

DEPARTMENT OF DESIGN

Driver Eye Height and Related Highway Design Features

CLYDE E. LEE, *Assistant Professor of Civil Engineering, University of Texas*

The trend in recent years toward lower vehicles has resulted in a gradual reduction of the height of the driver's eyes above the surface of the roadway and a consequential restriction of sight distance in many situations. Representative dimensions for driver eye height and for over-all vehicle height are used by the highway designer in calculating safe sight distances on vertical curves and in providing adequate horizontal sight distances at critical locations.

A study of some 2,000 large-format photographs showing drivers and vehicles operating at normal road speeds and under ordinary driving conditions has been conducted for the purpose of determining up-to-date information on eye height and vehicle height which can be used for design purposes. Data from this study are presented to show the magnitude of the downward trend in heights, to provide a measure of the range in dimensions resulting from many variables in vehicular and driver characteristics, and to establish a basis for the selection of representative design quantities.

Charts showing lengths of vertical curves required to provide passing and nonpassing sight distances for various combinations of speed and grade are used to show the effect of lowering driver eye position and over-all vehicle height from the currently recommended height of 4.5 ft to a dimension somewhat less than 4 ft, a height determined to be representative of passenger cars operating on the streets and highways today. These charts, derived from accepted methods of calculation of sight distances, may be used for design purposes.

For drivers whose eyes are less than 4 ft from the roadway surface, horizontal sight distance is restricted at many locations by stationary objects such as guardrails, wing walls, and parked vehicles. Moving vehicles likewise obstruct horizontal visibility in certain traffic merging areas. Photographs are used to illustrate some of these problem areas which have been created by reducing driver eye height. Through nominal changes in design, highway engineers can virtually eliminate the problem areas in future designs by recognizing quantitatively as well as qualitatively the effect of lower driver eye height on horizontal sight distance.

- PASSENGER CARS in recent years have become progressively longer, wider, and lower, and the number of small or compact cars with low silhouettes has increased appreciably. This trend has probably been encouraged primarily by

styling, but the consideration of greater stability has no doubt influenced width and height dimensions. Although lower vehicles are desirable from the standpoint of looks and performance, the effect on operating characteristics must be evaluated.

Height of the driver's eyes above the roadway surface is determined in large part by vehicular dimensions; thus a lowering of over-all vehicle height results in a proportional lowering of the position of the driver's eyes. Restricted sight distance on crest vertical curves is an obvious consequence of reduced driver eye height; likewise, horizontal sight distance is restricted at certain locations by the lower height.

Because vehicular dimensions and performance characteristics dictate limiting values for geometric design features, engineers use representative figures for critical vehicular dimensions as a basis for safe and economical highway designs. For the past several years, 4.5 ft has been widely accepted as a representative driver eye height for determining sight distance in the vertical and the horizontal planes and for designing geometric features which provide adequate sight distance. Observation of any late model car indicates that this height is no longer realistic, and that there is considerable variation in driver eye height with a few drivers viewing the road ahead from heights of 3.5 ft or less. Driver characteristics (such as height, weight, and posture) and vehicular characteristics (such as make, year, loading, seat design, and seat position) account for this variation and complicate the problem of selecting a representative driver eye height for use in geometric design.

A representative value for driver eye height should be based upon measurements made when drivers are in their normal driving positions and when they are operating their vehicles under normal roadway and traffic conditions. The fact that nearly 60 million passenger cars are currently registered in the United States indicates the impracticability of measuring all driver eye heights and points to

the need for a sampling technique in making this determination.

Photogrammetry provides a very convenient method for measuring physical quantities in dynamic situations, and permits selective sampling of observations. This science was used to measure driver eye height and over-all vehicle height for a selected sample of passenger cars as they operated routinely along streets and highways. By placing a camera at a known position with respect to the traffic lanes within which vehicles operated, side-view photographs of selected cars were obtained. From these photographs, accurate measurements of driver eye height and over-all vehicle height were made.

MEASURING TECHNIQUE

An aerial reconnaissance camera, type K-24, was selected for use in the study because of its many desirable features. Sturdy and relatively compact, it can be operated either electrically or manually. Under electrical operation, the shutter is triggered by a solenoid activated simply by closing a switch. Up to 3 pictures per second can be made if a 24-v power source is used, but experimentation showed that a 12-v wet cell battery was sufficient to produce 2 pictures per second. Because portability of equipment was a consideration and 2 exposures per second was adequate for most traffic conditions, the shutter solenoid was rewound to operate on 12 v, and an ordinary automobile battery was used to trip the shutter and advance the film.

Shutter speeds of 1/150, 1/450, and 1/900 sec are available on the focal plane shutter. The latter shutter speed was used in this study to "stop" the motion of vehicles moving at high speed. At this shutter speed, Tri-X film required an aperture setting of about $f = 4.0$ for most bright days. Film magazines used with the camera hold a 56-ft roll of 5½-in. wide film which makes about 120 pictures. Each picture measures 5 in. by 5 in.—a size permitting measurements to be made directly from the photographic negatives without projection.

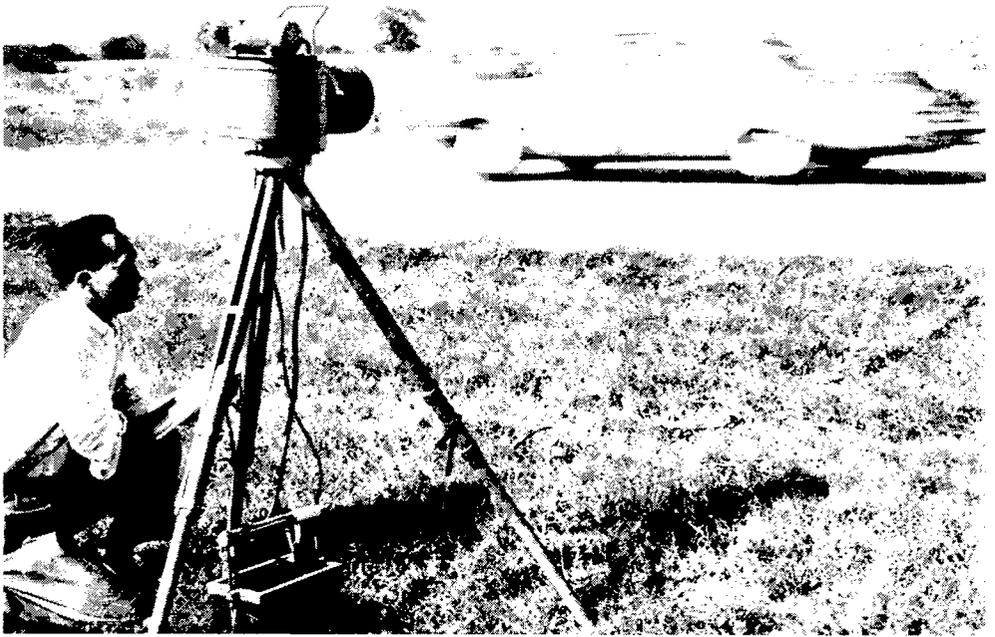


Figure 1. Camera used for making side-view photographs of passenger cars.

Figure 1 shows the camera mounted on a tripod and set up in the median of a divided highway. It was necessary to conceal the camera and operating personnel from the view of approaching drivers because most had a tendency to look at the camera. Either natural vegetation was used for concealment or a parked vehicle was used where no natural cover was present.

A device for triggering the camera shutter was made inconspicuous by suspending a length of 0.020-in. diameter piano wire about 2 in. above the roadway surface between a fixed iron stake and a spring-loaded plunger. The wire ran across all traffic lanes so that anchor stakes could be placed off the pavement. On spans over 36 ft, a small rubber disc was used as an intermediate support for the wire. A microswitch resting against the spring-loaded plunger activated the camera shutter solenoid each time the tires of a vehicle pressed down the taut wire. Because of the short time lapse between activations by the front and rear

tires and the relatively long camera cycling time, only the signal from the front tires was effective in triggering the shutter.

Trial exposures showed that a considerable variation in light intensity existed between the vehicle exterior and interior, especially when the windows were closed. Relatively uniform intensity was needed to produce side-view photographs which would show sharp exterior vehicle details and clear facial features of drivers. Photographs taken in early morning or late afternoon at locations where sunlight fell directly on the driver's face were found to be useless because a majority shielded their eyes from direct sunlight with either a visor or their hand, thus obliterating a view of their eye. A mirror approximately 18 in. by 48 in. mounted on a tripod and placed so that it reflected sunlight on the driver's face at the instant the camera shutter was open proved a solution to the light intensity problem. Since the mirror was placed at about 90 deg to the driver's area of acute

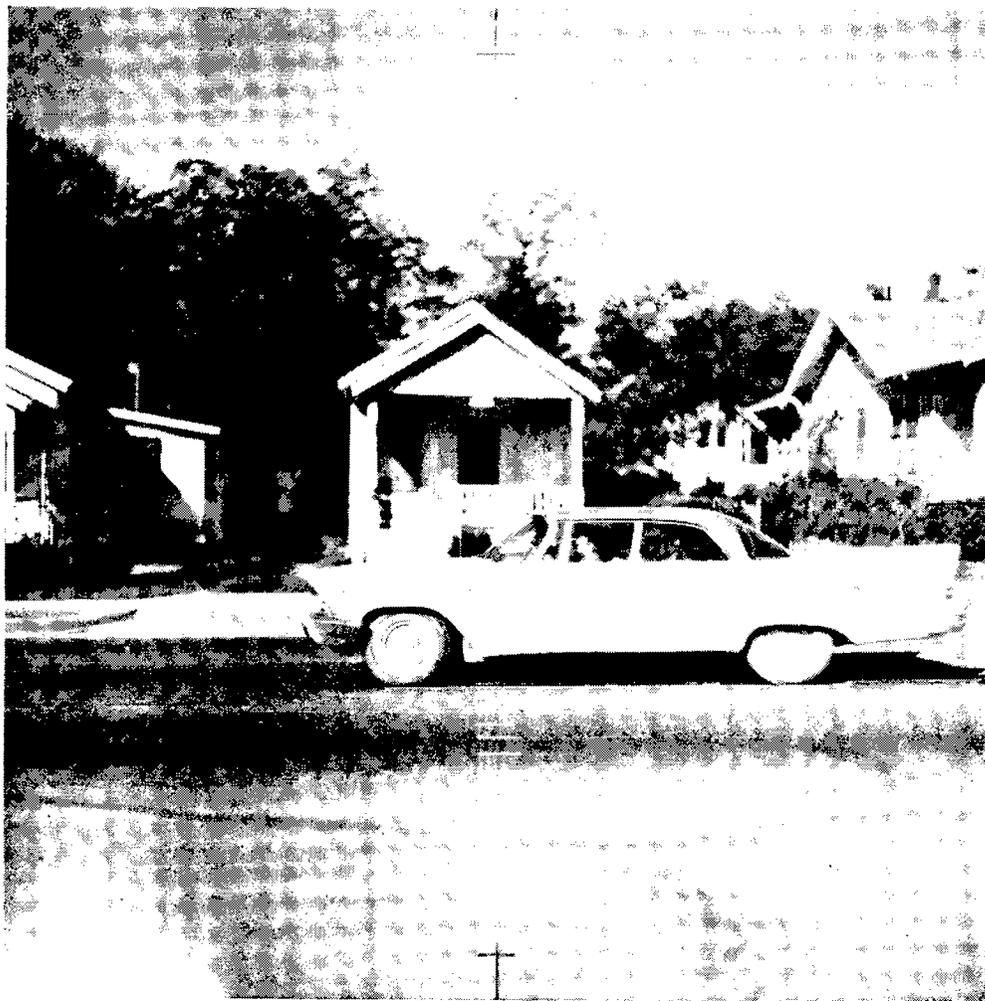


Figure 2. Contact print of a photographic negative used for driver eye height and over-all vehicle height measurements.

vision and the duration of high intensity reflected sunlight was very short when the vehicle was moving at road speed, no reaction to the bright light was observed. Of course, this technique necessitated the selection of study sites at which the camera and mirror could be properly oriented during certain hours of the day. Figure 2 shows a contact print made by this technique.

At each site, strips of 1- by 12-in. white plastic tape were placed on the pavement surface at approximately 2-ft intervals across the traffic lanes to serve

as reference points for determining the lateral placement of vehicles (Fig. 2). Photographs of a leveling rod were made at each new camera position to permit the determination of a scale factor for each photograph. The camera was placed so that it was between 35 and 50 ft from the vehicles and so that the optical axis was at right angles to the direction of vehicular movement, level, and about 4.5 ft above the roadway surface.

On each photograph, a line was scribed between the points at which front and rear tires of the vehicle came in contact

with the pavement surface, and another horizontal line was scribed at the driver's eye. The distance between these 2 lines on the photograph multiplied by a scale factor which corresponded to the lateral placement of the vehicle, or the distance of the vehicle from the camera, represented the driver eye height in feet. A similar measurement was made for over-all vehicle height. Measurements on the photographs were made with a glass scale graduated to show directly 0.1 mm. A 20-power microscope was used to read the scale graduations while the scale was held in place on the photograph by a jig. For most photographs used, 0.1 mm on the photograph corresponded to approximately 0.25-in. actual driver eye height or over-all vehicle height.

Nearly 2,000 photographs were made, and all were examined critically. A number of negatives were discarded because positive identification of vehicles as to make and year could not be made or eye height could not be determined. To facilitate positive identification, tentative identification and license numbers of each vehicle were recorded by an observer. These data were subsequently checked against make and year information in the records of the Motor Vehicle Division, Texas Highway Department, and then compared with visual identification of the vehicles shown on each negative. This 3-way check made possible positive identification of every vehicle as to make and year.

DRIVER EYE HEIGHT

For the evaluation of driver eye height and over-all vehicle height, measurements were made on 761 side-view photographs of different passenger cars. Selective sampling was used to secure measurements of each U. S. make for the years 1940-1959, but, in a few cases, observations were lacking. The sample includes, however, 21 U. S. makes and 18 foreign makes with model years ranging from 1933 through 1959. Some of the older U. S. models and some foreign makes were observed only once, while a few late model U. S. makes were photo-

graphed as many as 11 times. Observations were made at three different locations on U. S. highways near Austin between February and November 1959.

To facilitate analysis, complete data for each observation were coded and transferred to IBM cards. These data included driver eye height, over-all vehicle height, make of car, model year, license number, and a photograph identification number. High-speed sorting equipment and accounting machines made practicable the tabulation of data in any desired sequence.

Figure 3 shows average driver eye height and average vehicle height for each year and for all vehicles included in the sample. The trend to a lower vehicle and a lower eye height is definitely illustrated. Also, the relationship of eye height to vehicle height is apparent. Headroom has decreased somewhat as vehicles have become lower, but as Stonex (1) has pointed out a fair estimate of average eye height can be made from over-all vehicle height. Analysis of ten observations of 1959 Chevrolets showed, for example, that the difference between eye height and vehicle height varied from 0.62 ft to 0.84 feet with a 0.74-ft average. For eleven 1958 Chevrolets, the average difference was 0.75 ft. Over-all vehicle height used for estimating average eye height should be representative of the loaded vehicle. Heights of the 1958 Chevrolets varied from 4.94 ft, a value comparable to published figures for unloaded condition, to 4.58 ft with 7 passengers.

Another example of variation in eye height can be taken from two observations which were made of the same 1959 Cadillac on different days. In the first observation where a man was the driver and only occupant, vehicle height was 4.45 ft and his eye height was 3.91 ft. The second observation showed a woman driver as the only occupant with vehicle height and eye height equal to 4.48 ft and 3.81 ft, respectively. Thus a variation of 0.1 ft in eye height was observed for the same vehicle.

To arrive at a representative dimension for driver eye height which can be used

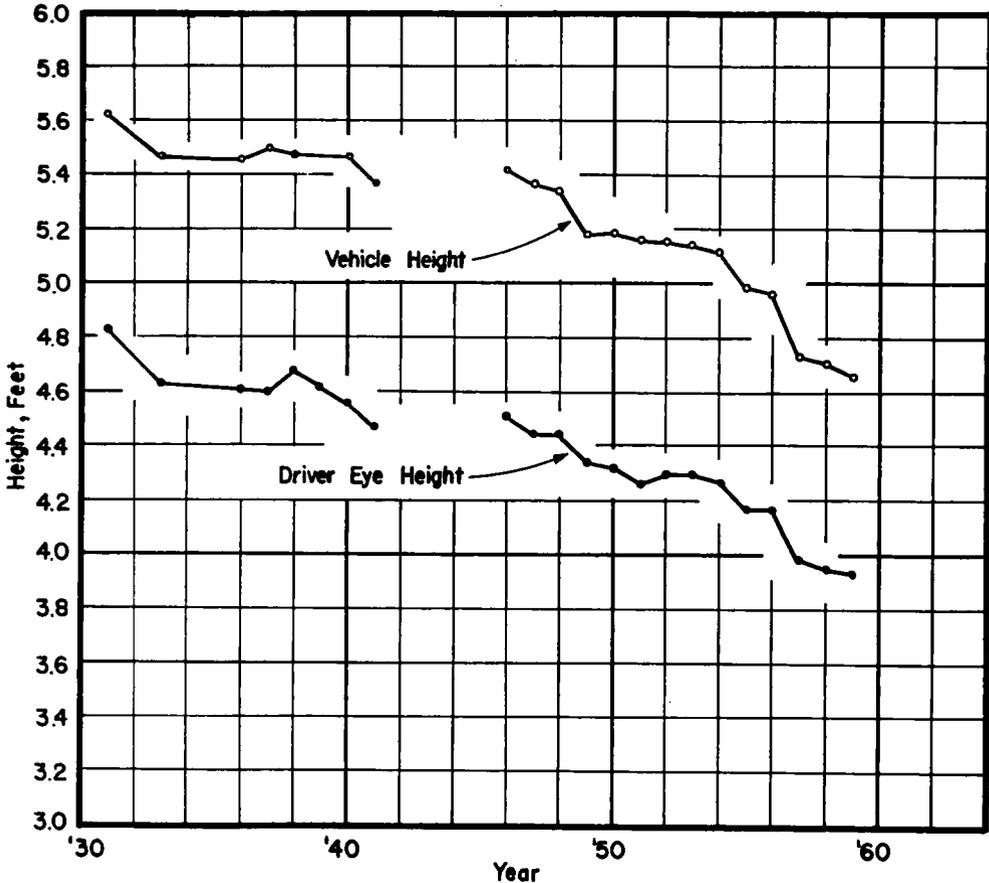


Figure 3. Average driver eye height and over-all vehicle height for each year as determined from 761 side-view photographs of passenger cars.

for design purposes, account must be taken of the relative number of cars in which drivers view the road from given heights. Average eye height and average vehicle heights were therefore calculated for each make and year of passenger car for which observations were present. For a few makes and years, no observations were made; therefore, average values for all makes for the particular year were assumed to be representative. Approximations of the percent of all vehicles currently in use in the United States as represented by each make and year were made from figures in *Automotive Industries* (2). It was estimated that about 2.2 percent of all vehicles presently in use are foreign made and that about 20 per-

cent of these foreign made vehicles are of the sport type. Standard size foreign cars were grouped for each year and average values for eye and vehicle height were calculated. Likewise, this procedure was followed for the relatively small number of sport cars in use.

Figure 4 shows estimated cumulative percentages of passenger cars in use in 1959 which have eye heights and vehicle heights greater than given values. This figure indicates that drivers operating less than 5 percent of the passenger cars view the road from heights greater than 4.5 ft and that one-half the drivers' eyes are less than 4.23 ft from the roadway surface.

Street and highway facilities should

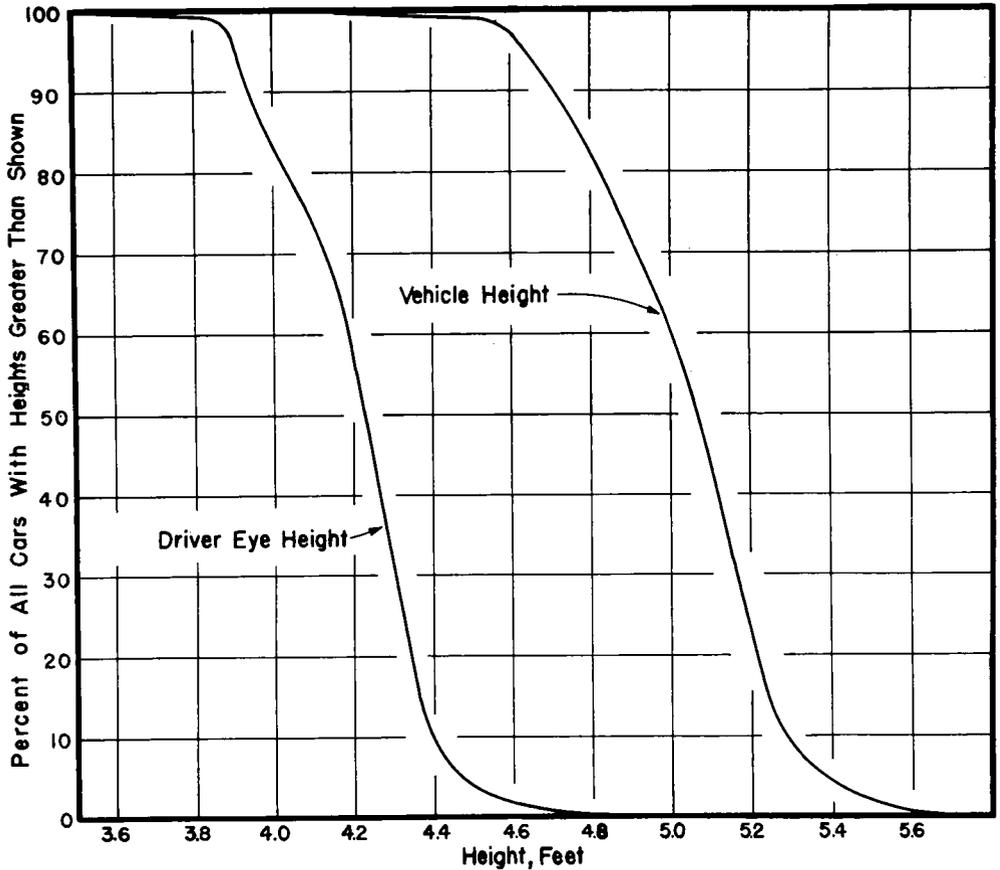


Figure 4. Percent of all passenger cars in use in 1959 with driver eye height and over-all vehicle height greater than shown.

not be designed to account for the capabilities and limitations of only half the users of the facility, but rather these designs should be based upon physical dimensions which are representative of most of the users, for example, 85 or 90 percent of the users. Figure 4 shows that a 3.95-ft driver eye height represents a lower limit for about 85 percent of the current drivers. This height will be used to illustrate the effect of lower eye height on the proportions of certain geometric design features, but 3.95 ft is not necessarily the lowest dimension to which representative eye height will go. Several observers have estimated an ultimate lower limit of 3.50 ft.

EFFECT ON GEOMETRIC FEATURES

The proportions of several geometric design features are influenced by driver eye height in that eye height affects sight distance. Crest vertical curves are normally designed to provide sight distances which permit a vehicle either to stop before striking an assumed 4-in. high object or to pass an overtaken vehicle in a normal manner. In either case, increased vertical curve length is required when driver eye height or object height is lowered if an equal degree of safety is maintained.

One way to illustrate the magnitude of this increased length requirement is to

refer to design curves developed from formulas which relate eye height, object height, algebraic difference in grades, sight distance, and length of vertical curve (Figs. 5 and 6). In cases where passing sight distance is less than the length of vertical curve and where eye height and object height are lowered from 4.5 to 3.95 ft, a 14 percent increase in vertical curve length is required. For example, Figure 5 applies when $h_e = h_o = 4.5$ ft and shows that a vertical curve 1,667 ft long is required for an algebraic difference in grades of 6 percent and a passing sight distance of 1,000 ft. Figure 6 applies for $h_e = h_o = 3.95$ ft and shows that a curve 1,899 ft is required for the same conditions of sight distance and difference in grades. The difference in curve length of 232 ft represents the 14 percent increase in required curve length which results from lowering eye height and object height. For cases in which sight distance is greater than vertical curve length, the 2-term formula (Figs. 5 and 6) applies, and no fixed percentage increase in curve length results from lowering eye and object height. For most practical conditions, however, the increase in curve length ranges from 12 to 15 percent.

Comparison of Figures 7 and 8 shows that vertical curves designed to provide safe stopping sight distances for eye and object height of 3.95 ft are 10.6 percent longer than comparable curves based upon eye and object height of 4.5 ft for cases in which sight distance is less than curve length. In nearly all critical cases of stopping sight distance encountered in practice, vertical curve length is greater than safe stopping sight distance.

Loutzenheiser (3) analyzes the effect of driver eye height on vertical curve design by determining the percent reduction in sight distance which results from lowering eye height and object height. This approach is particularly good for evaluating existing curves. Figures 5 through 8 can be interpreted to show the reduction in sight distance which results from changing eye height and object height from 4.5 to 3.95 ft for indicated conditions. Although the reduction

amounts to only 5 or 6 percent, actual distances range up to several hundred feet in some cases. This means that existing vertical curves which are designed to provide safe stopping sight distance at a 4.5-ft driver eye height do not provide the same degree of safety in operation for drivers with lower eye height. Of course, existing designs cannot be easily altered, but future designs should be based upon representative values of driver eye height.

In areas where vertical curves providing adequate passing sight distance can not be justified economically, curves are designed to provide safe stopping sight distance and no-passing zones are delineated. The length of these zones is determined by required sight distance; therefore, consideration should be given to the fact that about 90 percent of the passenger car drivers are viewing the road from heights less than 4.5 ft. A 3.95-ft driver eye height accounts for about 85 percent of the passenger car drivers and can be used for determining the length of no-passing zones. Because average driver eye height for all 1959 model passenger cars observed is 3.92 ft and the trend toward lower vehicles will probably continue, 3.95 ft is considered to be a realistic value.

Horizontal sight distance is restricted at many locations by a lower driver eye height. Stationary objects such as guardrails, wing walls, and parked vehicles may obstruct the driver's view. Figure 9 shows a situation in which the height of a wing wall is a critical factor. From a 4.5-ft height, the driver of a stopped vehicle can see traffic approaching the intersection, but from 3.5 ft he can see nothing but the wing wall.

Figure 10 shows the driver's view of traffic obstructed by a guardrail. From 4.5 ft, the driver on the frontage road can see the merging ramp traffic for a considerable distance, but from 3.5 ft, he cannot see the ramp traffic until the section of guardrail is passed.

These examples of restricted horizontal sight distance point out the fact that nearly all such problem areas can be eliminated if highway engineers realize

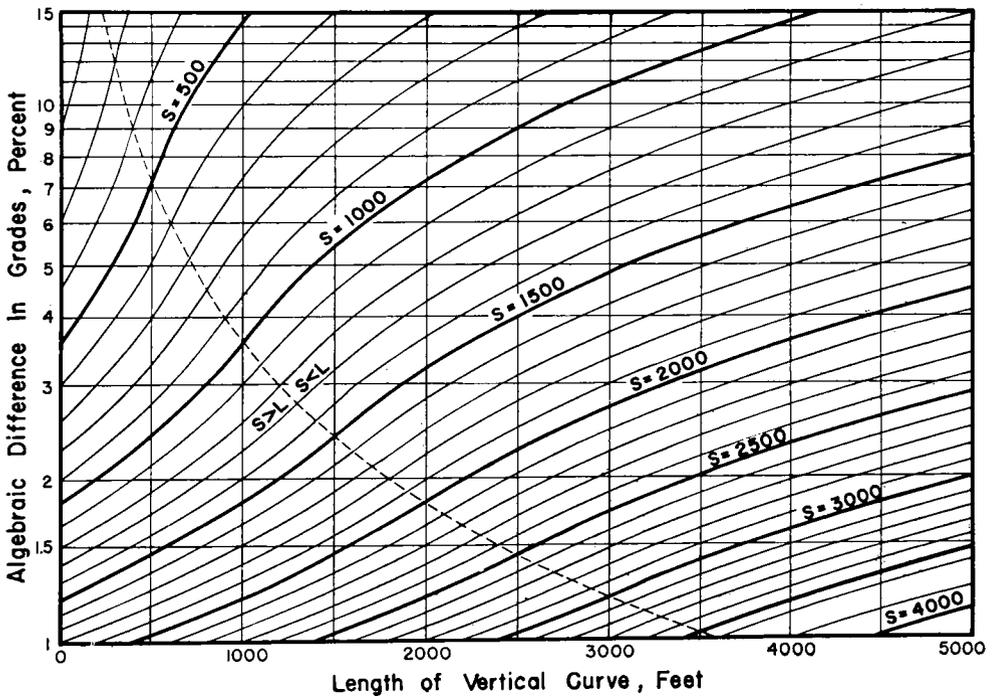
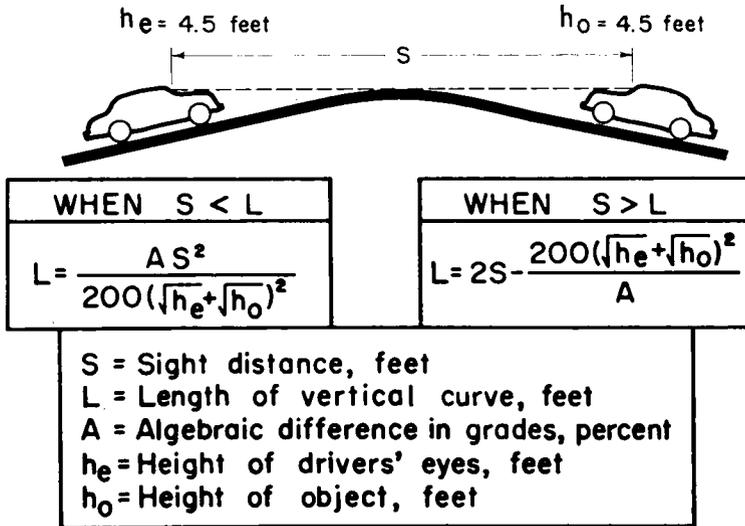
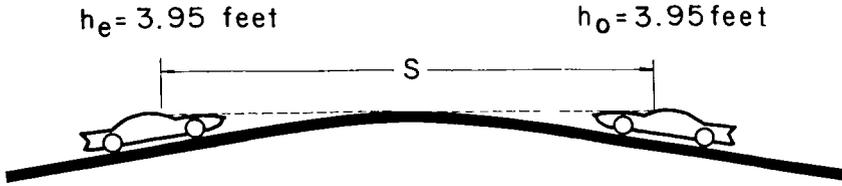


Figure 5. Length of vertical curve required for safe passing sight distance when eye height and object height are 4.5 ft.



WHEN $S < L$
$L = \frac{AS^2}{200(\sqrt{h_e} + \sqrt{h_o})^2}$

WHEN $S > L$
$L = 2S - \frac{200(\sqrt{h_e} + \sqrt{h_o})^2}{A}$

S = Sight distance, feet
L = Length of vertical curve, feet
A = Algebraic difference in grades, percent
h_e = Height of drivers' eyes, feet
h_o = Height of object, feet

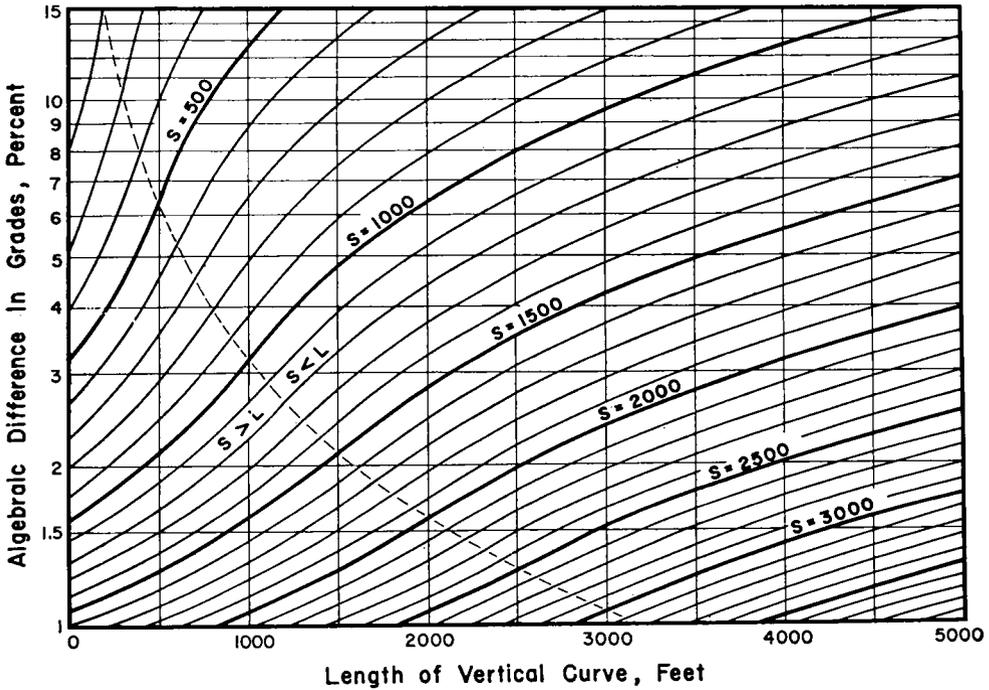


Figure 6. Length of vertical curve required for safe passing sight distance when eye height and object height are 3.95 ft.

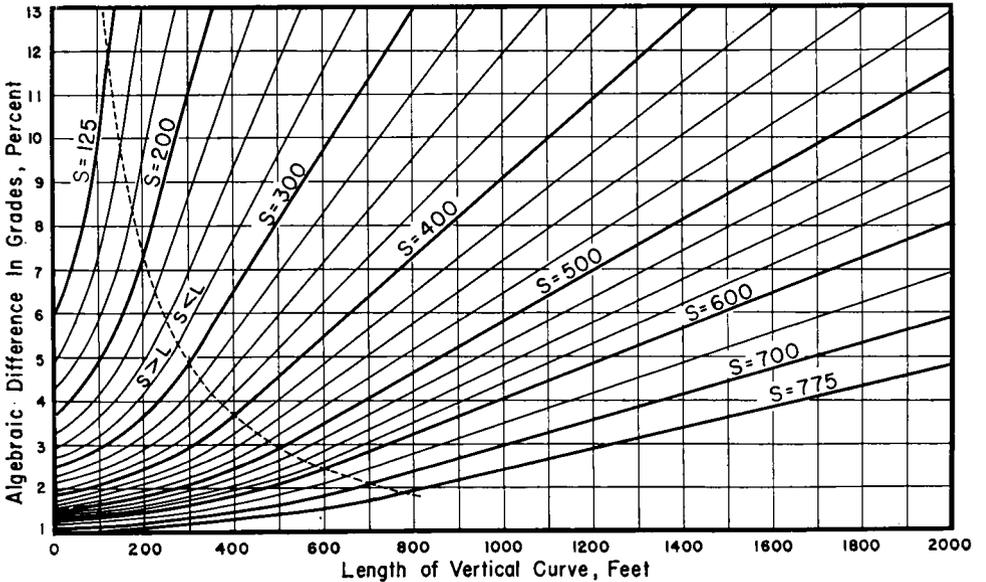
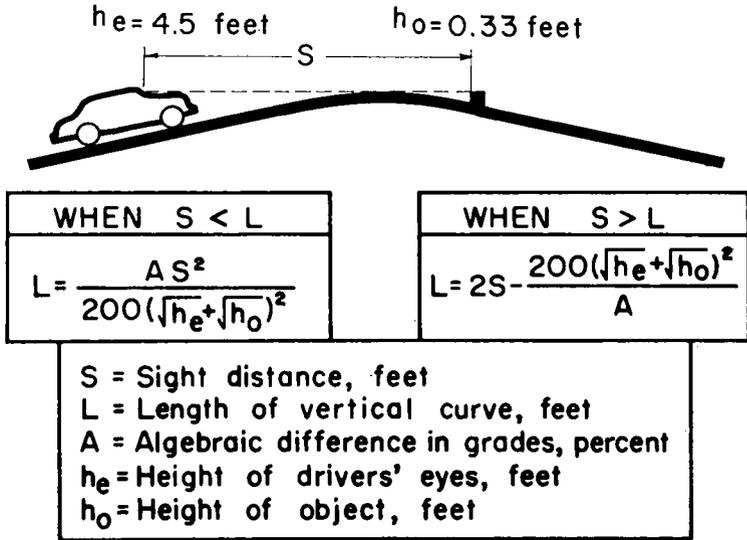


Figure 7. Length of vertical curve required for safe stopping sight distance when eye height is 4.5 ft and object height is 0.33 ft.

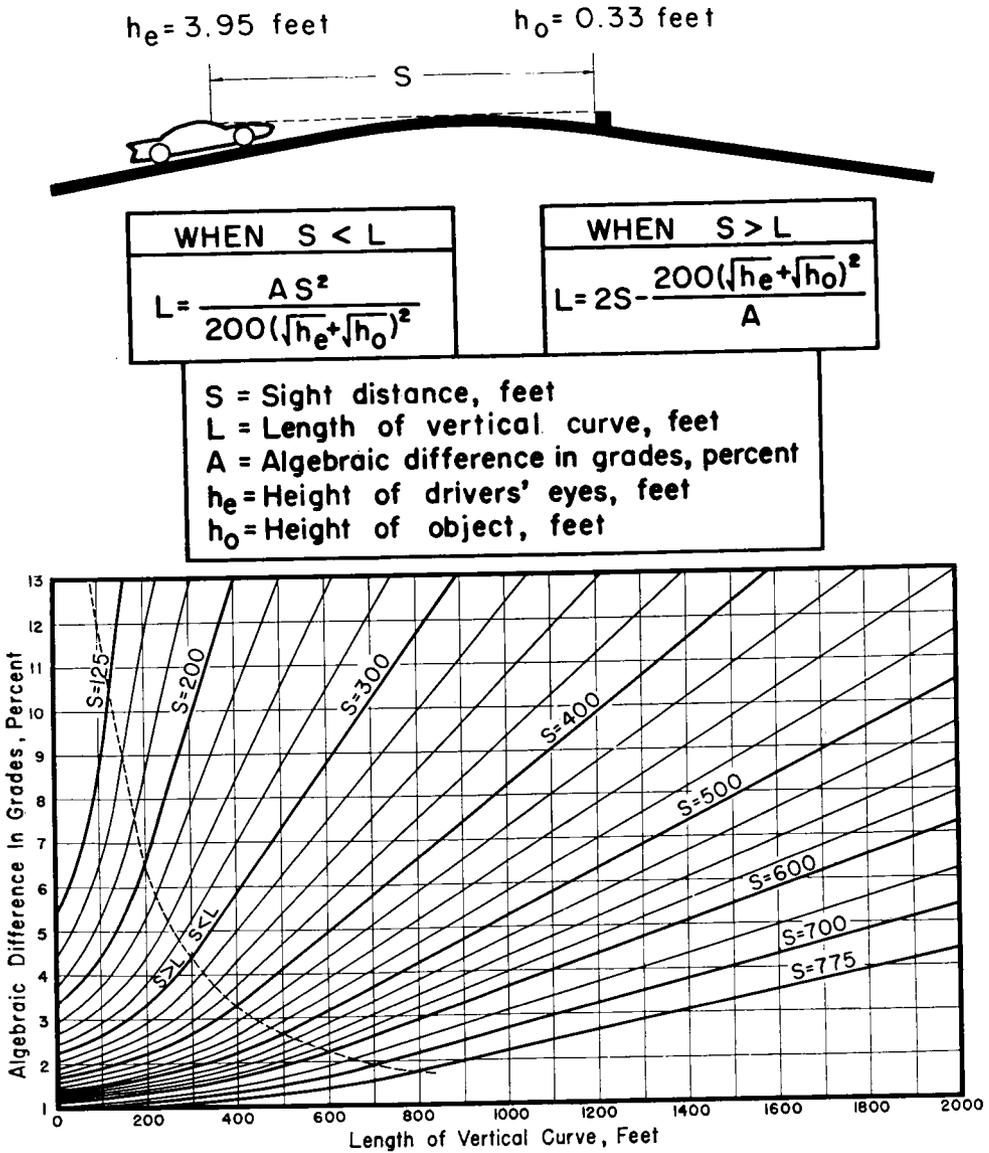


Figure 8. Length of vertical curve required for safe stopping sight distance when eye height is 3.95 ft and object height is 0.33 ft.

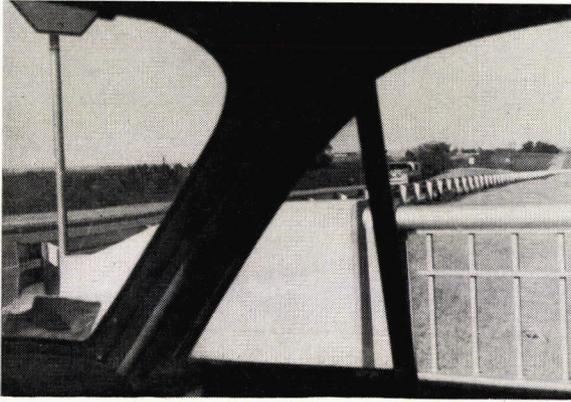


Figure 9. Intersection approach as viewed (upper) from height of 4.5 ft and (lower) from height of 3.5 ft.

that in late model cars the drivers' eyes are at heights of 3.6 to 4.0 ft rather than at 4.5 ft or higher.

The problem of headlight glare is perhaps aggravated by a lower position of the drivers' eyes, but the effect is probably very slight. Geometric design features such as wider medians can be used to alleviate or eliminate the problem, but other remedial measures such as shrubbery or light barriers are more practical in most areas where the glare problem is acute.

CONCLUSIONS

Accurate measurements of driver eye height and over-all vehicle height can be made by photogrammetric methods. This method permits selected observations of drivers and vehicles which are operating at normal speeds under usual traffic conditions to be used for determining representative dimensions for eye height and vehicle height.

Analysis of 761 side-view photographs of passenger cars shows that in normal operation only 5 percent of the drivers have eye heights of 4.5 ft or greater. One-half the drivers' eye heights are greater than 4.23 ft above the roadway surface, and 85 percent are greater than 3.95 ft. When practicable, geometric features should be designed to account for the characteristics of most of the users of the facility (85 or 90 percent). A 3.95-ft driver eye height is considered to be representative for design purposes.

A 12 to 15 percent increase in crest vertical curve length is required for safe passing sight distance when eye height and object height are reduced from 4.5 to 3.95 ft. For safe stopping sight distances, a 10.6 percent increase in vertical curve length is required.

No-passing zones can be marked to account for lower driver eye height. Sight distance restrictions which result from reducing eye height from 4.5 to 3.95 ft range up to about 6 percent. For safety in operation, length of no-passing zones should be based on representative driver eye height.

Horizontal sight distance is restricted

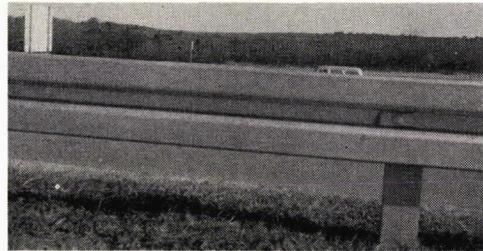
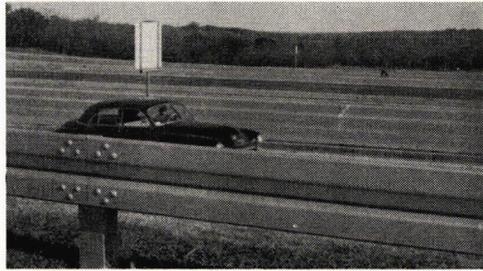


Figure 10. View of (a) freeway exit ramp merging with frontage road, (b) vehicle on ramp as seen from frontage road when eye height is 4.5 ft, and (c) ramp as seen from frontage road when eye height is 3.5 ft.

in many cases when eye height is below 4.5 ft. Height of stationary objects such as guardrails and wing walls becomes a critical factor. Nominal changes in design can virtually eliminate these problem areas, and future designs should be based on driver eye heights of about 3.6 to 4.0 ft.

ACKNOWLEDGMENTS

The Bureau of Engineering Research, University of Texas, provided financial support and personnel to make this research possible. Cecil F. Smith, Robert Pearce, William Wang, and Colin Cole assisted in collection and presentation of data. Appreciation is expressed to D. T.

Harkrider, Motor Vehicle Division, Texas Highway Department, for supplying information regarding vehicular identification. Helpful suggestions and services were offered by Mrs. Jewel Gibson, Lymon C. Reese, Robert Turpin, Clayton Chance, and other staff members of the University of Texas.

REFERENCES

1. STONEX, K. A., "Driver Eye Height and Vehicle Performance in Relation to Crest Sight Distance and Length of No-Passing Zones, I. Vehicle Data." HRB Bul. 195, pp. 1-4 (1958).
2. *Automotive Industries*, 120:No.6, Mar. 15, 1959; 120:No.5, Mar. 1, 1959; and 121:No.9, November 1, 1959.
3. LOUTZENHEISER, D. W., AND HAILE, E. R. JR., "Driver Eye Height and Vehicle Performance in Relation to Crest Sight Distance and Length of No-Passing Zones, II. Vertical Curve Design." HRB Bul. 195, pp. 4-8 (1958).