ATINER's Conference Paper Proceedings Series
CIV2021-0271
Athens, 8 November 2022

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ATINER's Conference Paper Proceedings Series
CIV2021-0271
Athens, 8 November 2022
ISSN: 2529-167X

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ABSTRACT

Sight distance is an important criterion in highway geometric design for traffic safety to ensure that the driver can see any possible road hazard insufficient time to take action and avoid an accident. Many Albanian roads have been designed and constructed before 1991 based on standards in place as of the construction time. More recently, investments have been made for upgrading and expanding the transport infrastructure in the country. The importance of providing adequate sight distance for safe and efficient traffic is well recognized by researchers and included in most design manuals. Horizontal curves, crest vertical curves, and rural intersections are the common sight restrictions considered in highway design. Stopping sight distance (SSD) is the most important of the sight-distance considerations since sufficient SSD is required at any point along the roadway. Technical road standards used in Albania before 1991 were based upon outdated standards. Currently, road design standards have been changed receiving considerable European standards. This paper analyses the sight distance estimation criterion using the upgraded manual. For this purpose, road design examples have been studied based on sight design requirements and geometric data. The results obtained through calculation were compared according to upgraded standards to investigate road safety associated with highway geometric design.

Keywords: *highway design, sight distance restrictions, road safety*

Introduction

Road transportation is an essential network for any country. Many Albanian roads have been designed and constructed before 1991 based on standards in place as of the construction time. More recently, investments have been made for upgrading and expanding the transport infrastructure in the country. Among all design aspects of road design, geometric design is a critical feature for traffic safety. Previous research on rural two-lane highway operations and safety has concluded that a sight distance profile is a useful tool for evaluating the impact on safety [1, 2, 3]. The Highway Safety Manual (HSM) and supporting implementation tool were developed by cooperative research [4]. Sight distance is an important design criterion in the geometry of highway roads, set out in the current Albanian road standards. In design practice, the available sight distance is compared to the required sight distance for various driving and controlling tasks [5]. This study aims to assess the safety of Albanian roads according to upgraded standards [5], largely derived from the design speed and sight distances. Design examples have been studied based on sight design requirements. The available, stopping and passing sight distance for 15 sections of two-lane rural highway, located in old Albanian road, was analyzed. For each highway segment, GIS-based software and in-site inspection were used to measure available sight distance on each curve located in each highway segment [6, 7, 8]. The results obtained through calculation were compared according to upgraded standards in order to investigate road safety associated with highway geometric design.

Figure 1 and 2 shows the Tepelenë-Gjirokastër route and road plan elevation respectively, positioned in the south country district. It is one of the main inter-urban roads in Albania, connecting Tirana with south of Albania and Greece. The driving distance between Tepelenë-Gjirokastër is 31 km. The road is carrying more than 5000 vehicles per day. It is classified as a type C highway based on the current standard [5].

Figure 1. *Map Showing Tepelenë-Gjirokastër Road within Albania (Google Earth 2020) [6, 8]*

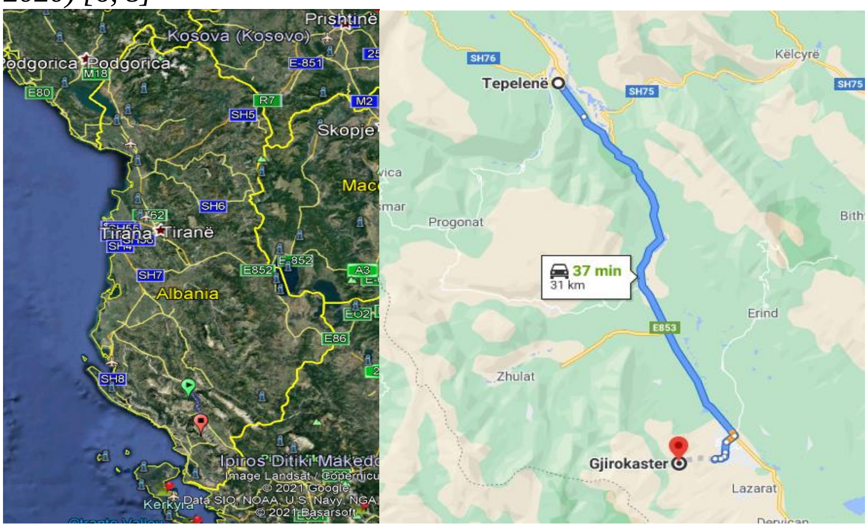

Figure 2. *Elevation Plan Showing Tepelenë-Gjirokastër Road (Google Earth 2020) [6, 8]*

Methodology/Materials and Methods

The Albanian upgrade manual for geometric design of roads, analyses a two-dimensional analytical methodology for available sight design estimation. This procedure considers horizontal and vertical alignments separately.

Theory/Calculation

Sight distance is the length of the roadway ahead that is visible to the driver. This distance is dependent on the height of the driver's eye above the road surface, the specified object height above the road surface, and the height and lateral position of sight obstructions within the driver's line of sight [5, 9]. Adequate sight distance provides time for drivers to identify hazards and take appropriate action to avoid them [10]. Following are the four types of sight distance:

- Stopping Sight Distance.
- Passing Sight Distance.
- Decision Sight Distance.
- Intersection Sight Distance.

Stopping sight distance is required at all locations along the highway and enables the driver to see an object in the roadway with enough distance to stop. It consists of two distances: the distance traversed during the to make the decision of braking (called perception-reaction distance) and the distance to apply the brake to stop the vehicle. The stopping sight distance of a vehicle on a level roadway traveling at the design speed of the roadway may be determined from the following equation [5, 11]:

$$D_A = D_1 + D_2 = \frac{V_o}{3.6} t - \frac{1}{3.6^2} \int_{V_o}^{V} \frac{V}{g \cdot \left[f_1(V) \pm \frac{i}{100} \right] + \frac{R_a(V)}{m} + r_o(V)} dV \quad \text{(m)}$$

Where;

D_1 : length of roadway travelled by vehicle from driver perception to brake application (m);
D_2 : roadway distance required to stop the vehicle from the instant of brake application (m);
i : longitudinal grade (%);
t : the brake reaction time (s);
g : gravitational acceleration (m/s^2);
R_a : aerodynamic resistance;
f_1 : the minimum side friction coefficient;
V : final vehicle speed which is 0 km/h when the stop is done
V_0 : design speed
m : vehicle weight

The relationship between aerodynamic resistance, vehicle weight, and the vehicle speed on standard air conditions is given in the following equation [5, 11]:

$$\frac{R_a}{m} = 2.61 \times 10^{-5} \times V^2 \quad \text{(N/Kg)}$$

Table 1 shows the recommended friction coefficient for highways and other types of roads use in geometric design by Albanian upgraded manual [5]. This coefficient represents the lateral acceleration that acts on the vehicle. They provide a reasonable margin of safety for various speeds.

Table 1. *Friction Factors Based on Various Speeds*

Design speed (km/h)	**f_1 (highway)**	**f_1 (Other types of roads)**
25	-	0.45
40	-	0.43
60	-	0.35
80	0.44	0.30
100	0.40	0.25
120	0.36	0.21
140	0.34	-

On the other hand, passing sight distance is the minimum required distance to safely overtake another vehicle without colliding with a vehicle in the opposing lane. Passing sight distance is specifically critical in two-lane two directional roadways. Factors that affect the passing sight distance evaluation are:

1. Velocities of the overtaking vehicle, overtaken vehicle and the vehicle coming from the opposite direction.
2. Spacing between vehicles.
3. Driving skills, experience and reaction time of the driver.
4. Rate of acceleration of overtaking vehicle.
5. Gradient of the road.

The passing sight distance for two-lane highways depends on design speed [5, 9, 11]. It is calculated from the following equation:

$$D_p = 20 \cdot v = 5.5 \cdot V \quad \text{(m)},$$

Where;
D_p : passing sight distance for two-lane highways.
v : design speed in (m/s).
V : design speed in (km/h).

Table 2 shows the required passing sight distance values for various speeds [5, 11].

Table 2. *Passing Sight Distance for Design of Two-Lane Highways [5]*

Design speed (km/h)	**Passing sight distance (m)**
60	475
70	500
80	525
90	575
100	625

Case Studies

Available distance and stopping sight distance have been analyzed for 15 sections of two-lane interurban road located in the Tepelenë-Gjirokastër region, with a total length of 31 km and 3.5m lane width. This road is designed with technical road standards used in Albania before 1991. In the case of a two-lane two directional highway, passing sight distance should also be measured and calculated in addition to stopping sight distance. Figure 3 shows an overview of Tepelenë-Gjirokastër national road.

Figure 3. *Tepelenë-Gjirokastër Highway Photo Image*

The distance measurement of available sight distance was made using geographical information systems GIS-Albania [6, 12]. Stopping sight distance calculation was made according to the upgraded Albanian geometric design criterion. The input data sets required for the calculation are design speed, grade, side friction, reaction time, the height of the driver's eye, and the height of the target obstacle. The driver's eye and target obstacle height values are presented in

Table **3**. Table 4 shows the available distances (AD), stopping sight distances (SSD), and passing sight distances (Dp) calculated with the upgraded Albanian manual.

Table 3. *Assumptions and Parameter Values for the Case Study*

Parameter	**Stopping sight distance**	**Passing sight distance**
Traveling direction	Outward	Outward and return
Overpass inserted	With and without overpass	With overpass
Driver's eye height (m)	1.1	1.1, 1.5, 2.0, and 2.5
Target height (m)	0.5	0.5 and 1.1

A summary of the computed stopping and passing sight distance values in the example is presented in Table 4 and Table 5.

For the sight distance calculations, the driver's perception-reaction time (t) is considered 2.5s [5].

The definition of speed is one of the main elements of traffic safety [13, 14]. Speed limits in this analysis were classified into three levels. The minimum design speed on-road selected is 40 km/h, the 85th percentile operating speed is 60 km/h and the maximum design speed is 100 km/h. The speed data were collected for all types of vehicles in the traffic stream under free-flow conditions. The sight distance calculations are calculated for all three speed limits.

The side friction factor (f) (

Table **1**) also depends on the vehicle's speed [5]. Gravitational acceleration (g) value is taken 9.8 m/s^2 in calculations. Aerodynamic resistance (R_a) on standard air condition depends on the speed of the vehicle. The roadway grade values are computed based on GIS measurement for different stations as summarized in Table 4.

Table 4. *Calculated Stopping Sight Distances (SSD) on Tepelenë-Gjirokastër Road Stations*

Stations	AD (m)	Roadway Grade	V (km/h)	SSD (m)
From 3 + 400 to 3 + 500	100	+0.005	40	43
			60	81
			100	**223**
5+020 to 5+090	70	+0.10	40	39
			60	73
			100	**181**
5+100 to 5+250	150	-0.026	40	41
			60	79
			100	**212**
5+290 to 5+440	150	+0.027	40	43
			60	79
			100	**211**
5+550 to 5+630	130	+0.030	40	43
			60	78
			100	**209**
5+640 to 5+770	130	+0.006	40	42
			60	81
			100	**222**
6+179 to 6+290	111	-0.049	40	44
			60	88
			100	**265**
6+290 to 6+360	70	+0.086	40	40
			60	74
			100	**186**
7+129 to 7+240	111	-0.018	40	43
			60	84
			100	**239**
7+270 to 7+460	190	-0.021	40	43
			60	84
			100	**241**
7 +720 to 7+880	160	+0.150	40	38
			60	70
			100	**167**
8 +320 to 8+430	111	+0.045	40	41
			60	77
			100	**202**
12+680 to 12+800	120	+0.042	40	41
			60	77
			100	**204**
12+800 to 12+940	140	-0.050	40	44
			60	88
			100	**266**
25+580 to 25+650	70	+0.188	40	39
			60	71
			100	**176**

Table 5. *Calculated Passing Sight Distances (D_p) Based on Speed Vehicle*

Vehicle speed (km/h)	Passing sight distance (Dp)
40	220
60	475
100	625

As shown in Table 4, the driver's speed should not be higher than 60 km/h. The computed stopping sight distance for maximum speed value does not meet the current requirements. Stopping sight distances are appropriate for 40 km/h speeds but not for 60 km/h and 100 km/h in the current upgraded manual. Furthermore, as presented in the Table 5, passing sight distance does not meet the criteria for all speed variations. The results show that the roadway is exposed to the risk of a vehicle accident for 60 km/h and 100 km/h speed vehicle [5, 6, 15]. However, no relationship between the length or proportion of sight distance and accidents could quantifiably predict the impact of infrastructure decisions on safety [1, 16]. For this reason, 60 km/h of maximum speed and no-overtaking highway traffic sign set-up is recommended. These speed control signs have been placed on some stations of this road as shown in Figure 4.

Figure 4. *Speed Control Sign Photo*

Conclusions

For the safety of highway operations according to AASHTO and upgrading Albanian standards, the designer must provide sight distances of sufficient length along the highway to avoid collision with other vehicles and objects that conflict with their path. In this perspective, the main conclusions arising from the sight design requirements of Tepelenë-Gjirokastër road analysis are:

When the driver travels with a minimum design speed of 40 km/h operating, the stopping sight distance criterion meets the standard. Higher speeds of over 60 km/h do not complete functional requirements for stopping sight distance and do not meet the upgraded standard. Sites with lower posted speed limits have been placed and are necessary.

As shown in the case study analysis, the passing sight distance values do not meet the current road design requirements. Set up of no-overtaking highway traffic signs is necessary in order to increase the safety on the roadway. The study results show insufficient sight distance and limited forward visibility of old Albanian roads.

Based on the study analysis, the needs of sight distance improvements should be successfully integrated to allow drivers to safely control their vehicles, according to upgraded standards of Albanian highway geometric design. If sight distance cannot be significantly improved, speed management or traffic control and/or driver warning signs may be considered along the appropriate locations in the roadway. Future policies on safety investments should be specific on current geometric design, well-targeted to maximize the benefit in safety improvement, and would be necessary to investigate crash risks associated with highway geometric design.

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