Sight Distance

A fundamental principle of good design is that the alignment and cross section should provide adequate sight lines for drivers operating their vehicles.

Design guidance provides for five types of sight distance:

- Stopping sight distance
- Intersection sight distance
- Passing sight distance
- Non-Striping Passing sight distance
- Decision sight distance

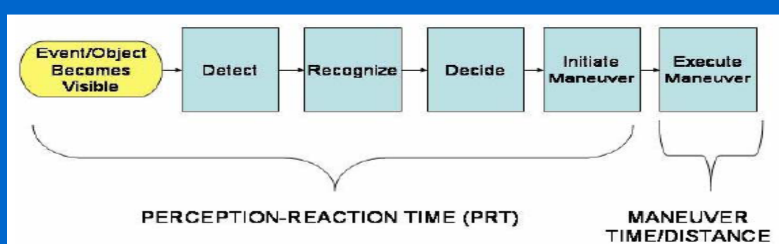
Stopping Sight Distance (SSD)

Distance required to perceive an object in roadway and bring vehicle to a stop

"… the sight distance at every point along a roadway should be at least that needed for a below-average driver or vehicle to stop."

- AASHTO Green Book Chapter 3

SSD Model Human Factors Basis



SSD = perception reaction distance + braking distance

SSD = 1.47 V *t* + (1.075 V^2 / a)

V = design speed in mph

***t* = percept reaction time (2.5 sec)**

a = deceleration rate (11.2 ft/sec^2)

SSD Historical Perspective

Parameters	1940 A Policy on Sight Distance for Highways	1954 A Policy on Geometric Design - Rural Highways	1965 A Policy on Geometric Design - Rural Highways	1971 A Policy on Geometric Design of Highways and Streets	1984 and 1990 A Policy on Geometric Design Highways and Streets
Design Speed	Design Speed	85 to 95 percent of design speed.	80 to 93 percent of design speed.	Min. - 80 to 93 percent of design speed. Des. - design speed.	Min. - 80 to 93 percent of design speed. Des. - design speed.
Perception - Reaction Time	Variable: 3.0 sec at 30 mph 2.0 sec at 70 mph	2.5 sec	2.5 sec	2.5 sec	2.5 sec
Design Pavement/ Stop	Dry Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop
Friction Factors	Ranges from 0.50 at 30 mph to 0.40 at 70 mph	Ranges from 0.36 to 30 mph to 0.29 to 70 mph	Ranges from 0.36 to 30 mph to 0.27 at 70 mph	Ranges from 0.35 at 0.30 mph to 0.27 at 70 mph	Slightly higher at higher speeds than 1970 values
Eye Height	4.5 ft	4.5 ft →	3.75 ft	3.75 ft	3.5 ft
Object Height	4.0 in	4.0 in →	6.0 in	6.0 in	6.0 in

Table 1- NCHRP 400

SSD Historical Perspective

History of the Object Height

(Kahl and Fambro, TRR 1500)

- 1954 AASHO policy: the 4" object height offered a compromise between the cost of excavation and the ability of the driver to see the road ahead. "A 4-in. control was considered the approximate point of diminishing returns."

SSD Historical Perspective

History of the Object Height

(Kahl and Fambro, TRR 1500)

- In the 1965 AASHO policy, the object height was increased from 4” to 6”; however, the rationale used to justify the 6” object was the same rationale used for the 4” object. It has been suggested that the object height was increased to offset a decrease in the driver’s eye height and thus keep the required lengths of crest vertical curves relatively constant.

SSD Historical Perspective

History of the Object Height

(Kahl and Fambro, TRR 1500)

- In 1984, the rationale for using the 6” object changed. The 1984 and 1990 Green Books state that an object height of 6” is “largely an arbitrary rationalization of possible hazardous objects and a driver’s ability to perceive and react to a hazardous situation.”

Object-Related Accident Study

- "only 0.07% of the reportable accidents involved small objects in the roadway. More than 90% of these accidents occurred at night on straight, flat roadways… and they did **not** result in serious injuries."

Research performed at the Texas Transportation Institute

Change to the SSD Model in 2001

Changes were based on NCHRP 400 study

- Object height changed from 6 inches to 2 feet
- Uses a design deceleration rate rather than a friction coefficient

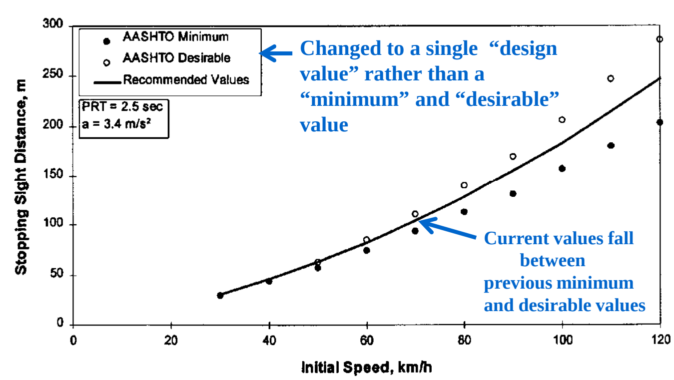


Figure 19. Comparison of 1994 AASHTO and recommended values for stopping sight distance.

SSD Design Values

Consider the effect of steep grades

US Customary						
Design speed (mph)	Stopping sight distance (ft)					
	Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %
15	80	82	85	75	74	73
20	116	120	126	109	107	104
25	158	165	173	147	143	140
30	205	215	227	200	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375

From Exhibit 3-2, AASHTO Green Book
SSD on Grades

Stopping Sight Distance (SSD)

"Stopping sight distances exceeding those shown in Exhibit 3-1 should be used as the basis for design wherever practical. Use of longer stopping sight distances increases the margin of safety for all drivers …"

"The recommended stopping sight distances are based on passenger car operations and do not explicitly consider design for truck operation."

- AASHTO Green Book

Insights on AASHTO SSD Model

- Uses upper percentile values
  - 90th percentile deceleration rate
  - 90+ percentile eye and object height
- Uses same design value for a given design speed irrespective of other conditions
- "for moderate reductions in available stopping sight distance, there are no noticeable safety problems"

NCHRP Report 400

Conceptual Safety Relationship

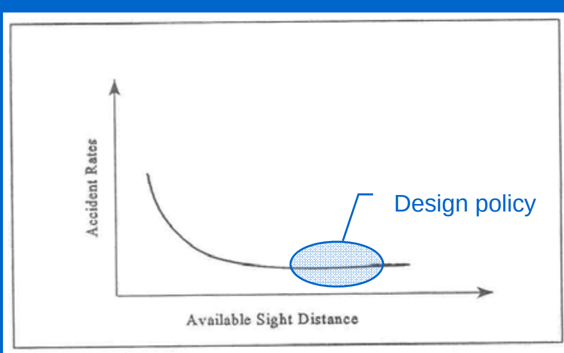


Figure 4. Conceptual Relationship Between Available Sight Distance and Safety at Crest Vertical Curves

Past studies that examined the relationship between SSD and safety have been inconsistent and inconclusive

NCHRP 400

Risk Assessment Guidelines

Guide for Achieving Flexibility in Highway Design - **AASHTO**

- Assess the risk of a location with SSD below current criteria. Risk is related to traffic volume (exposure) and other features within the sight restriction (intersections, narrow bridges, high-volume driveways, sharp curvature)

- *"Where no high-risk features exist within the sight restriction, nominal deficiencies as great as 5-10 mph may not create an undue risk of increased crashes."*

Risk Management

Relative Safety Risk of Various Conditions in Combination with Non-Standard Stopping Sight Distance

Geometric Condition	Relative Safety Risk
Low-volume intersection	Significant
Y-diverge on road	
Sharp curvature <1000 ft radius	Significant
Steep downgrade (>5%)	Significant
Narrow structure	Significant
Narrow Pavement	Significant
Freeway lane drop	Significant
Exit or entrance downstream	Significant

Source: FHWA "Mitigation Strategies for Design Exceptions"

Risk Considerations

Situation: Horizontal sight restriction at the end of a downgrade

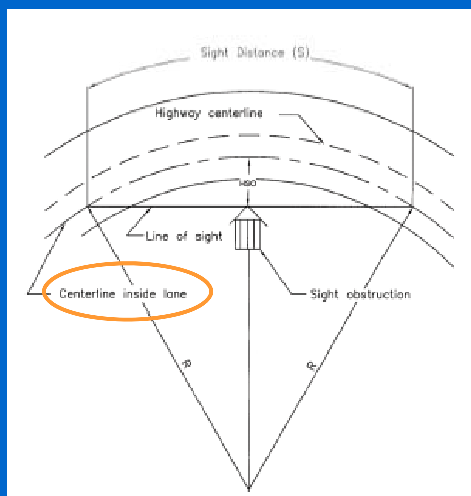
Specific Concern: Truck speeds may be high at the end of a long downgrade and the greater eye height of the truck driver is of little advantage seeing past a horizontal sight obstruction

Risk Considerations

Situation:
Intersection within a horizontal sight restriction

Specific Concern: Insufficient sight distance for driver to judge acceptable gaps in traffic approaching from the horizontal sight obstruction

Effect on Horizontal Curve Design



US Customary

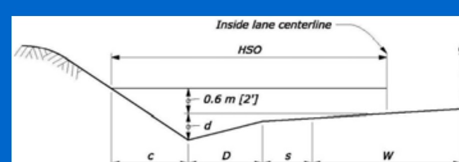
$$HSO = R\left[1 - \cos\left(\frac{28.65\,S}{R}\right)\right]$$

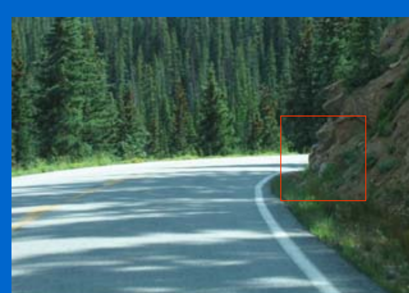
where:

S = Stopping sight distance, ft
R = Radius of curve, ft
HSO = Horizontal sightline offset, ft

Horizontal Sightline Offset

- Design parameters
  - Design speed
  - SSD
  - Offset to object
  - Curve radius
- Minimum Values
  - Use HSO equation





Decision Sight Distance

Distance allowed for:

- Detecting complex or unexpected conditions
- Recognizing information difficult to perceive
- Corroborating advance warning and performing appropriate maneuvers (i.e. path change, speed change)
- Performing evasive maneuvers

Decision Sight Distance

DSD design values vary based on location (rural, suburban or urban) and type of "avoidance" maneuver

- DSD is substantially greater than SSD
  - **Example – 50 mph design speed**

    SSD = 425 ft / DSD = 890 ft (speed/path/direction change on suburban road)

Appropriate design criteria when the situation is complex, the driver information load is high, and there is substantial risk for driver error

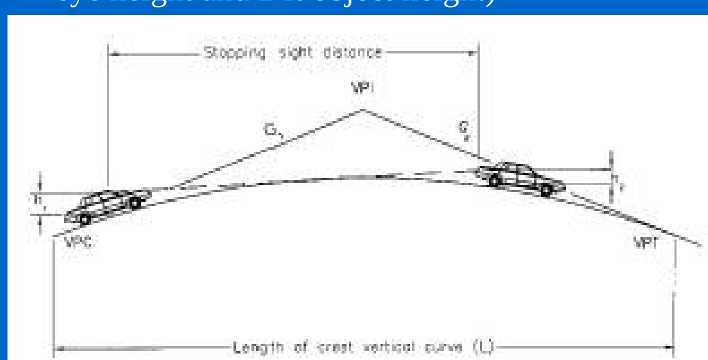
Decision Sight Distance

- If over 90% of crashes have a driver component, how might Decision Sight Distance correlate to those crashes?
- Consider Decision Sight Distance during Project Safety Reviews of the design

Design Criteria for Crest Vertical Curves

Minimum lengths of crest vertical curves are based on sight distance criteria

- AASHTO stopping sight distance criteria (3.5 ft eye height and 2 ft object height)



Changes in 2001 AASHTO Policy

Crest Vertical Curve Lengths

- Shorter crest vertical curves
- Elimination of curve length ranges

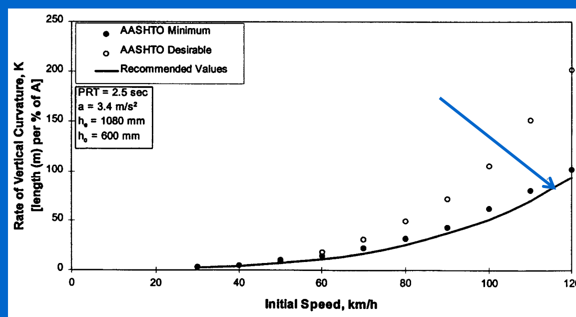


Figure 20. Comparison of 1994 AASHTO and recommended K values for crest vertical curves.

2001 AASHTO Policy Model produces shorter vertical curves

Design Criteria for Sag Vertical Curves

Sag Vertical Curves Based on

- *Headlight Sight Distance* ← Safety
- *Comfort criterion*

– Refer to 2004 Green Book Exhibit 3-75

Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a] Calculated	Rate of vertical curvature, K[a] Design
15	80	9.4	10
20	115	16.5	17
25	155	25.5	26
30	200	36.4	37
35	250	49.0	49
40	305	63.4	64
45	360	78.1	79
50	[illegible]	[illegible]	[illegible]

Exhibit 3-75. Design Controls for Sag Vertical Curves

"Sag vertical curves shorter than the lengths computed from Exhibit 3-75 may be justified for economic reasons in cases where an existing feature, such as a structure not ready for replacement, controls the vertical profile."

-AASHTO Green Book – p. 276

Maximum Grades

- Based on Design Speed and Terrain Context
  - 5% max grade for 70 mph design speed
  - 7% - 12% for 30 mph design speed depending on terrain
  - Interstate Standard
    - 6% max grade for mountainous terrain and 50 mph design speed

Critical Length of Grade

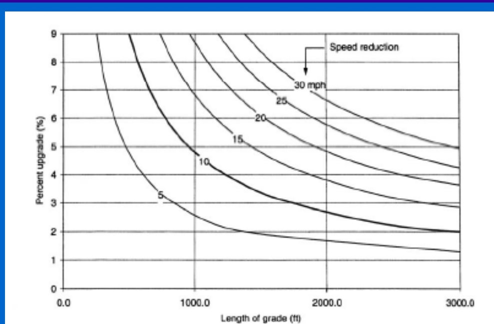


Exhibit 3-59. Critical Lengths of Grade for Design, Assumed Typical Heavy Truck of 120 kg/kW [200 lb/hp], Entering Speed = 110 km/h [70 mph]

Combination of grade and length of grade affects speeds of heavy vehicles

"Critical Length of Grade" – max length of an upgrade without unreasonable reduction in speed

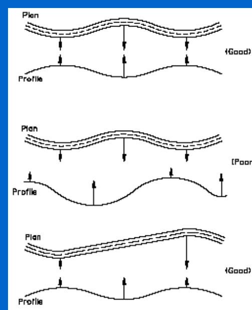
Operational Considerations

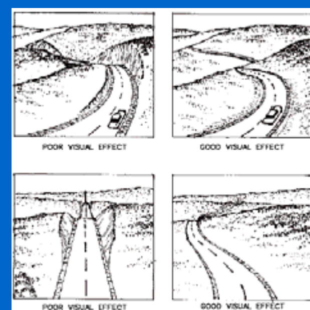
- Downgrades increase braking distance and vehicle speeds
- Upgrades increase speed differentials between passenger cars and heavy vehicles
- Upgrades slow traffic and may create platooning
- Vertical curvature may limit sight distance

Vertical Alignment and Safety

- Vehicle Speed Differential: a 10 mph differential between free-flowing traffic and a slowed heavy vehicle is a potential safety threshold (especially for two-lane highways)
- Collision frequency increases with gradient on downgrades
- Long steep downgrades impact truck braking

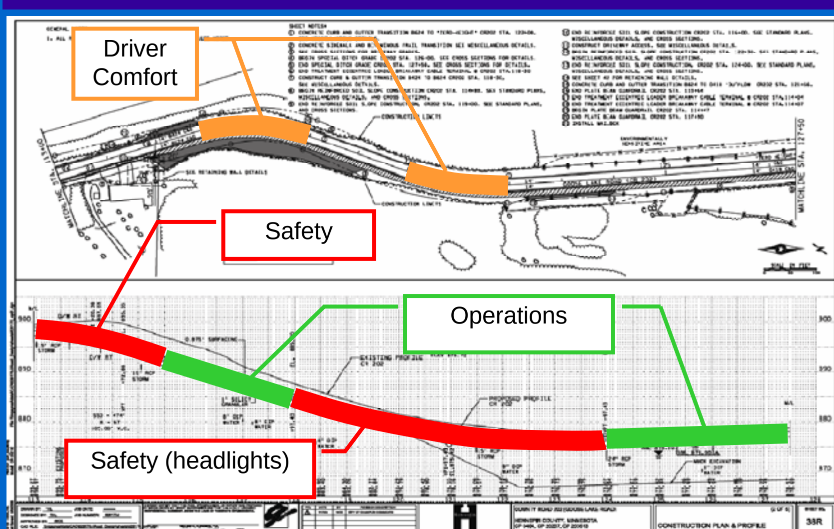
Coordination of H&V Alignment

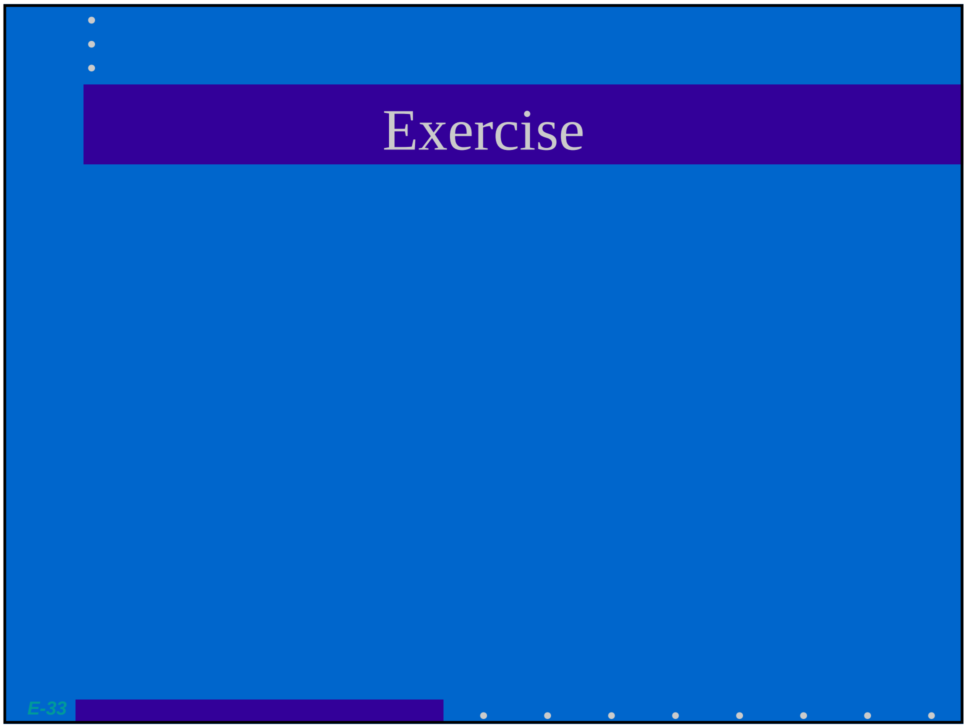




- Avoid sharp horizontal curves near top of a pronounced crest vertical curve (i.e. make the horizontal curve long enough so that it leads the vertical curvature)
- Avoid sharp horizontal curves near low point of a pronounced sag curve because driver's view is foreshortened and speeds may be higher at bottom of grade

Basis for Standards




Exercise
E-33