



AKADÉMIAI KIADÓ

The role of driver's eye height in the design of crest curves of roads

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Pollack Periodica •
An International Journal
for Engineering and
Information Sciences

18 (2023) 3, 113–118

DOI:

[10.1556/606.2023.00808](https://doi.org/10.1556/606.2023.00808)

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Received: December 30, 2022 • Revised manuscript received: April 28, 2023 • Accepted: May 2, 2023

Published online: June 5, 2023

ABSTRACT

The driver's eye height from the ground, as what drivers can see on the road, is essential for their safety and for avoiding road hazards. Using the statistical analysis of vehicles sample, the statistical parameters of the measured set of values were determined. A one-sample *t*-test was done to check whether the measured sample differs from the driver's eye height value specified in the Hungarian design guidelines. A new range of driver's eye height has been found, which is considered an update to the current value and might be applied in the upcoming road design. Parallel with the eye-height analysis, sight distances at vertical crest curves were modeled by AutoCAD Civil 3D. The minimum radiuses of the crest curves were defined for human eye height and for sensors of autonomous vehicles.

KEYWORDS

sight distance, autonomous vehicles, driver's eye height, crest curve, Zala Zone, AutoCAD Civil 3D

ORIGINAL RESEARCH PAPER



1. INTRODUCTION

This study aims to analyze the current driver's eye height and suggest new values for it. Given that the driver's eye height values in the Hungarian Guidelines [1] have not been changed for nearly 40 years, and the automobile industry with its explosive growth contribute to finding cars with various dimensions that in turn affect the driver's eye height. These reasons together formed the motivation for conducting this study.

The height of the driver's eye is affected by human differences that include the height and gender of the driver, however in this study; the focus was on the height of the driver's eye without looking at these differences because they exist continuously and are not the focus of the study [2].

For this purpose, a sample of passenger cars of various shapes, sizes, and drivers (of both genders) was surveyed. Since current guidelines will be affected by the recent technology, autonomous vehicles must also be considered, which in turn will influence current driver eye height design values assigned to road design in the case of human drivers and their physical and mental capabilities.

The height of the driver's eye in Autonomous Vehicles (AVs) is represented by the height of the sensors installed on the self-driving cars.

Therefore, sight distances were tested on a vertical crest curve model using AutoCAD Civil 3D for several driver eye height values, which included camera height, Light Detection And Ranging (LIDAR) height radar, and human driver eye height.

By comparing the values of resulted sight distances with their design values in the Hungarian Guidelines for road design, the minimum vertical curve radius corresponding to each sighting distance and design speed was found.

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2. BACKGROUND

By reviewing some of road design guidelines, it was found that the value of the driver's eye height has values that differ from one country to another. Some of these values have been fixed for decades and have not undergone any change, and some of them are constantly updating.

For example, the value of the driver's eye height suggested for the design in the first edition of American code [3] was 1,676 mm in 1920, then it was reduced in 1994 (i.e., after 70 years) to become 1,070 mm, passing by a value of 1,445 mm in 1936 and 1,295 mm in 1957, to keep up with changes in the vehicles fleet. After 2001 it has become 1,080 mm till now [3].

The height of the driver's eye is considered one of the parameters that enter into the calculation of the minimum radius of the vertical crest curve. Some studies [4] conducted surveys to determine an updated value for the driver's eye height in Italian standards [4] and investigated the effects of the difference in the driver's eye height. It was concluded that the current values of the driver's eye height are different, even from the updated values between 2003 and 2008 [4].

Based on the perception reaction time and sensor height of fully automated self-driving cars, the vertical and low vertical curve lengths and stopping visual distance were calculated and compared with the values for human drivers in the US's Green Book [3]. It was concluded that autonomous vehicles need Stopping Sight Distances (SSD) less than the required SSD in the case of human drivers, thus the lengths of the vertical curves of the sag and crest will be less in the case of AVs [5].

Using photogrammetry, was found that the driver's eye height should be greater than the current value in the United Kingdom Highway Standard [6], which equals 1.05 m, where all the driver's eye heights in the conducted survey were bigger than this value with the minimum value of the driver's eye height for any vehicle being 1.062 m [6].

A study [7] was conducted on a model of crest vertical curve using AutoCAD Civil 3D, tests were done using the checking visibility tool, and it was concluded that autonomous vehicles are able to obtain a sight distance higher than what that a human driver can obtain under the same geometric conditions of the vertical curve [7].

Magyari [8] used a laser scanner to assess the sufficiency of the visibility at a roundabout. They found that 3D models can describe objects more precisely than 2D views. The study also suggested that automated mobile laser scanners could be used for quick analysis of the visibility of various elements of the road network.

3. AIM OF THE STUDY

The first aim of this study is to analyze the expected changes in the driver's eye height value. How it could be affected by the rapid development in the vehicle industry?

The second aim is to present and discuss the resulted radiuses of the vertical crest curve using AutoCAD Civil 3D visibility check model.

4. METHODOLOGY

4.1. Analyzing the changes in the driver's eye height

Due to the importance of the driver's eye height, and the essential updates on its value in the Hungarian Guidelines, a survey was conducted on Hédervári street (Győr, Hungary, July 19, 2022) that included a two-hours video recording.

4.1.1. Analyzing the video recording. This analysis included, counting the cars within the two hours recording, and exclude the inappropriate vehicles including buses, small trucks, or goods vehicles. The final number of the accepted cars (passenger cars) was 266.

4.1.2. Calculating the driver's eye height. From the actual value of the pole's height, the distance between the driver and the pole (pole's distance), and the distance between the driver and the camera (driver's distance), are driver's eye height can be calculated Fig. 1.

The concept of visual angle (or angular size) describes how the distant objects appear shorter and smaller, Fig. 2.

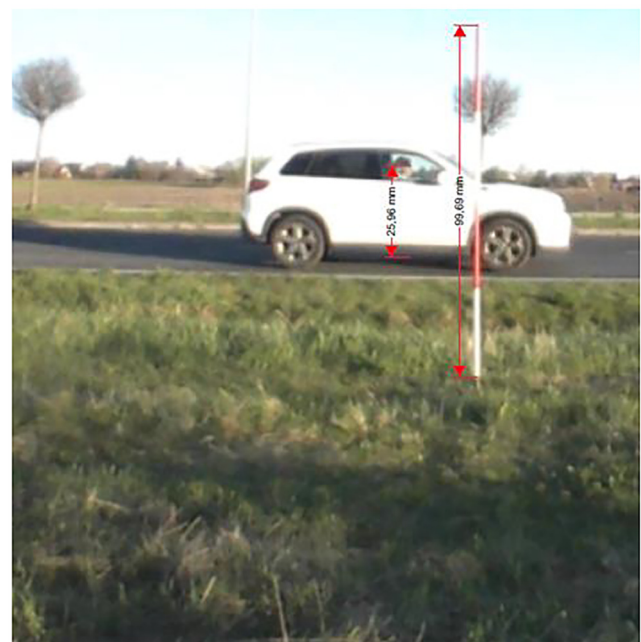


Fig. 1. Measurements in AutoCAD



Fig. 2. Visual angle (distant objects)

Also, the far end of roads seems narrower, Fig. 3.

The calculated driver’s eye height was determined for each car. Using AutoCAD software, the height of the pole, and the driver’s eye height were possible to be defined as it is shown in Fig. 1. Based on the parameters illustrated in Fig. 4, Eq. (1) was extracted:

$$H_c = \frac{D_d}{D_p} \cdot h_{d,CAD} \cdot \frac{h_p}{h_{p,CAD}}, \quad (1)$$

where H_c is the calculated eye height (m); D_d is the driver’s distance (the distance between the camera and the driver), 15 m; D_p is the pole’s distance, (the distance between the driver and the pole), 10 m; h_p is the pole’s height, 2 m; $h_{p,CAD}$ is the pole’s height measured in AutoCAD, (m); $h_{d,CAD}$ is the eye’s height measured in AutoCAD, (m).

4.1.3. Determine the driver’s eye height by using one-sample t-test. In the Hungarian Guidelines, the driver’s eye height is 1.1 m, in this study; the following hypothesis (null hypothesis) was examined:

- H_0 : There is no significant difference between the mean of the driver’s eye height in the studied sample and the driver’s eye height in the Hungarian Guideline.

One-sample *t*-test was done using SPSS software and the results are in Table 1.

To determine if the difference in eye height (calculated eye height - guideline eye height) is statistically different



Fig. 3. Visual angle (narrower roads)

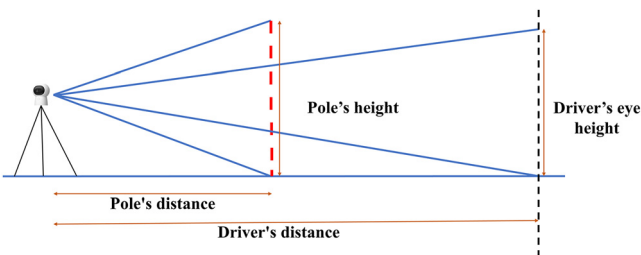


Fig. 4. Illustration of the used parameters

Table 1. Measures of central tendency and dispersion

Descriptive Statistics				
	N	Mean	SD	Standard error mean
Driver eye height	266	1.31100	0.20491	0.01256

from zero ($\alpha = 5\%$), a 2-tailed, one-sample *t*-test was conducted. Table 2 shows the results:

4.1.4. Other guidelines. To verify that the resulting range of the driver’s eye height can be generalized and attempt to find an international interval based on the analysis of the same sample. Therefore, the same statistical analysis was repeated for the driver’s eye height in the guidelines for the countries in Table 3. As its shown in Table 3, some countries have not changed this value over a long time and still use the old value.

The results for each country’s guidelines are illustrated in the following tables, from Tables 4 to 8.

In a similar way, it is found that the interval of driver’s eye height = 1 + 0.2862, 1 + 0.3357 = 1.2862, 1.3357 m.

Driver’s eye height = 1.05 + 0.2362, 1.05 + 0.2857 = 1.2862, 1.3357 m.

Driver’s eye height = [1.08 + 0.2062, 1.08 + 0.2557 = 1.2862, 1.3357 m.

Driver’s eye height = 1.15 + 0.1362, 1.15 + 0.1857 = 1.2862, 1.3357 m.

Driver’s eye height = 1.2 + 0.0862, 1.2 + 0.1357 = 1.2862, 1.3357 m.

In case of Italy, Netherlands, and Sweden, the driver’s eye height equals to 1.1 m, it is similar to its value in the Hungarian Guidelines, which means the interval of the driver’s eye height is equal to 1.1 + 0.1862, 1.1 + 0.2357 m.

4.2. Finding the minimum crest radiuses in case of human driver and AVs using Civil 3D

In previous work, the sight distances of AVs and Conventional Vehicles (CVs) on crest vertical curves were examined and compared using AutoCAD Civil 3D road design models. It’s found that AVs using LIDAR sensor or camera can reach higher sight distances than CVs.

Recently the previous work was completed using AutoCAD Civil 3D, it is found that the minimum crest radiuses, which meet each sight distance in the Hungarian Guidelines in the case of a human driver and for each calculated sight distance in the case of AV sensors. Table 9 is summarized all these results after a plenty number of tests.

In table R_v_min_CV_ÚME refers to the minimum radiuses of the vertical crest curve in the Hungarian Guidelines; R_v_min_CV_visibility check refers to the resulted minimum radiuses of the vertical crest curve in case of CVs using the visibility check tool in AutoCAD Civil 3D. In this case, the driver’s eye height was 1.1 m; R_v_min_LIDAR refers to the resulted minimum radiuses of the vertical crest

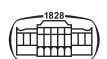


Table 2. 2-tailed, one-sample *t*-test

One-sample test						
Test value = 1.1 m						
	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference (m)	95% Confidence interval of the difference (m)	
					Lower	Upper
Driver eye height	16.79200	265	0.00000	0.21098	0.18620	0.23570

df: degrees of freedom; Sig. (2-tailed): significance value (2-tailed).

Table 3. Driver's eye height in other guidelines

Countries	Value (m)
Austria, France, Germany	1.00
Canada, England, Australia 2002	1.05
United States before 2001	1.07
United States after 2001	1.08
Italy, Netherlands, Sweden	1.10
Australia 1962÷2002	1.15
Japan	1.20

curve in case of AVs using the visibility check tool in AutoCAD Civil 3D based on the LIDAR's height. For these tests, it was assumed 1.75 m; R_v_min_CAMERA refers to the resulted minimum radiuses of the vertical crest curve in case of AVs using the visibility check tool in AutoCAD Civil 3D based on the CAMERA's height, which was 1.3 m; and R_v_min_RADAR refers to the minimum radius of the vertical crest curve in case of AVs using the visibility check tool in AutoCAD Civil 3D based on the RADAR's height 0.6 m.

Table 4. Austria, France, Germany, 1 m

One-sample test						
Test value = 1.00 m						
	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference (m)	95% Confidence interval of the difference (m)	
					Lower	Upper
Driver eye height	24.75100	265	0.00000	0.31098	0.28620	0.33570

Table 5. Canada, England, Australia 2002, 1.05 m

One-sample test						
Test value = 1.00 m						
	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference (m)	95% Confidence interval of the difference (m)	
					Lower	Upper
Driver eye height	20.77200	265	0.00000	0.26098	0.23620	0.28570

Table 6. United States 2001, 1.08 m

One-sample test						
Test value = 1.08 m						
	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference (m)	95% Confidence interval of the difference (m)	
					Lower	Upper
Driver eye height	18.38400	265	0.00000	0.23098	0.20620	0.25570



Table 7. Australia 1962–2002, 1.15 m

One-sample test						
Test value = 1.15 m						
	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference (m)	95% Confidence interval of the difference (m)	
					Lower	Upper
Driver eye height	12.81300	265	0.00000	0.16098	0.13620	0.18570

Table 8. Japan, 1.20 m

One-sample test						
Test Value = 1.20 m						
	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference (m)	95% Confidence interval of the difference (m)	
					Lower	Upper
Driver eye height	8.83300	265	0.00000	0.11098	0.08620	0.13570

Table 9. Minimum vertical crest radiuses

Speed, (km h ⁻¹)	Speed, (m s ⁻¹)	Sight distance (CVs), (m)	Sight distance (AVs), (m)	R_v_min_CV ÚME	R_v_min_CV visibility check	R_v_min LIDAR	R_v_min CAMERA	R_v_min RADAR
30	8	25	17	160	-	-	-	-
40	11	35	24	350	450	-	-	-
50	14	50	36	700	750	130	320	750
60	17	65	48	1,200	1,350	330	430	1,160
70	19	85	66	2,100	2,150	910	1,160	2,000
80	22	110	88	3,500	3,300	1,620	2,000	3,400
90	25	140	115	5,500	4,650	2,375	3,250	5,250
100	28	170	142	8,500	7,600	3,800	3,500	8,500
110	31	210	179	9,200	11,900	6,100	7,000	13,600
130	36	300	264	15,500	24,250	13,000	16,500	29,500

5. RESULTS AND DISCUSSION

Based on Table 1, it can be noted that the mean value of the measured driver's eye height for the 266 cars was 1.31 m with a standard deviation of 0.2049 and a standard error mean of 0.01256, this mean values is different from the driver's eye height used in the Hungarian Guidelines [1] which is 1.1 m.

From Table 2, the *t*-test value for the sample of 265 vehicles was $t_{265} = 16.792$. Since the value of *P* (*P* = level of marginal significance) was equal to 0.000, which is less than the α (level of significance): i.e., $P = 0.000 < \alpha = 5\%$, therefore, it can be concluded that the sample mean is statistically significantly different, and the null hypothesis was rejected.

It can be estimated the 95% confidence interval of the driver's eye height as follows: driver's eye height = 1.1 + 0.1862, 1.1 + 0.2357 = 1.2862, 1.3357 m. This means that the driver's eye height should be modified to be 1.29 m at minimum and 1.34 m at maximum in the Hungarian Guidelines.

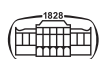
Based on the resulted radiuses, the following can be concluded:

- The minimum value of the sight distance 17 m or higher at any radius starting with radius 130 m can be reached in case of AVs, which is less than the minimum radius value in case of conventional vehicles;
- On the other hand, the minimum radius in case of human driver is 450 m, or even less than this value can be enough to get an adequate sight distance;
- At high speeds 110, 130 km h⁻¹, LIDAR sensor needs radiuses lower than the required ones in case of conventional vehicles to obtain an appropriate sight distance.

6. CONCLUSION AND FURTHER STEPS

The interval of driver's eye height = 1.2862, 1.3357 m can be generalized to the guidelines mentioned previously.

This leads to new results represented in the need to modify the driver's eye height in the current guidelines



and add new criteria in road design to involve the AVs as well, where the eye height can be higher than this range.

Add new values for the minimum radiuses of vertical crest curves to involve the autonomous vehicles requirements.

Some experiments at ZalaZone (vehicle test place) were conducted on an electric vehicle contains LIDAR sensor assembled on both sides of the vehicle. The objective is to measure the sight distance in case of LIDAR sensor and human's eye under the same circumstances of the road geometry and the existing obstacles. For this purpose, the most appropriate crest section was selected, and the obstacles were cubic boxes with different dimensions 10, 20, 30, 60 cm.

In these experiments, the sight distances for several positions of the objects right, left, and middle of the lane have been checked. Based on the car specifications and crest radius, it is expected to get sight distance values that can be compared with the values in the Hungarian guidelines for the same radius and vehicle speed.

Currently, the outcome from LIDAR sensor and the camera are analyzed using Foxglove Studio software.

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