Determination of Windshield Levels Requisite for Driving Visibility

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SYNOPSIS

THE 1950 revised American Standard Code for Safety Glazing Materials for Motor Vehicles establishes requirements for glazing materials installed within "levels requisite for driving visibility."

A study to determine the extent of glazed areas necessary for driving visibility is reported upon. Data on current passenger cars are given showing the areas available for seeing by all but the tallest $2\frac{1}{2}$ percent and all but the shortest $2\frac{1}{2}$ percent of California licensed drivers. Visibility angles required for observance of traffic signals are also given.

From the above data and information on human dimensions, a method is suggested for determining the levels requisite for driving visibility applicable to any automobile for various percentages of drivers.

The dimensions and technique for checking windshields to establish a level that will include 85 percent of the drivers is given. This percentage was tentatively agreed upon as a practical value by the Engineering Committee of the American Association of Motor Vehicle Administrators in June 1951.

The American Standards Association on May 16, 1950 approved the revised American Standard Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways, Specification Z26.1-1950.(1) Section 4, Items 3, 5, 7, and 9 of the code permit the use of material having less than 70 percent luminous transmittance in certain locations in a vehicle "except at levels requisite for driving visibility."

No definition of these levels is given in the new code. At present, each state must determine the levels that are applicable for the conditions of operation within its boundaries. It is desirable that a definition be adopted which would apply to all states and be made a part of the ASA Code.

Assuming there is for each particular height of driver's eyes some level or angle above or below which it is not necessary to see with maximum efficiency under the driving conditions normally encountered, some method must be devised to determine these levels in each instance. A specification satisfactory for all but a small percentage of the drivers can then be drawn up which will set a reasonable level applicable to each type of vehicle.

Before definite conclusions were reached it was found advisable to make a study of the visibility angles of tall and short drivers in recent models of several makes of automobiles. The results were then compared with angles subtended by objects which must be seen for safe operation of a vehicle.

PROCEDURE

Measurements were taken at the driver's eye position of the angles subtended by solid parts of the vehicle body at points every 10 deg. from 90 deg. left of the driver to 90 deg. right. An arbitrary decision was made to measure the angles above and below which approximately 5 percent of the drivers cannot see due to obstruction by the various parts of the vehicle.

Statistics on adult human dimensions obtained by Pearson and others and reprinted in Moon (2) were assumed to apply to drivers within reasonable limits and were used in determining the eye heights from a sitting position. The standard deviation of the dimensions was used in computing the eye heights that are exceeded by approximately $2\frac{1}{2}$ percent of the driving population and not reached by another $2\frac{1}{2}$ percent. About 270,000 drivers in California would fall outside these limits as calculated from the information available.

Using the dimensions thus obtained, an instrument was constructed for measuring visibility angles from the eye positions of the short and the tall driver. With the facilities available it was not feasible to construct a cylindrical test board upon which the shadows of the vehicle could be projected from a light at the eye position, so the following method was used:

A platform (shown in Fig. 1) was designed to hold the pivot of a small transit at either the tall or the short eye position. The device was placed directly behind the center of the steering wheel and the seat was moved fully back for the tall readings and fully forward for the short readings. Seat depression in each vehicle was measured using a 150- or 180-lb. subject sitting in a relaxed position, and allowance was made for the variations in cushion firmness in setting the eye level for each vehicle.

A shadow diagram was then plotted for each set of data. Traffic signals for various street widths were added to show their position with respect to the driver's eyes.

CALCULATIONS

The following data were used in calculating the dimensions of the test stand shown in Figure 1.

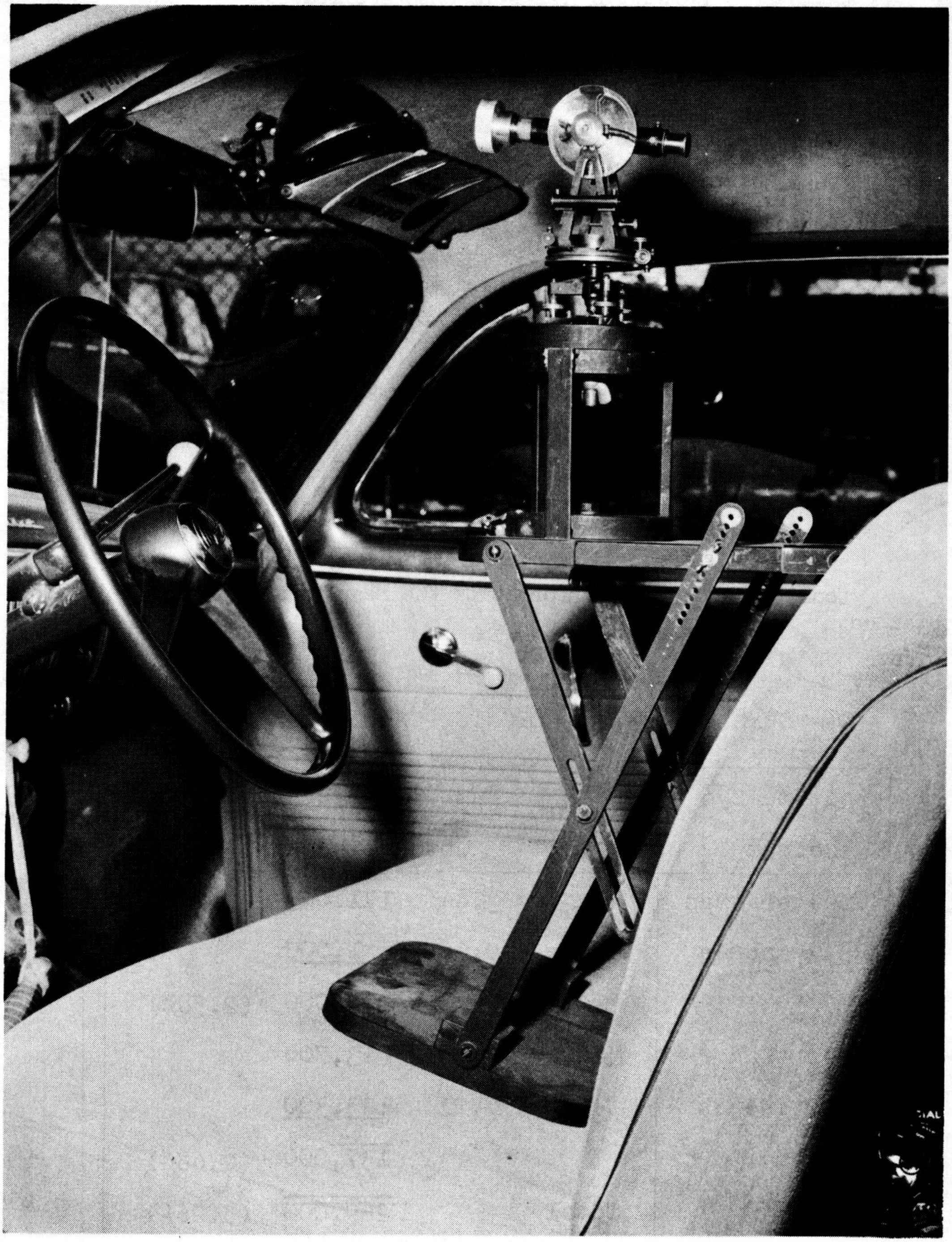


Figure 1(a). Equipment for measuring visibility angles.

The California Department of Motor Vehicles had 5,106,048 operator's and chauffer's licenses in effect as of January 1, 1951. A breakdown of drivers taken from 175,000 driver's license applications submitted in March 1950 indicate the following distributions:

33.48% of applications by women
66.52% of applications by men
100.00% Total

Assuming the same percentages hold true for the whole driving population and neglecting a small duplication of driver's and chauffer's licenses, there are in California:

1,710,000 licensed women drivers
3,400,000 licensed men drivers
5,110,000 licensed total drivers

Figures given in Moon (1) of seat-to-eye height are as follows:

	Mean Seat to Eye Height	Standard Deviation
	in.	in.
Male	31.5	1.24
Female	29.9	1.17

Combining the above information the results shown in Table 1 are obtained.

TABLE 1

SUMMARY OF EYE HEIGHTS, CALIFORNIA DRIVERS

Seat-to-Eye Height	Numbers of Drivers Outside Limits			
Greater than	Men	3.84%	131,000	
33.7 inches	Women	0.06%	1,000	
			132,000	(2.58%)
Less than	Men	0.40%	13,700	
28.2 inches	Women	7.21%	123,300	
			137,000	(2.68%)
Both	Total		269,000	(5.26%)

To determine the viewing angles required to observe critical objects, the data contained in the excellent work of W. E. Schwanhausser, Jr., "Visibility of Traffic Signals" (3) was used. A number of driving situations were analyzed in the above reference, but only two of the most important cases are considered in this report. These are typical of California practice and are (a) for right curb mounted signals and (b) for right overhead signals. The plane and elevation sketches for signals at intersections for these two cases are given in Figure 2. The tabulated data on angles are given in Table 2.

TABLE 2

TRAFFIC SIGNAL VIEWING ANGLES

From W. E. Schwanhausser, Jr. (3)

(Refer to Fig. 2 for legend)

FAR RIGHT CURB MOUNTED SIGNALS

W	Y	d (horiz)	8 ft (vert)	10 ft (vert)
30 ft	56 ft	13.1°	6.5°	8.5°
40	66	15.3	5.5	7.2
50	76	16.7	4.7	6.1
60	86	18.1	4.2	5.4
70	96	19.0	3.7	4.8
80	106	19.7	3.3	4.4

FAR RIGHT OVERHEAD SIGNALS

W	Y	d (horiz)	S	15 ft (vert)
30 ft	56 ft	3.1°	8 ft	13.0°
40	66	2.6	13	10.9
50	76	6.3	13	9.5
60	86	5.3	18	8.4
70	96	7.7	18	7.5
80	106	7.0	23	6.7

The angles are based on a road-to-eye height of 4 ft. 6 in.. For the very tall driver this height was found to vary from 4 ft. 6¼ in. to 5 ft. 10 in., depending on the make of car checked. This variation would amount to approximately 1/3 ft. in eye height position. For the 10-ft. mounting heights of the signals used in California this difference would not seriously affect the angles tabulated.

RESULTS

The dimensions shown in Tables 3 and 4 and Figures 1 to 7 were obtained for eight cars and visibility angles are plotted.

TABLE 3

Passenger Car	Weight of Subject, Pounds	Seat Depression, Inches	Road-to-Eye Height	
			Tall	Short
B 1941	180	2½	4' 10"	4' 5½"
B 1951	180	3	- - -	4' 3"
C 1949	180	2½	4' 9"	4' 4½"
C 1951	150	4	4' 6¼"	4' 3/4"
F 1950	150	3-3/4	4' 6½"	4' 1¼"
O 1950	150	3½	4' 8¼"	4' 2¼"
P 1951	180	3	4' 9½"	4' 4"
S 1950	150	3¼	4' 6¼"	4' ½"

DISCUSSION

The visibility of drivers in a motor vehicle is greatly influenced by their height; very short drivers look between the steering wheel and hood with a very restricted view of the highway for a considerable distance ahead; very tall drivers have their view of signs, signals, and portions of nearby vehicles cut off by the top of the car.

Usually the highest objects needed to be seen for driving are traffic lights. In determining the angles required for proper visibility of these lights, the angles subtended at the driver's eye should be considered the controlling factor. The standard mounting height of signals in California is 10 ft. Schwanhausser's data (3) on curb mounted signals at this height were used in plotting the signal light positions with respect to the driver's eyes as shown in Figures 3 to 6.

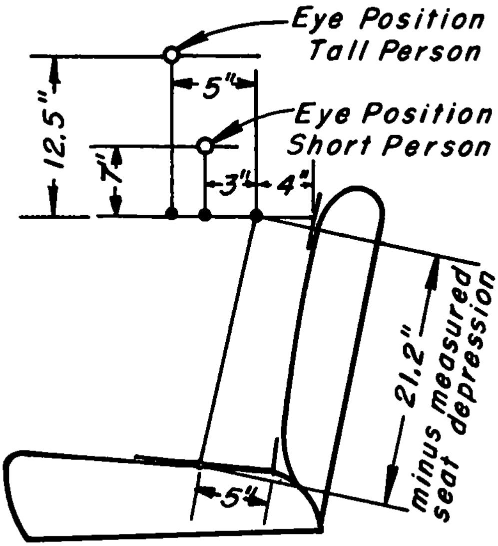


Figure 1(b). Dimensions of measuring equipment.

The diagrams show that the shorter drivers would have little difficulty seeing the signals even though a large portion of the top of the windshield were blocked off. They would have as good upper-angle visibility with the windshield shaded 10 deg. to 18 deg. down from the top as a tall man has with no shading. In the case of the small person, a large part of the upper windshield might be considered as not important for normal driving visibility and could be of low-transmission material.

Since automobiles are not custom made to fit each driver, the upper visibility limits must be determined by the tall person and lower limits by the short person operating the same automobile. If cars were equipped with seats having vertical adjustments as well as the present horizontal adjustments, the restriction on low-transmission or nontransparent areas could be less restrictive. Each driver could then adjust the seat height to fit his particular stature and could improve his visibility.

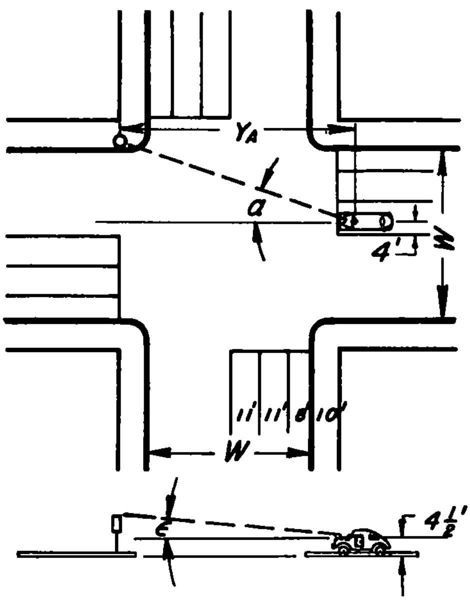


Figure 2(a). Viewing angles for far right curb-mounted signal.

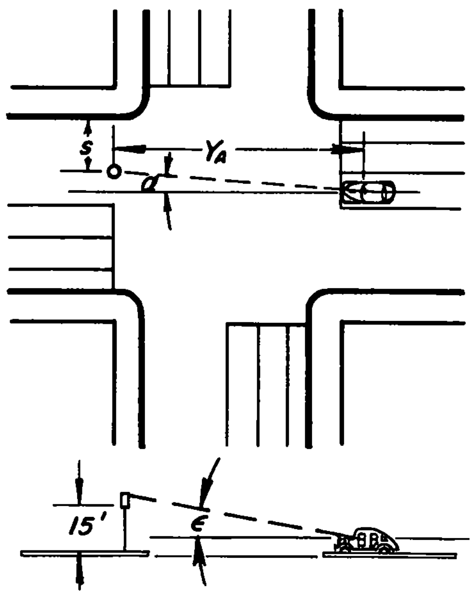
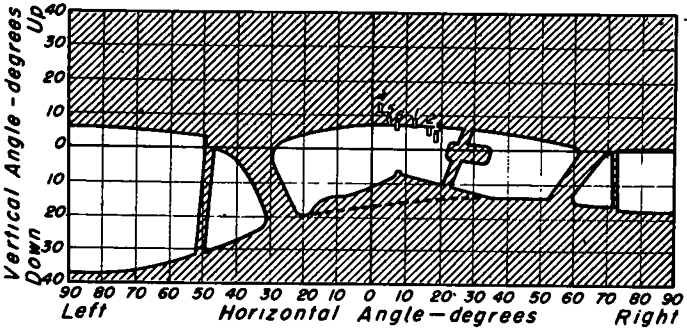


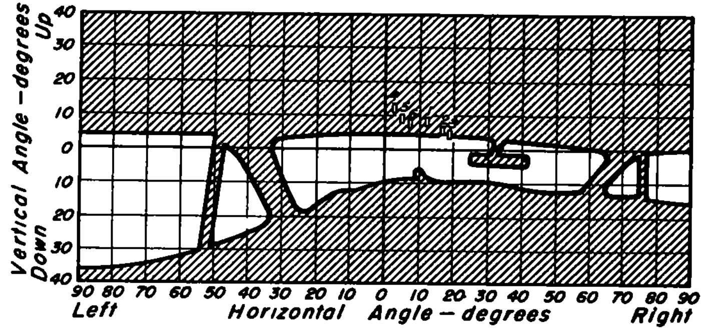
Figure 2(b). Viewing angles for far right overhead signal.

TABLE 4

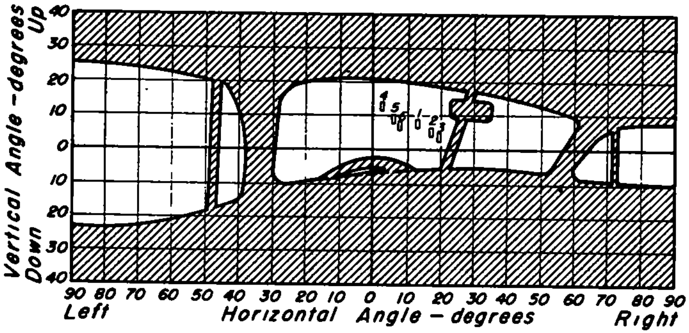
Standing Height Male (approx.)	California Drivers Taller Than Column 1	Percent Shorter Than Column 1		Passenger Cars			Commercial Vehicles		
		Total	Men	Seat-Eye Height 20° Slant Inches	Seat Depression, Inches	Undepressed Seat-Eye Height Inches	Seat-Eye Height 5° Slant Inches	Seat Depression, Inches	Undepressed Seat-Eye Height Inches
6' ¼"	132,000	97%	96%	32.4	3.4	29	33.7	2.2	31½
5' 11⅛"	252,000	95	93	32.1	3.1	29	33.3	2.3	31
5' 10½"	511,000	90	85	31.6	3.1	28½	32.8	1.8	31
5' 9-3/4"	741,000	85	79	31.3	3.3	28	32.5	2.0	30½
5' 8-3/4"	1,230,000	76	66	30.8	3.3	27½	32.0	2.0	30
5' 6-3/4"	2,532,000	50	34	29.8	3.3	26½	31.0	2.0	29



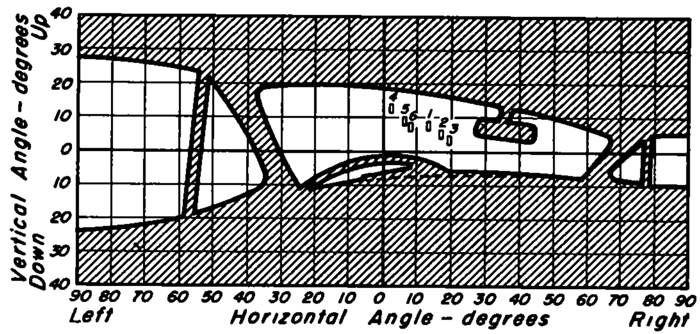
a. Tall driver, Car B1, 1941.



c. Tall driver, Car B2, 1951.



b. Short driver, Car B1, 1941.



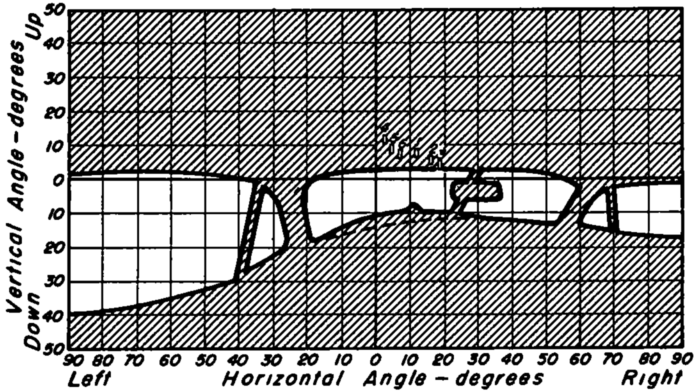
d. Short driver, Car B2, 1951.

Notes: Eye heights at positions shown in Fig. 1.

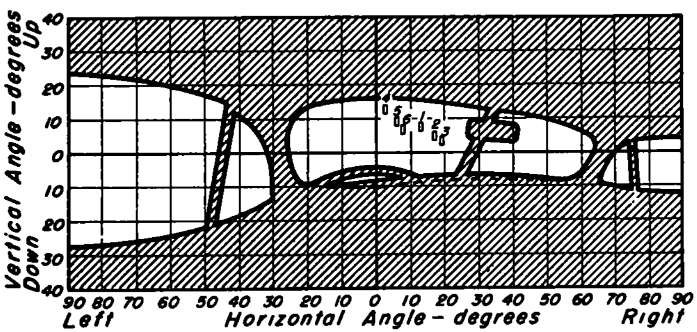
Signal positions are plotted from data in Table 2.

Legend — Signal Positions:
1. 30-ft street, curb-mounted
2. 50-ft " " "
3. 70-ft " " "
4. 30-ft street, overhead-mounted
5. 50-ft " " "
6. 70-ft " " "

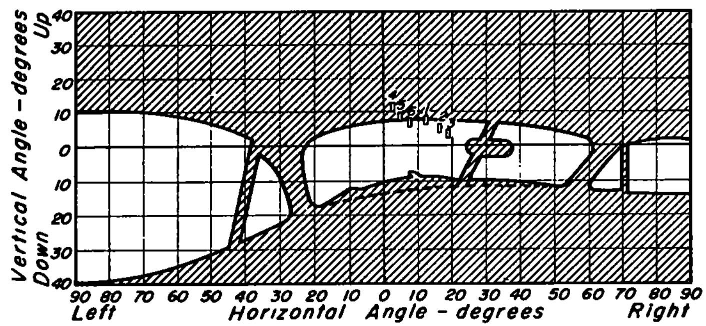
Figure 3. Visibility angles from driver's seat.



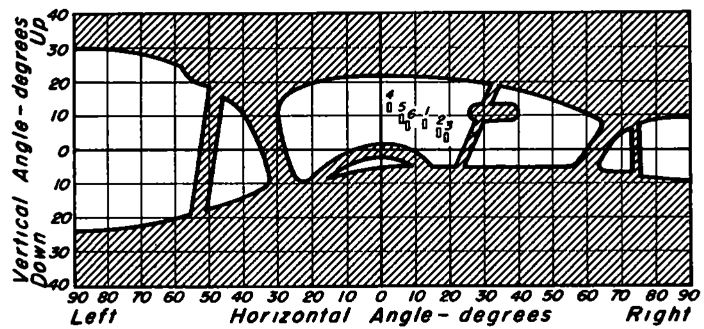
a. Tall driver, Car C, 1949.



b. Short driver, Car C, 1949.



c. Tall driver, Car C, 1951.



d. Short driver, Car C, 1951.

Notes: Eye heights at positions shown in Fig. 1.

Signal positions are plotted from data in Table 2.

Legend— Signal Positions:
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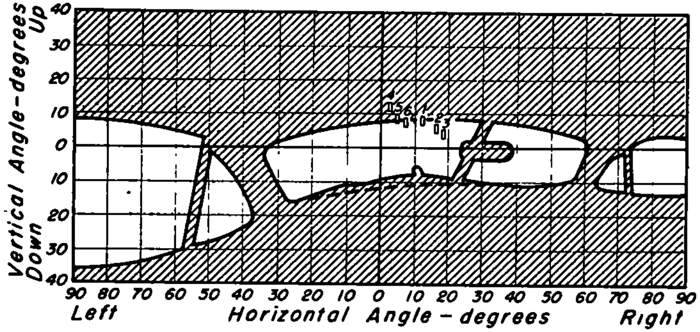
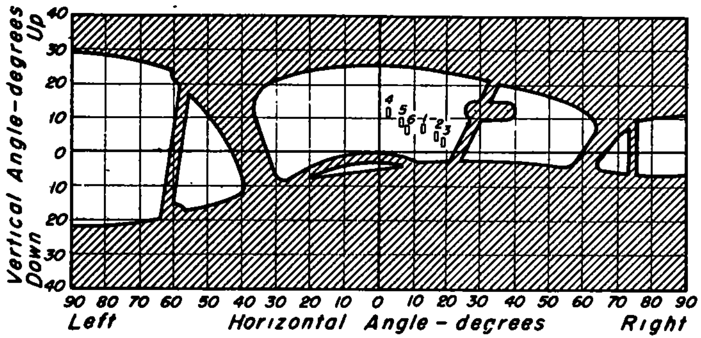
3. 70-ft " " "
4. 30-ft street, overhead-mounted
5. 50-ft " " "
6. 70-ft " " "

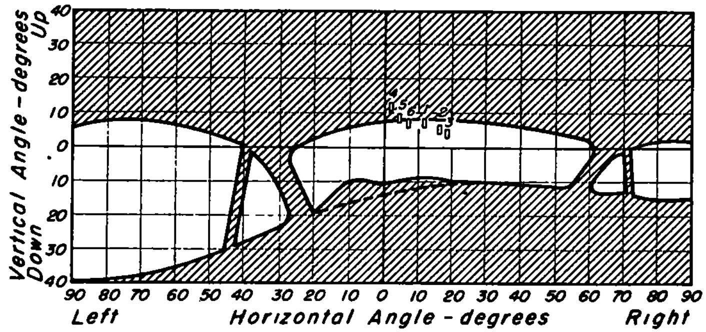
Figure 4. Visibility angles from driver's seat (continued).



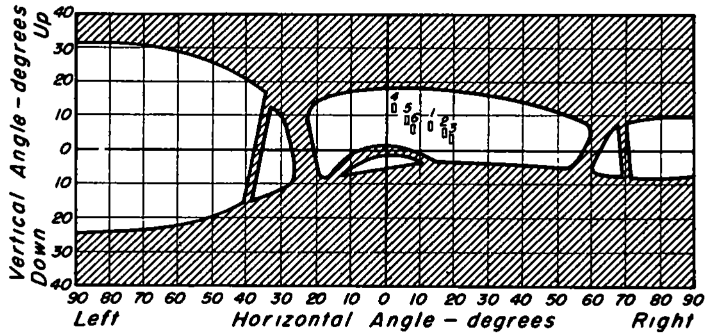
a. Tall driver, Car F, 1950.



b. Short driver, Car F, 1950.



c. Tall driver, Car O, 1950.



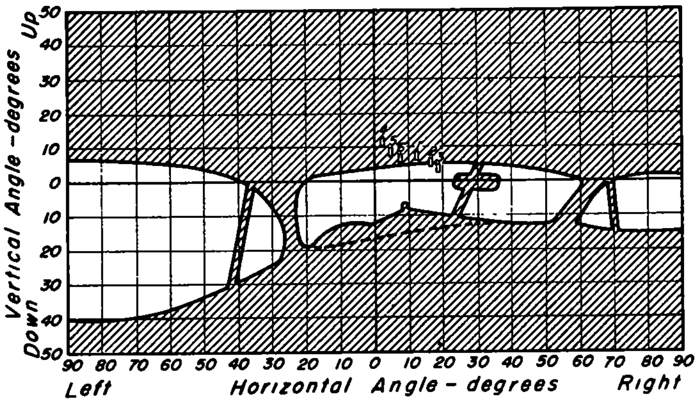
d. Short driver, Car O, 1950.

Notes: Eye heights at positions shown in Fig. 1.

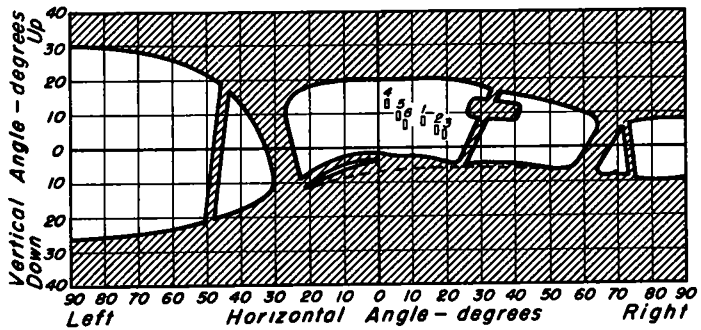
Signal positions are plotted from data in Table 2.

Legend— Signal Positions:
1. 30-ft street, curb-mounted
2. 50-ft " " "
3. 70-ft " " "
4. 30-ft street, overhead-mounted
5. 50-ft " " "
6. 70-ft " " "

Figure 5. Visibility angles from driver's seat (continued)



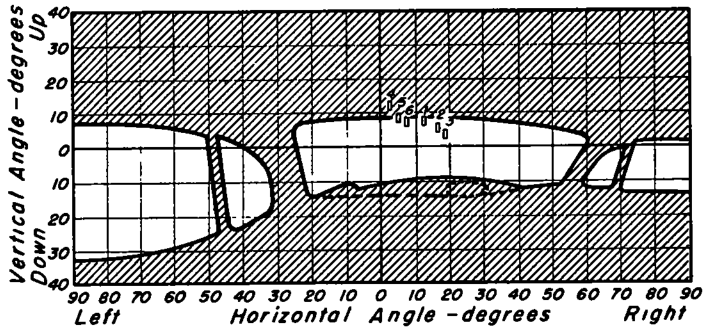
a. Tall driver, Car P, 1951.



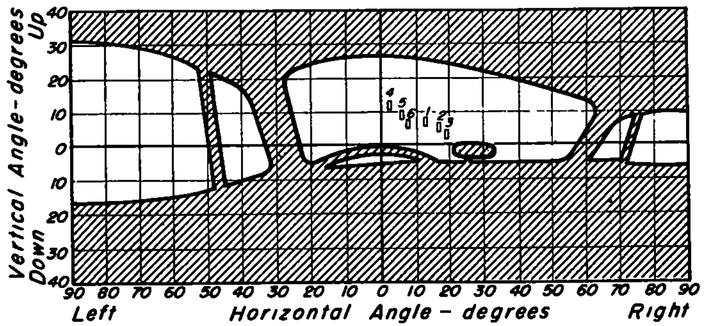
b. Short driver, Car P, 1951.

Notes: Eye heights at positions shown in Fig. 1.

Signal positions are plotted from data in Table 2.



c. Tall driver, Car S, 1950.



d. Short driver, Car S, 1950.

Legend— Signal Positions:
1. 30-ft street, curb-mounted
2. 50-ft " " "
3. 70-ft " " "
4. 30-ft street, overhead-mounted
5. 50-ft " " "
6. 70-ft " " "

Figure 6. Visibility angles from driver's seat (concluded).

At present the only recourse that short drivers have for better visibility of the nearby roadway is the employment of an additional cushion to raise their eye height. The inconvenience of a loose cushion usually precludes its use, as evidenced by the not uncommon sight of a short person peering between the dash and the rim of the steering wheel. Since levels requisite for driving visibility also apply to short drivers, it is necessary to determine levels below which nontransparent material may be located. Figure 7 and the shadow diagrams indicate that all glass below eye level in the vehicles checked is necessary for seeing by short drivers.

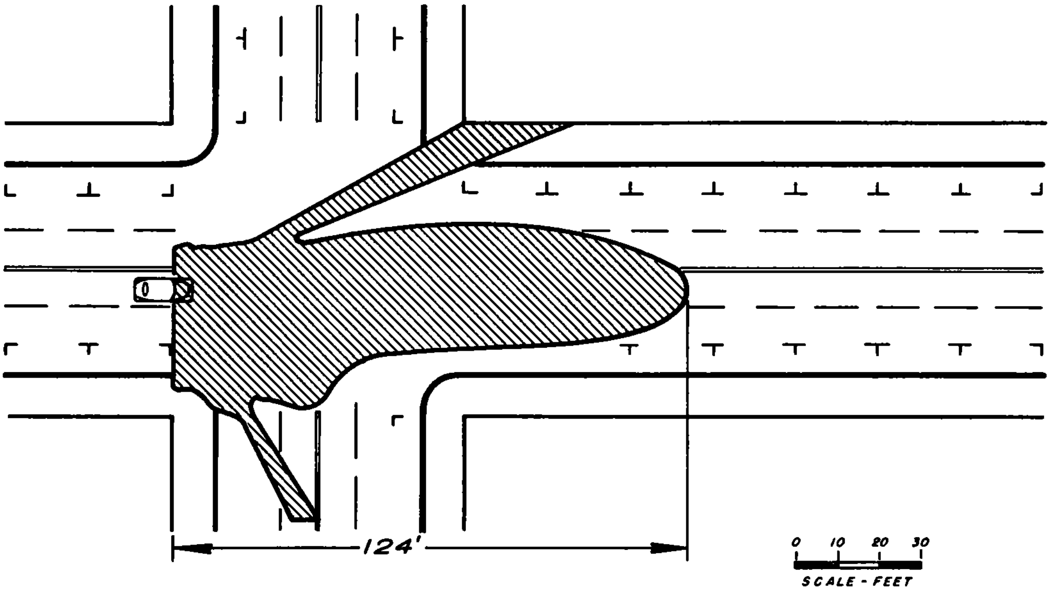


Figure 7. Blind area - - Short driver, Car P, 1951.

It would thus appear that from the viewpoints of both the taller and the shorter driver all transparent areas currently provided in most passenger cars is requisite for good driving visibility. This is especially true for the tall driver, since approximately 49 percent of U.S. total traffic (4) (approximately 55 percent in California) is in cities where upward visibility of signals is of great importance.

Nothing should be done which would decrease the driver's view and understandability of traffic signals, for as Schwanhausser points out:

"...motorists can ill afford to spend more than, or as much as, a fraction of a second to recognize a signal. Tests have indicated that it takes one or more seconds to react to an impulse. Hence, high speeds and dense traffic make it essential that motorists be alert and ready to maneuver their vehicle immediately upon sighting an obstacle or change in signal indication if accidents are to be avoided.

"When we come to contrast, we have a variable over which there is some control. When an object lacks contrast with its background, it is not easily detected. Hence objects such as traffic signals, if placed with some thought towards rapid discernment, should be carefully located against a contrasting, rather than a similar background. Uniformity of the background also helps improve contrast."

Likewise, dark-colored transparent materials on the windshield obscuring view of the signals should be avoided, because of the resulting decrease in brightness difference between the signal light and its background and the change in the color contrast of the signal light.

Viewing angles of curb-mounted traffic-control signals should determine the upper level in terms of angular measure from the driver's eyes. Overhead signals, although at higher angles, are not the limiting condition, since these signals are usually used in conjunction with curb-mounted signals and are intended for the motorist who is 100 ft. or more from the intersection.

The vertical angles for the curb-mounted signals range from 8.5 deg. for the 30-ft. intersection to 4.4 deg. for the 80-ft. intersection. Horizontal angles range from 13.1 deg. to the right for the 30-ft. street to 19.7 deg. to the right for the 80-ft. street. These angles pertain to the vehicle on the inside lane stopped at the crosswalk. The angles would be less for all other vehicles approaching the intersection. Some other forms of signal arrangement would require greater horizontal and vertical viewing angles, but the types shown are representative of those in general use.

The seat-to-eye height of the driver to be used as a standard from which to measure signal angles depends on the seat depression and the percentage of the driving population that should be included within the upper limit. The seat depression was found to vary between $2\frac{1}{2}$ to 4 in. for the 150- and 180-lb. subjects, depending on the make of car. Since the seat depression varies considerably according to the weight and build of the individual, it is difficult to set a value that would correspond with each height of driver.

Reference to the seat depression measurements in Table 3 would indicate that variation between the cars checked is quite small for a given driver. The variation between drivers, however, is fairly large. An average value of $3\frac{1}{4}$ in. for passenger cars was decided upon, plus or minus a small amount to make the undepressed seat-to-eye height a whole number or easily measured fraction.

Table 4 gives different seat-to-eye heights and corresponding percentages of excluded drivers. The data of this Table assume that human dimensions as given in Moon (2) apply to the driving population. If the height distribution of drivers is not the same as the distribution of the samples used in the statistical survey, then the table may be subject to revision.

As there were no figures at hand on the proportion of miles driven by men and women, the calculations were based on the number of driver's licenses. However, the most representative figures of included driver percentages would be those given for men alone, since the large majority of vehicle-miles can be attributed to male drivers.

CONCLUSIONS

In determining what height is necessary for driving visibility, it must be considered that above this level the ASA Code will allow glazing material having a transmittance ranging from 70 percent down to zero. Under certain conditions objects may be visible through a glazing material even though the transmission is less than 70 percent, but this fact will not permit the approval of the glazing material under the present provisions of the code unless such material is above "the level requisite for driving visibility."

The data on drivers, vehicles, and required visibility angles reported here would lead to the development of the following definition adequate for approximately 97 percent of all drivers:

> Levels requisite for driving visibility in passenger cars include all glazed areas lower than a level of 29 in. above the undepressed driver's seat, measured from an eye position directly above a point 5 in. forward of the junction of seat and back rest and directly in line with the center of the steering wheel. Windshields in addition should have at least 70 percent transmission at all angles included within 8½ deg. above horizontal and between 10 deg. left and 20 deg. right.

A definition using the above figures would be impractical on most cars, for many of the windshields do not extend as high as would be specified. In order to permit low-transmission areas in the upper zone of a windshield, the words "driving visibility" might be interpreted as "roadway visibility", thus assuming that nearby traffic signals are not required for "driving." Under such a modified meaning any glazing material above eye level would not be of prime importance for seeing the roadway or other vehicles but would still be necessary for recognition of traffic signals and in developing a comfortable visual field.

If a more practical attitude toward a definition is taken such that the level would include approximately 85 percent of all drivers (79 percent of male drivers) instead of 97 percent, and if certain manufacturing problems associated with curved windshields are taken into consideration, a definition could be developed as follows:

> The levels requisite for driving visibility are established as all levels below a horizontal plane 28 in. above the undepressed driver's seat for passenger cars and 31½ in. above the undepressed driver's seat for other motor vehicles. Measurements shall be made from a point 5 in. ahead of the bottom of the backrest, and directly behind the center of the steering wheel, with the driver's seat in the rearmost and lowest position and the vehicle on a level surface.
>
> Areas requisite for driving visibility shall include all glazed areas below this plane, except side windows to the rear of the driver and other rear windows not used for

vision directly to the rear. All windows capable of being moved within the locations specified shall meet the 70-percent-minimum-transmittance requirement over the entire window area.

Corresponding eye heights may be used for specially designed vehicles or vehicles designed for standing drivers. The eye heights are based upon an average seat depression of 3.3 in. for passenger cars and 2.0 in. for other vehicles.

In order to accommodate curved glazing materials and manufacturing procedures for shaded windshields, it may be permissible to reduce the luminous transmittance of the glazing material at each side of the windshield to below 70 percent for a distance from each corner post not to exceed 10 percent of the width of the windshield. This area of reduced transmittance shall not extend more than $1\frac{1}{2}$ in. below the level requisite for driving visibility.

It is recommended that a lower limit of luminous transmittance and color distortion be added to the ASA Code to apply to glazing materials in areas not required for roadway visibility but necessary for signal visibility. The exact value could be found from studies made to determine the minimum acceptable limits of transmission and color for recognition of signals and highway warning signs both day and night. This requirement would help to control the use of opaque areas at the top of the windshield which entirely eliminate upward seeing.

It is also recommended that motor vehicles be manufactured with vertical as well as forward-and-back seat adjustments to enable the shorter and the taller drivers to obtain better roadway visibility.

REFERENCES

1. American Standard Safety Code for "Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways, Z26.1-1950." American Standards Association, Inc., 70 East Forty-Fifth Street, New York 17, N. Y., May 16, 1950.

2. Moon, Parry. "The Scientific Basis of Illuminating Engineering." New York and London: McGraw-Hill Book Company, Inc., 1936, pages 517 to 520.

3. Schwanhausser, W. E., Jr. Visibility of Traffic Signals. "Municipal Signal Engineer." Nov.-Dec. 1950.

4. Automobile Manufacturers Association. "Automobile Facts and Figures." New Center Building, Detroit 2, Michigan. 1950. Page 66.

5. Report on Levels Requisite for Driving Visibility to AAMVA Engineering Sub-Committee by Special Study Committee for AMA, June 18, 1951.