 mm (2 ft.) height, even assuming some upward diffusion of the lights. A height of object of 1080 mm (3.5 ft.), the new 2001 AASHTO standard for passing sight distance, would yield a target of 220-250 mm (9-10 in.) in height, which would assure an approaching vehicle would be seen. Where the decision sight distance criteria is applied to the back of queue or to avoid vehicles elsewhere in the traffic stream, the object height may be either the height of the vehicle or the height of the tail-light. The height of tail-light according to NCHRP Report 400 must be no lower than 380 mm (15 in.) nor higher than 1830 mm (72 in.); the mean tail-light height was found to be 726 mm (2.38 ft) for passenger cars. This would typically result in an object height of 460-760 mm (1.5-2.5 ft.). For vehicles entering the roadway at night, the height of the headlights may be used, or 600 mm (2 ft.). The new AASHTO standard for object height is 1080 mm/ (3.5 ft.) for both passing sight distance and intersection sight distance, according to the 2001 Greenbook.

Pavement sight distance should be provided in channelized intersections, on turning roadways, or at locations where the alignment may take an unexpected direction. This is provided with an object height of 0.0 mm (0.0 ft.).

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OBJECT HEIGHT (Continued)

In summary:

	<u>2001</u> <u>AASHTO</u>	<u>2001</u> <u>CALTRANS</u>	<u>2001</u> <u>ODOT</u>	<u>2001</u> <u>WSDOT</u>
Object for stopping sight distance	600 mm (2.0 ft.)	150 mm (0.5 ft.)	150 mm (0.5 ft.)	150 mm (0.5 ft.)
Object for decision sight distance	600 mm (2.0 ft.)	150 mm (0.5 ft.)	150 mm (0.5 ft.)	150 mm (0.5 ft.)
Object for passing sight distance	1080 mm (3.5 ft.)	1300 mm (4.25 ft.)		1300 mm (4.25 ft.)
Object for intersection sight distance	1080 mm (3.5 ft.)	1300 mm (4.25 ft.)		1300 mm (4.25 ft.)

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VEHICLE SPEED

The speed employed in the analysis of stopping sight distance is typically the design speed in Oregon and other states, in particular for vertical sight restrictions. Until the 2001 AASHTO Policy, AASHTO allowed the running speed to be used, since the design coefficient of friction was for wet pavements, and drivers were expected to slow on wet pavements. However, AASHTO indicates that recent data shows that drivers do not slow appreciably on wet pavement. The 2001 AASHTO Policy on Geometric Design has eliminated stopping sight distance based on running speed, and stopping sight distance based on design speed is specified. Therefore, design speed should be used to determine sight distance criteria. When the facility is an existing facility, or design speed is not known, the operating speed on the roadway can be used.

The relationship between average speed, 85th percentile speed and design speed is not well defined. However, the approximate relationship can be defined as follows, based on the standard normal distribution. The design speed has been defined as about the 95th to 98th percentile speed; therefore:

Average operating speed = mean speed

85th percentile speed = mean speed + 1 std. deviation

Design speed (97% speed) = mean speed + 2 std. deviations

Typically, the standard deviation for speeds is about 5-6 mph. Thus, if the standard deviation is not known, a rule-of-thumb is:

85th percentile speed is mean operating speed + 5 mph (10 km/h)

Design speed is 85th percentile speed + 5 mph (10 km/h)

Small variations in speed result in very large differences in stopping sight distance, since stopping sight distance varies as the square of velocity. Decision sight distance varies linearly with the speed, so the speed definition is not as critical.

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PAVEMENT COEFFICIENT OF FRICTION

Until 2001, the coefficients of friction used for design on arterials or open highways in the 1990 and 1994 AASHTO Green Books (1) are based on the results of a number of studies that measured the locked-wheel skid resistance on poor wet pavements. These AASHTO design values corresponded to a comfortable deceleration rate of 9.6 to 12.9 kph/sec (6 to 8 mph/second); they are shown in Table 3.

Table 3. 1990 and 1994 Design Coefficients of Friction for Stopping Sight Distance

Design Speed		Running Speed		1990 and 1994 AASHTO Coeff. of Friction for f_{WET}	AASHTO Coeff. of Friction for trucks, f_{TR}	Acceptable Deceleration for Trucks, a_{TR} ft/sec ²
30 kph	(20 mph)	32 kph	(20 mph)	0.40	0.25	8.1
50 kph	(30 mph)	45 kph	(28 mph)	0.35	0.21	6.8
65 kph	(40 mph)	58 kph	(36 mph)	0.32	0.19	6.1
80 kph	(50 mph)	71 kph	(44 mph)	0.30	0.18	5.8
100 kph	(60 mph)	84 kph	(52 mph)	0.29	0.17	5.5
115 kph	(70 mph)	93 kph	(58 mph)	0.28	0.16	5.1

With trucks the safe coefficient of friction for braking is less than for passenger cars because a truck can't safely make a locked-wheel stop without the risk of losing control. Therefore, the deceleration rate when stopping is less for trucks than for passenger cars, on the order of 5.6 kph/sec (3.5 mph/sec) to 8.9 kph/sec (5.5 mph/sec); these decelerations correspond to "f" values of 0.16 to 0.25, respectively. Design coefficients of friction based on truck performance are given in the last column of Table 3 above. Note that the coefficient of friction corresponding to a deceleration rate is determined from the relationship:

$$f = \frac{a \text{ (mph/sec)} \times 1.4667 \text{ (fps/mph)}}{32.2 \text{ fps}^2} \quad (\text{U.S. Customary})$$

$$f = \frac{a \text{ (m/sec}^2\text{)}}{9.8 \text{ (m/sec}^2\text{)}} \quad (\text{Metric})$$

The new 2001 AASHTO Policy on Geometric Design uses a deceleration criterion to determine the braking distance term for stopping sight distance of 3.4 m/sec² (11.2 ft/sec²).

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STOPPING SIGHT DISTANCE (Continued)

The stopping sight distance is comprised of the distance to perceive and react to a condition plus the distance to stop:

$$SSD = 0.278 Vt + \frac{V^2}{254 (f \pm g)} \quad (\text{Metric})$$

or

$$SSD = 0.278 Vt + \frac{V^2}{254 \left(\frac{a}{9.81} \pm g\right)} \quad (\text{Metric})$$

$$SSD = 1.47 Vt + \frac{V^2}{30 (f \pm g)} \quad (\text{U.S. Cust.})$$

or

$$SSD = 1.47 Vt + \frac{V^2}{30 \left(\frac{a}{32.2} \pm g\right)} \quad (\text{U.S. Cust.})$$

where SSD = required stopping sight distance, m or ft.
V = speed, kph or mph
t = perception-reaction time, sec., typically 2.5 sec. for design
f = coefficient of friction, typically for a poor, wet pavement
g = grade, decimal.

The 1990 and 1994 AASHTO Greenbooks provided for a minimum and a desirable stopping sight distance. The desirable stopping sight distance was provided based on the design speed and a coefficient of friction for a poor, wet pavement. The minimum stopping sight distance was provided based on the running speed and a coefficient of friction of a poor, wet pavement. The NCHRP Report 400 recommended new design criteria to AASHTO using a deceleration rate of 0.34 g (3.4 m/sec² or 11.2 ft/sec²) instead of the wet coefficient of friction. The running speed is the average operating speed on the roadway and is typically less than design speed, about 83% to 100% of design speed for 113 kph to 32 kph (70 mph to 20 mph), respectively. As indicated previously, AASHTO has found that drivers do not slow on wet pavement so the use of running speed is not appropriate to determine stopping sight distances. Table 4 gives the stopping sight distances for a range of design speeds. For comparison, it also gives typical emergency stopping sight distances, with short emergency reaction times of 1 sec. and wet and dry pavement conditions. In this table, the coefficient of friction for a wet pavement is assumed to be those

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STOPPING SIGHT DISTANCE (Continued)

used for stopping sight distance in the 1990 and 1994 Greenbooks, and for dry pavement is assumed to be 0.6.

It is interesting to note that with low beam headlights, a driver may be able to see from 37 m to 107 m (120 ft. to 350 ft.) and with high beams from 61 m to 152 m (200 ft. to 500 ft.). Thus, drivers driving faster than 88 kph (55 mph) at night are overdriving their headlights.

The new 2001 AASHTO Greenbook recommends a minimum stopping sight distance based on design speed with a deceleration rate of 3.4 m/sec^2 (11.2 ft/sec^2) and a perception-reaction time of 2.5 seconds for design. The “minimum” minimum stopping sight distance based on running speed has been abandoned.

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STOPPING SIGHT DISTANCE (Continued)

Table 4A. Design Stopping Sight Distances and Typical Emergency Stopping Distances (Metric Units)

Speed	Stopping Sight Distance, (m)		Typical Emergency Stopping Distance, (m)	
Design Speed (km/h)	Calculated (2.5 ^s , a=3.4 m/sec ²)	Design (2.5 ^s , a)	Wet Pave. (1 ^s , f _{wet})	Dry Pave. (1 ^s , f _{dry})
30	31.2	35	17.1	14.2
40	46.2	50	27.7	21.6
50	63.5	65	42.0	30.3
60	83.0	85	59.6	40.3
70	104.9	105	81.7	51.6
80	129.0	130	106.1	64.2
90	155.5	160	131.2	78.1
100	184.2	185	163.4	93.4
110	215.3	220	200.6	110.0
120	248.6	250	235.7	127.9

Table 4B. Design Stopping Sight Distances and Typical Emergency Stopping Distances (English Units)

Speed	Stopping Sight Distance, (ft.)		Typical Emergency Stopping Distance, (ft.)	
Design Speed (mph)	Calculated (2.5 ^s , a=11.2 FPS ²)	Design (2.5 ^s , a)	Wet Pave. (1 ^s , f _{wet})	Dry Pave. (1 ^s , f _{dry})
20	111.9	115	63	52
25	151.9	155	92	71
30	196.7	200	130	94
35	246.2	250	172	120
40	300.6	305	225	148
45	359.8	360	284	179
50	423.8	425	357	212
55	492.4	495	417	249
60	566.0	570	495	288
65	644.4	645	581	330
70	727.6	730	686	375

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

DECISION SIGHT DISTANCE

Decision Sight Distance Appropriate for Access Management

There are many situations where stopping sight distance is not sufficient for safe and smooth operations, as indicated in the discussion of perception reaction time and stopping sight distance. Complex conditions, problems of expectancy, high volumes and high speed require more time for the perception-reaction process. These conditions are present on arterial streets and highways, particularly in urban areas. The AASHTO Policy on Geometric Design has provided for such situations through the decision sight distance.

Distinction Between Stopping Sight Distance and Decision Sight Distance

The distinction between stopping sight distance and decision sight distance must be understood.

- Stopping sight distance is used when the vehicle is traveling at design speed, and one clearly discernable object or obstacle is presented in the roadway. The vehicle must decelerate to a stop at an acceptable rate to avoid the object.
- Decision sight distance applies when conflicts are numerous, conditions are complex, driver expectancies may vary, or visibility to traffic control or design features is impaired.

Most situations presented on arterials for access management require stopping sight distance at a minimum; however, decision sight distance often should be provided for safety and smoother operations.

AASHTO Decision Sight Distance

The decision sight distance as defined by the AASHTO Green Book is “the distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard or its threat potential, select an appropriate speed and path, and initiate and complete the required maneuver safely and efficiently.” According to 1990 and 1994 AASHTO, the decision sight distance requires about 6 to 10^s to detect and understand the situation and 4 to 4.5^s to perform the appropriate maneuver. For 1990 and 1994 AASTHO Greenbook, the sight distance was typically measured from a 1070 mm (3.5 ft.) height of eye to 150 mm (6 in.) object; however, this should depend on the condition that requires the decision sight distance. For example, if the condition of concern is a vehicle, such as the rear of a queue of vehicles, an object height of vehicle tail lights of 600 mm (2.0 ft.) would be appropriate. A table showing the recommended decision sight distances for various maneuvers is given in Table 5.

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DECISION SIGHT DISTANCE

AASHTO

Decision Sight Distance (Continued)

The new standard for 2001 AASHTO has specified eye height as 1080 mm (3.5 ft.) with a 600 mm (2.0 ft.) object for decision sight distance. This often is appropriate for decision sight distance.

Various avoidance maneuvers have been defined by AASHTO to address the variety of operating conditions that occur in traffic.

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Table 5A. Decision Sight Distance (Metric Units)

Design Speed (km/h)	Decision Sight Distance for Avoidance Maneuver, (meters)				
	A	B	C	D	E
50	70	155	145	170	195
60	95	195	170	205	235
70	115	235	200	235	275
80	140	280	230	270	315
90	170	325	270	315	360
100	200	370	315	355	400
110	235	420	330	380	430
120	265	470	360	415	470
130	305	525	390	450	510

Table 5B. Decision Sight Distance (English Units)

Design Speed (mph)	Decision Sight Distance for Avoidable Maneuver, (ft.)					
	A	B	C	D	E	
25	180	280	400	375	400	525
30	220	350	490	450	535	620
35	275	425	590	525	625	720
40	330	505	690	600	715	825
45	395	590	800	675	800	930
50	465	680	910	750	890	1030
55	535	775	1030	865	980	1135
60	610	875	1150	990	1125	1280
65	695	980	1275	1050	1220	1365
70	780	1090	1410	1105	1275	1445
75	875	1200	1545	1180	1365	1545
80	970	1320	1685	1260	1455	1650
	Rural	Suburban	Urban	Rural	Suburban	Urban

*Note: Avoidance Maneuvers

1. Avoidance maneuver A: Stop on rural road - $t = 3.0^s$
- 1a. Stop on suburban road - Assume $t = 6.0^s$
2. Avoidance maneuver B: Stop on urban road - $t = 9.1^s$
3. Avoidance maneuver C: Speed/path/direction change on rural road
4. Avoidance maneuver D: Speed/path/direction change on suburban road
5. Avoidance maneuver E: Speed/path/direction change on urban road

Source: AASHTO Greenbook, 2001.

Various operating conditions require different maneuvers in response to a situation, as well as different perception-reaction times. The perception-reaction times are shorter for the less complex rural conditions than for urban.

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

Appendix A

Evaluation of 600 mm (2 ft.) Height of Object Criteria

This appendix evaluates the efficacy of using a 2 ft. height of object for analyzing stopping sight distance, as proposed in the new 2001 AASHTO Greenbook. The new 2001 AASHTO Greenbook sets the 600 mm (2.0 ft.) height of object for stopping sight distance because it represents the height of tail light for an automobile, the object that is most likely to be hit in an accident. This object of height on the surface seems reasonable and prudent. However, there are a number of issues that must be considered when raising the object height from 150 mm (0.5 ft.) to 600 mm (2.0 ft.), including;

1. The most frequently hit object on the roadway is an automobile, because it is the most frequently found object on the roadway.
2. Other objects of 150 mm (0.5 ft.) to 600 mm (2.0 ft.) are not frequently hit because the previous stopping sight distance standards provide sight distance to see an object of 150 mm (0.5 ft.) or more.
3. Objects of less than 150 mm (0.5 ft.) do not typically cause accidents because an automobile can drive over them, or they do not have sufficient mass to give major problems.
4. Design elements on the roadway are not visible from an adequate preview distance to accommodate safe operations on the roadway for roadway geometrics designed based on a 600 mm (2.0 ft.) object height.
5. Headlight sight distance over a crest vertical curve at night is severely restricted, and dangerous for vertical curves designed based on a 600 mm (2.0 ft.) object height.

The roadway section that is visible to a driver at stopping sight distance is reduced appreciably, that is, the side slopes, ditch sections and other visual cues that drivers use to operate their vehicle are not available. Consequently, unfamiliar drivers might be expected to slow at such locations. Other drivers are going to have less time to react and adjust to roadway conditions.

A comparison of the preview distance to a 150 mm (0.5 ft.) object for a vertical curve designed under the 2001 criteria, versus the 1990-94 criteria, shows how restricted operations become under the new criteria.

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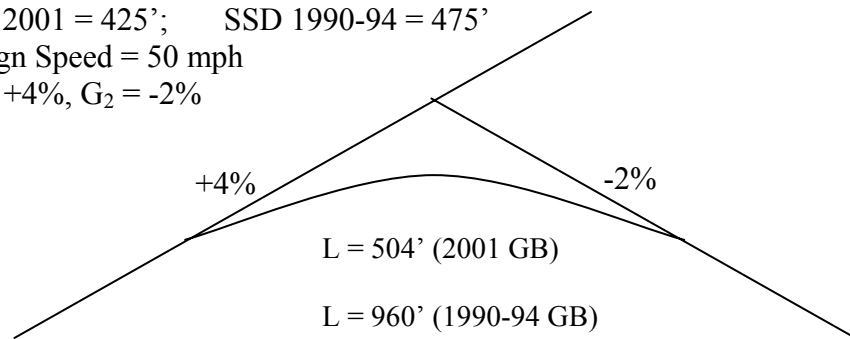
Appendix A

Example – Comparison of a Typical 50 mph Vertical Curve Design

Given: SSD 2001 = 425'; SSD 1990-94 = 475'

Design Speed = 50 mph

$G_1 = +4\%$, $G_2 = -2\%$



Vertical Curve Design:

2001 Greenbook Design

$$L = KA; \quad L = 84 \times 6$$

$$L = 504'$$

1990-94 Greenbook Design:

$$L = KA; \quad L = 160 \times 6$$

$$L = 960'$$

Preview Distance Calculation:

Preview distance with an

Object height = 0.5':

Equation relating length and sight distance for vertical* curves:

$$S < L: \quad L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$

$$504 = \frac{6S^2}{100(\sqrt{2 \times 3.5} + \sqrt{2(.5)})^2}$$

$$S = 333 \text{ ft.}$$

Required Length of Vertical Curve:

The length of vertical curve is nearly cut in half with the new criteria, 504 ft. versus 960 ft.

Distance to Stop before a 150mm (0.5 ft.) Object Height for 2001 Curve Design (with 2.0 ft. Object):

The available preview distance is 333 ft. to see a 0.5 ft. object, where stopping sight distance under the 1990-94 criteria requires 475 ft. to stop, and 425 ft. for the 2001 criteria.

Minimum Available Maneuver Time:

If we assume the vehicle can maneuver around the 0.5 ft. object with a comfortable lateral movement, only 4.5 seconds travel time are available for this maneuver, as the vehicle travels 333 ft at 50 mph;

$$TT \text{ Prov} = \frac{333}{1.47(50)} = \underline{\underline{4.5^s}}$$

* See AASHTO Geometric Design Greenbook or a Route Surveying text for equation development

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STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

Appendix A

Total Required Maneuver Time

The total distance required to maneuver around an object is the perception / reaction distance plus the maneuver distance. Typical lateral movement velocities of 3-4 ft/sec have been observed. The required maneuver time for the example curve, for both rural and urban areas, is longer than available, by 1 second urban and 2 seconds rural, respectively, as shown below.

	PRT		Maneuver Time		
Urban	2.5^s	+	$\frac{12 \text{ ft}}{4 \text{ FPS}}$	=	<u>$5.5^s > 4.5^s$</u>
Rural	2.5	+	$\frac{12 \text{ ft}}{3 \text{ FPS}}$	=	<u>$6.5^s > 4.5^s$</u>

If we assume that we need a preview distance that is equal to stopping sight distance, it is also inadequate. As shown, 5.8 seconds is required compared to 4.5 seconds provided.

$$\text{Preview Distance} = \text{SSD}$$

$$\text{Preview Time} = \frac{425}{1.47(50)} = \underline{\underline{5.8^s > 4.5s}}$$

Further, if we look at the pavement sight distance condition with a height of object equal to "0", the available pavement sight distance is;

$$S < L : L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$

$$504 = \frac{6S^2}{100(\sqrt{2 \times 3.5} + \sqrt{2 \times 0})^2}$$

$$S = 242 \text{ ft.}$$

with a travel time available for maneuvering of;

$$TT_{\text{PROV}} = \frac{242}{1.47(50)} = 3.3 \text{ sec.}$$

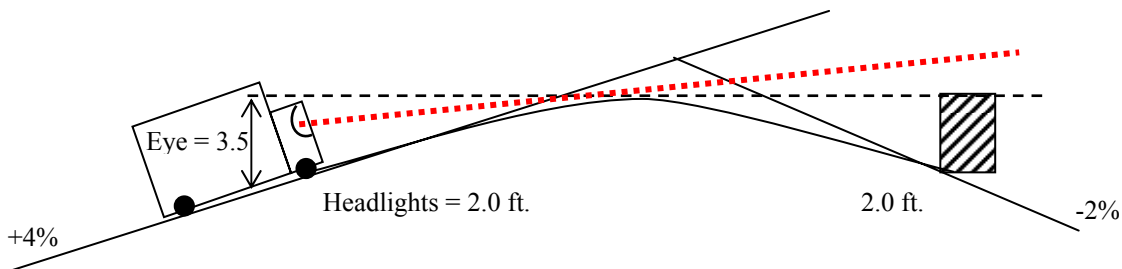
Only 3.3 sec. of travel time and 242 ft. of travel distance are available for a driver to see the pavement, react and maneuver the vehicle. Clearly, very short by the maneuver distance or the stopping sight distance standard.

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

Appendix A

Headlight Sight Distance over a Crest Vertical Curve

The headlight sight distance over a crest vertical curve has been accommodated, somewhat, by the more conservative height of object criteria of 150 mm (0.5 ft.). However, the headlight sight distance over a crest vertical curve is restricted for vertical curves designed with a 600 mm (2.0 ft.) object height. For the previous curve example, it provides only 366 ft. to a vehicle that is stopped without tail lights lit, where the reflection of the tail lights from the vehicle's headlights shows as the object. Notice for the example curve, an object must be 1080 mm (3.5 ft.) high to be visible with the headlights at the stopping sight distance of 425 ft.; no objects shorter than 1080 mm (3.5 ft.) would be lit by the headlights at 425 ft. Therefore, there is not adequate stopping sight distance at night for any objects shorter than 1080 mm (3.5 ft.).



Headlight S.D. over the “2001” Example Crest Vertical Curve with Headlight Height of 600 mm (2 ft.) for an Object Height of 600 mm (2 ft.):

$$L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$

$$504 = \frac{6S^2}{100(\sqrt{2 \times 2} + \sqrt{2 \times 2})^2}$$

$$S = 366 \text{ ft} < 425 \text{ ft}$$

with a travel time of

$$TT_{\text{PROV}} = \frac{366}{1.47(50)} = 5.0 \text{ sec} > 4.5 \text{ sec}$$

Thus, the travel time of 5.0 sec. required to see and stop before a 600 mm (2 ft.) object is only slightly larger than the necessary available maneuver time to avoid the object.

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STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

Appendix A

Headlight S.D. with 2 ft. Headlight and 0.5 ft. Object over the “2001” Example Vertical Curve:

The headlight sight distance to a 0.5 ft. object in the roadway is:

$$L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$
$$504 = \frac{6S^2}{100(\sqrt{2 \times 2.0} + \sqrt{2 \times 0.5})^2}$$
$$S = 275 \text{ ft.} < 425 \text{ ft.}$$

with a travel time of

$$TT_{\text{PROV}} = \frac{275}{1.47(50)} = 3.7 \text{ sec.} < 4.5 \text{ sec.}$$

The driver cannot see a 0.5 ft. object until he/she is 275 ft. away, with a required stopping sight distance of 425 ft. The travel time of 3.7 sec. to the object is less than the required maneuver time of 4.5 sec. to avoid the object.

Headlight S.D. to Pavement from Headlight over the “2001” Example Vertical Curve:

The distance from which the pavement can be seen is;

$$L = \frac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$
$$504 = \frac{6S^2}{100(\sqrt{2 \times 2.0} + \sqrt{2 \times 0})^2}$$
$$S = 183 \text{ ft.} < 425 \text{ ft.}$$

with a travel time of

$$TT_{\text{PROV}} = \frac{183}{1.47(50)} = 2.5 \text{ sec.} < 4.5 \text{ sec.}$$

This provides time for the to perception / reaction time for design, but leaves no time for the action to steer to avoid a condition in the pavement, such as, a pothole. The available time to perceive, react and follow the lane comfortably is not sufficient.