Challenges of Road Design in Areas with Complex Topography

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Abstract

The geometric design of a road is made up of various elements that define the route of a vehicle and its interaction with the road, directly influencing fundamental aspects such as safety, speed, economy and traffic comfort. Its correct planning is essential to guarantee the functionality and operability of the road infrastructure.

This study performs a comparative analysis of the geometric design of the El Encano – Santiago road, contrasting it with the guidelines established in the geometric road design manuals issued by the National Institute of Roads (INVIAS) in 1998 and 2008. To this end, determining parameters such as horizontal and vertical alignment, visibility distances, design speed, cant transition and cross-section were evaluated, in order to identify the degree of regulatory compliance and possible deficiencies in the current design.

This study does not constitute a new design of the road, but a detailed analysis of its geometric composition, with the purpose of detecting inconsistencies and evaluating their impact on the safety and efficiency of vehicular traffic. From the analysis of the different parameters and their comparison with the regulatory standards, elements that do not comply with the established requirements were identified, which could generate operational and safety problems for road users.

The results obtained are presented through a systematic approach that includes a theoretical basis extracted from the INV-1998 and INV-2008 Geometric Road Design Manual, a rigorous methodological development and a quantitative analysis of the elements evaluated. Finally, conclusions and recommendations are established aimed at optimising the geometric design, prioritising the safety and efficiency of the road to improve mobility conditions and reduce the risks associated with its use.

Keywords: Geometric design of roads, Road infrastructure, Road safety, INVIAS Regulations, Comparative analysis.

Roads play a fundamental role in the economic and social development of regions, as they facilitate the mobility of people and goods, promote interregional connectivity and contribute to the productive growth of communities. Poor road infrastructure can lead to isolation, limit opportunities for trade and affect the quality of life of the population. In this context, the geometric design of roads is an essential component to guarantee the safety, efficiency and sustainability of vehicular traffic.

The geometric design of a road comprises a set of technical elements that determine its functionality, including horizontal and vertical alignment, visibility distances, design speed, cross-section, and cant. The proper application of these parameters makes it possible to optimize the operating conditions of the road, reducing the risk of accidents and improving the user experience. In Colombia, the National Institute of Roads (INVIAS) has established specific regulations for the geometric design of roads, embodied in its manuals of 1998 and 2008, with the purpose of standardizing planning criteria and guaranteeing road safety in the different categories of roads in the country.

In this study, a comparative analysis of the geometric design of the section between El Encano (department of Nariño) and Santiago (department of Putumayo) is carried out, with the aim of evaluating its degree of compliance with the standards established in the current manuals of INVIAS. To this end, the main geometric design controls are analysed, identifying possible deficiencies that may compromise the operability and safety of the road.

The section under study is of great importance for regional connectivity, however, it presents topographical and geometric characteristics that could represent challenges in terms of safe and efficient transit. Through a methodological approach based on the analysis of geometric parameters and their comparison with the established regulations, this study seeks to offer a detailed technical diagnosis of the current state of the road and propose recommendations aimed at its optimization.

The article is structured in several sections. First, the theoretical framework is presented, where the principles of geometric road design and the applicable regulations are addressed. Subsequently, the methodology used for data collection and analysis is described. The results and discussion are presented below, with a comparative approach between the existing design and the technical standards of INVIAS. Finally, the conclusions and recommendations are presented, highlighting the opportunities for improvement in the geometric design of the section under study and its impact on regional mobility.

Objective

To evaluate compliance with the parameters of the geometric design of the El Encano – Santiago road in relation to the INVIAS 2008 regulations, identifying its main deficiencies and proposing improvements in horizontal alignment, visibility and cross-section to optimize road safety.

Methodology

This study is developed under an analytical and comparative approach, using geometric design evaluation tools to determine the degree of compliance of the El Encano – Santiago road in relation to the current regulations of the INVIAS 2008 Geometric Road Design Manual. The methodology is structured in four main phases:

3.1 Data collection and processing

- Detailed information on the route of the track was collected, including its geometric characteristics, such as horizontal and vertical alignment, visibility distances and cross section.
- Plans, topographic profiles, and field measurements were analyzed when necessary.
- References were taken from the standards established in the INVIAS 2008 regulations to establish the comparison criteria.

3.2 Evaluation of geometric parameters

- Horizontal alignment: The continuity and conformity of the curves, minimum radii and intertangencies with current regulations were verified.
- Visibility distance: Visibility in plan and profile was evaluated to determine if it allows safe maneuvers, especially in overtaking and emergency stops.

• Cross section: The width of the road, the distribution of lanes and the cant were reviewed, comparing these values with the minimum requirements of INVIAS.

3.3 Comparative analysis with the INVIAS 2008 regulations

• The results obtained in the geometric evaluation were contrasted with the minimum and maximum parameters allowed in the INVIAS regulations.

• Deficiencies in the design were identified, pointing out the critical points that could represent risks to road safety.

• Compliance percentage values were established to determine which elements of the road do or do not meet the established standards.

4. Proposal of improvements and recommendations

• Based on the findings of the comparative analysis, recommendations were made focused on the optimization of the geometric layout, proposing adjustments in the elements that do not comply with the regulations.

• Mitigation strategies were considered to improve visibility, safety in sharp curves and cross-sectional adequacy.

Results

4.1 Comparative analysis of the geometric design of the Encano - Santiago highway referenced to the 2008 manual – main road of one carriageway

4.1.1 Controls for geometric design.

The El Encano – Santiago road has a length of 27791.60 m, the geometric design of this road is divided into 3 sectors. Initially it goes from PR23+246.92 to PR32+577.92, the second sector is between PR36+469.87 to PR40+477.07 and finally there is the PR40+654.38 to PR51+038.52. From the abscissa 32+577.92 to 36+469.87 there is no geometric design which is why it is not analyzed, on the other hand the sectors mentioned will be worked as homogeneous sections.

Design Speed

"The design speed of a homogeneous section (VTR) is defined according to the category of the road and the type of terrain.

Table 1. Homogeneous Sections Design Speed (VTR) values based on road category and terrain type

CATEGORY OF THE ROAD	TYPE OF TERRAIN	DESIGN SPEED OF A SPAN HOMOGÉNEO VTR (Km/h)									
		20	30	40	50	60	70	80	90	100	110
Two-carriageway primary	Flat										
	Wavy										
	Mountainous										
	Steep										
Primary of a roadway	Flat										
	Wavy										
	Mountainous										
	Steep										
High school	Flat										
	Wavy										
	Mountainous										
	Steep										
Tertiary	Flat										
	Wavy										
	Mountainous										
	Steep										

From the above table, it is identified that for a main road of one carriageway and with mountainous to steep terrain, the speed of the corresponding homogeneous VTR section is 60Km/h. When comparing this value with the speed equal to 30Km/h with which the road was designed, a discrepancy is noticed, that is, the speed used in the design by INESCO S.A. does not conform to the requirements of the geometric design manual for roads of 2008.

Due to the above, a double analysis was carried out taking into account a minimum theoretical VTR of 60 km/h and a VTR of 30 km/h speed with which the road was designed and thus be able to carry out the comparative analysis between the two versions of the regulations.

However, the analysis for a VTR of 30km/h was performed, therefore, the present analysis is performed for a theoretical minimum VTR of 60km/h.

As for the minimum section length of 4000 meters for a speed between

60 and 110 Km/h it is evident that the three homogeneous sections proposed satisfy this condition.

Visibility Distance

The visibility distances that must be considered in the geometric design of a road under the INVIAS – 2008 regulations are: stopping visibility distance (Dp), overtaking visibility distance (Da) and crossing visibility distance (Dc). This project includes the analysis of the first two because they are a main road with two lanes of traffic in different directions. The Dc will not be analyzed because the present work does not include the study of intersections.

Stop visibility distance (Dp)

Minimum length of the convex vertical curve according to safety criteria

The analysis consists of calculating the minimum theoretical Dp associated with the perception-reaction distance and the braking distance and comparing it with the existing Dp. If the latter turns out to be at least equal to the theoretical Dp, the vertical curve complies with this parameter. On the contrary, it is said that this curve does not have sufficient stopping visibility distance and therefore it is a sector that goes against the safety of the user who travels on this road.

As for the 1998 regulations, this parameter is only evaluated in convex vertical curves, since these by their very shape of inflection represent the critical situation for the user to stop safely in the face of an obstacle.

Overtaking Visibility Distance (Da)

Table 2 presents the minimum recommended values for the overtaking visibility distance (Da), calculated for two-lane, two-way roads.

Table 2 Minimum overtaking visibility distance for two-lane, two-way roads

SPECIFIC SPEED OF THE HORIZONTAL INTERTANGENCY AT WHICH THE VETH MANOEUVRE IS PERFORMED (Km/h)	OVERTAKEN VEHICLE SPEED (Km/h)	VEHICLE SPEED OVERTAKING, V (Km/h)	MINIMUM VISIBILITY DISTANCE OF OVERTAKING DA (m)	
			CALCULATED	ROUNDED
20	-	-	130	130
30	29	44	200	200
40	36	51	266	270
50	44	59	341	345
60	51	66	407	410
70	59	74	482	485
80	65	80	538	540
90	73	88	613	615
100	79	94	670	670

110	85	100	727	730
120	90	105	774	775
130	94	109	812	815

Efforts should be made to obtain the maximum possible length in which the overtaking visibility is higher than the minimum in the table above. Therefore, as a design standard, it must be designed, for two-lane two-way roads, sections with an overtaking visibility distance, so that in sections of five kilometers, there are several subsections of distance greater than the minimum specified, according to the speed of the element in which it is applied."

In accordance with the above, for the road under study considering a VTR = 60 Km/h, for the straight section to have sufficient distance in which the overtaking maneuver can be carried out safely, it must be at least 410 m.

After carrying out the analysis of the Da in all the horizontal intertangencies that make up this road, it was found that none of them has a sufficient distance to carry out this maneuver. Therefore, this road has 0.0 % of Da for a VTR = 60 km/h.

Assessing visibility on drawings

A. Evaluation and presentation of on-site visibility

For the evaluation of the visibility distance of the stop in the plant read on plans, the regulations issued by INVIAS in 2008 modify some values with respect to that of 1998 such as the height of the driver's eyes and the height of the object that the driver must see, but the average of the two is maintained, which is 0.65 meters. Therefore, the analysis of this aspect regardless of the manual version used yields the same values with respect to lateral obstructions (slopes) that limit visibility.

Therefore, this analysis was not carried out for the 2008 regulations since it would result in what was obtained when doing the study with the 1998 manual.

B. Assessing profile visibility

This analysis for vertical curves whose inflection shape is of the convex type has already been carried out and turns out to be more accurate because it is a mathematical process.

4.1.2 Plan design of the axis of the Horizontal Curves road. As already mentioned, this project includes the study of 505 horizontal curves, of which most are simple circular and only 6 have spiral type joints.

Minimum bend radius (RCmin)

Table 3 shows the minimum radius values for different Specific Velocities (VCH) according to the maximum superelevation (emax) and maximum friction (fTmax).

Table 3. Minimum radii for maximum emmax cant = 8% and maximum friction

Velocity Specifies VCH (Km/h)	Camber Maximum (%) and max	Coefficient of Fricción Transversal f tmax	Total e max+ f tmax	Minimum radius R (m)	
				Calculated	Rounded
40	8.0	0.23	0.31	40.6	41
50	8.0	0.19	0.27	72.9	73
60	8.0	0.17	0.25	113.4	113
70	8.0	0.15	0.23	167.8	168
80	8.0	0.14	0.22	229.1	229
90	8.0	0.13	0.21	303.7	304
100	8.0	0.12	0.20	393.7	394
110	8.0	0.11	0.19	501.5	501
120	8.0	0.09	0.17	667.0	667
130	8.0	0.08	0.16	831.7	832

Therefore, the minimum radius analysis was carried out for a minimum speed for the road conditions with the regulations of the year 2008 VTR=60 km/h considering as a limit value 113m

The following is the way to analyze the minimum radius for a VTR = 60 Km/h.

Table 4. Analysis of minimum radii for VTR of 60 km/h

PI No.	Type of splice	Radio Existing (m)	RExistente≥Rmín; Rmin = 113m
129	Circular	18.47	NOT COMPLIANT
130	Circular	25.36	NOT COMPLIANT
131	Circular	39.04	NOT COMPLIANT
132	Circular	14.93	NOT COMPLIANT
133	Circular	185.06	MEETS

After the study of the minimum radius in the 505 horizontal curves that make up the geometric design of this road, it was determined that for a homogeneous section speed VTR = 60 km/h, 471 (93.27%) curves have a radius of less than 113 meters.

Minimum and maximum length of the spiral

The study of the minimum and maximum length of the 6 spirals that are in this project for a VTR of 60 Km/h is presented below. (See table 5)

Table 5. Analysis of minimum and maximum length of spirals for a VTR = 60km/h

PI No.	Splice Type	Superelevation e% (Design)	Radio R (m)	Le Existing (m)	Criterio I A min (m)	Criterio II A min (m)	Criterio III1 A min (m)	Criterio III2 A min (m)	Top Envelope A min (m)	A max (m)	Min (m)	Max (m)	Lemin≤El≤ Lemax Check
8	E-C-E Yes	8.0	70.04	25.50	72.85	56.14	37.89	22.66	72.85	77.04	75.77	84.74	NOT COMPLIANT
9	E-C-E Yes	5.0	39.42	15.55	78.45	33.30	24.62	12.76	78.45	43.36	156.11	47.70	NOT COMPLIANT
11	E-C-E Asim	8.0	47.00	19.00	75.74	45.99	28.09	15.21	75.74	51.70	122.05	56.87	NOT COMPLIANT
				12.00	75.74	45.99	28.09	15.21	75.74	51.70	122.05	56.87	NOT COMPLIANT
12	E-C-E Yes	8.0	20.07	14.00	78.99	30.05	14.84	6.49	78.99	22.07	310.93	24.28	NOT COMPLIANT
15	E-C-E Yes	7.0	11.00	10.00	80.21	20.81	9.45	3.56	80.21	12.10	584.92	13.31	NOT COMPLIANT
30	E-C-E Yes	4.0	21.89	20.00	80.06	22.19	15.84	7.08	80.06	24.08	292.82	26.49	NOT COMPLIANT

For a VTR = 60km/h, of the 6 horizontal curves with spiral type junction present on this road, none meets the minimum spiral length.

Road overwidth

The road overwidth is a very important parameter that provides safety to the user when traveling on a curved section of the road, this because it gives him a margin of travel space in case of emergency, the INV – 2008 manual presents us with two situations under which the overwidth is calculated: the first for rigid vehicles whose analysis is similar to that already carried out by the INV – 1998 manual and the second for articulated vehicles.

For the analysis of the overwidth, those values greater than or equal to 0.6 m that are constructively adequate and should be applied only on the inner edge of the roadway were taken into account, otherwise the analysis DOES NOT APPLY.

Table 6. Analysis of articulated vehicle overwidth for a VTR = 30km/h

PI No.	Splice Type	Radio Rc (m)	VCH (Km/h)	Ancho AT (m)	No. Lanes n	In the (m)	C (m)	AGO (m)	With (m)	AC Width (m)	Minimum overwidth calculated (m)	Existing overwidth (m)	Existing ≥ Calculated
6	Circular	69.64	30.00	7.30	2.00	2.94	0.93	0.11	0.07	7.92	0.62	0.00	NOT COMPLIANT
5	Circular	609.19	30.00	7.30	2.00	2.63	0.93	0.01	0.02	7.15	0.00	0.00	NOT APPLICABLE
4	Circular	39.57	30.00	7.30	2.00	3.22	0.93	0.20	0.09	8.57	1.27	0.00	NOT COMPLIANT
3	Circular	43.92	30.00	7.30	2.00	3.15	0.93	0.18	0.08	8.42	1.12	0.00	NOT COMPLIANT
2	Circular	88.83	30.00	7.30	2.00	2.87	0.93	0.09	0.06	7.73	0.43	0.00	NOT APPLICABLE
1	Circular	117.54	30.00	7.30	2.00	2.80	0.93	0.07	0.05	7.57	0.27	0.00	NOT APPLICABLE

From the geometric design of the road under study, it was determined that none of the horizontal curves has an overwidth. In addition, for VTR = 60 Km/h, 49 are curves that constructively are not feasible to overwidth and the remaining 456 do not comply with a minimum overwidth of 0.6 m, equivalent to 90.30% of the total curves analyzed.

Visibility in horizontal curves

From the geometric analysis of the M arrow, visibility in horizontal curves can be evaluated, hence the importance of this parameter with respect to safety to travel through a curved sector, the present analysis is not carried out because the results are those already obtained through the INV Manual – 1998, since the theoretical support does not present variation, moreover, the calculation is not a function of speed.

Spiral curves

The section of road to be analyzed has a total of 505 horizontal curves, of which 6 have a spiral junction and the rest are circular.

Superelevation transition

Due to the scarcity of information regarding the cambering transition, the analysis of this parameter is performed only for the section between the abscissas PR36 + 469.87 to PR 40 + 477.07.

The methodology used to carry out the analysis of this parameter is presented below; for which curves with radii less than 113 m will not be analyzed because they are associated with speeds below 60 km/h.

For those curves whose analysis DOES NOT APPLY, it is due to a lack of information regarding the cambering transition or because the value of the radius is below the minimum limit already analyzed in the parameter absolute minimum radii.

Table 7. Maximum cant analysis for VTR=60 km/h

PI No.	Splice Type	Specific Speed Horizontal Curve VCH (Km/h)	Radio R (m)	Peralte e% (Theoretical)	Superelevation e% (Design)	Checkup
2	Circular	60.00	70.02	-16.60	3.00	NOT COMPLIANT
3	Circular	60.00	181.32	-16.84	2.00	NOT COMPLIANT
4	Circular	60.00	55.00	-16.48	8.00	NOT COMPLIANT

5	Circular	60.00	30.00	-16.06	**	NOT APPLICABLE

As can be seen in the previous table (for VTR = 60 Km/h) all the curves analyzed (100%) have an inadequate cant according to what is stated in the INV – 2008 manual.

Superelevation transition

Since the theoretical basis for the superelevation transition parameter does not change with respect to the INV-1998 manual, the results are the same, and they were taken as representative for the current study.

Cant ramp

Because the theoretical basis for the superelevation transition parameter does not present changes with respect to the INV – 1998 manual, the results were the same, it should also be taken into account that the present analysis is not a function of speed, therefore, the results are the same as previously stated and they will be taken as representative for the current study.

Horizontal intertangency

The study of this parameter, indicating an analysis table for some intertangencies, is presented below:

Table 8. Analysis Maximum and minimum horizontal intertangency VTR=60 km/h

Abscissa End	**Type of curves Adjacent**	**Adjacent curves "In the same sense"**	**Vd (km/h)**	**Entretangencia Minimum theoretical**	**Entretangencia Maximum theoretical**	**Observation**
PR 40 + 686.70	Circular	NO	60	83.3	900.00	NOT COMPLIANT
PR 40 + 736.07	Circular	NO	60	83.3	900.00	NOT COMPLIANT
PR 40 + 806.77	Circular	NO	60	83.3	900.00	NOT COMPLIANT
PR 40 + 887.70	Circular	NO	60	83.3	900.00	NOT COMPLIANT
PR 40 + 940.81	Circular	NO	60	83.3	900.00	NOT COMPLIANT

As a result of the present analysis, it was found that most of the entretangencias do not exceed the minimum value. Of a total of 501 horizontal intertangencies that constitute this project, only 7 (1.40%) of them meet the minimum and maximum conditions.

4.1.3 Vertical design pending. The values of the maximum allowable slope are indicated, which depends on the category of the road and the Specific Speed of the vertical tangent (VTV).

Table 9. Ratio of Maximum Slope (%) to Vertical Tangent Specific Velocity (VTV)

CATEGORY OF ROAD	SPECIFIC SPEED OF THE VERTICAL TANGENT VTV (Km/h)											
	20	30	40	50	60	70	80	90	100	110	120	130
Two-carriageway primary	-	-	-	-	-	6	6	6	5	5	4	4
Primary of a roadway	-	-	-	-	8	7	6	6	5	5	5	-
High school	-	-	10	9	8	7	6	6	6	-	-	-
Tertiary	14	12	10	10	10	-	-	-	-	-	-	-

Next, the analysis process is presented in terms of "Maximum and Minimum Slope of vertical alignments" as follows:

For VTR of 60 km/h, the minimum recommended slope is 0.5%.

Based on table 110, we have: for VTR of 60 km/h, the associated vertical curve speeds (VCV) are also 60 km/h and taking into account the category of the road as the main one on a road, the maximum slope is 8%, a value that is taken as a reference for study and analysis.

However, the reference values obtained as maximum and minimum slope values are similar to those obtained considering the road as secondary for the 2008 Geometric Design of Roads Manual.

Maximum length

The analysis process for the parameter under study is indicated below:

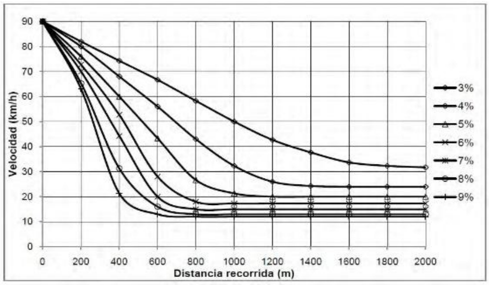

Figure 1. Effect of slopes on vehicles with a weight-to-power ratio of 180 kg/HP

Table 10. Analysis of Critical Length VTR = 60 km/h

Entretangencia vertical No.	Existing Pte (%)	L Existing (m)	Critical Length of Slope (m)	Checkup Existing L ≤ Lc
1	-1.350	11.67	>1200	OK
2	8.420	75.52	210	OK
3	-0.090	5.79	>1200	OK
4	6.840	11.72	280	OK
5	-4.750	13.81	>1200	OK

The geometric design in the profile of the Encano – Santiago highway with a total of 324 vertical intertangencies for VTR = 60 Km/h, 0 (0.00%) have a length greater than the critical slope, determining that the design is adequate with respect to this parameter according to specifications issued by INVIAS.

4.1.4 Cross-section. Zone width or right-of-way.

The analysis is equivalent to that already carried out through the INV-98 Manual, this because the theoretical support does not present variation with respect to the manual used in the current study and analysis, however, as stated it is not possible to analyze this parameter, because the information of the width of the area or right of way is not registered in the plans of this highway. However, it is known that the width of the road corresponds to 15m from its axis, although in sectors where there are houses next to the road there is no such width.

Transverse slope in horizontal intertangencies

Table 11 shows the corresponding values

Table 11. Roadway pumping

Type of Running Surface	Pumping (%)
Surface in hydraulic or asphalt concrete	2
Surface treatments	2-3
Surface of land or gravel	2-4

Based in a general way on the data in the table presented above, it can be said that it is appropriate to take a minimum pumping value equal to 2% (a very frequent value in geometric design projects); and comparing with the cambering transition diagrams for the section that presents it (PR36 + 469.87 to PR 40 +

477.07), it can be said that this parameter is totally adequate (100% complied with).

Conclusions

This study has allowed a comparative analysis of the geometric design of the El Encano - Santiago road based on the regulations established in the Manuals of Geometric Design of Roads of INVIAS (1998 and 2008). From the evaluation of the fundamental geometric parameters, critical aspects that affect road safety and road operability were identified.

The results showed that the geometric design of the road is partially compliant in some aspects, but also reveals significant deficiencies in others, especially in relation to horizontal and vertical alignment, visibility distances and cross-section.

In terms of design speed, it was found that the value adopted in the design (30 km/h) is consistent with current regulations, since it corresponds to the secondary category of the road and the topography of the terrain. However, the evaluation of the stopping visibility distance revealed that 74 horizontal curves (14.65%) do not meet the minimum required values, which represents a risk to the safety of drivers, especially in emergency situations or sudden braking.

On the other hand, the analysis of the overtaking visibility distance determined that the road does not have sufficient subsections to carry out safe overtaking maneuvers, since the percentage of compliance is 7%, when what is required is at least 20% of the total length of the road. This deficiency increases the risk of accidents, especially on a road with a high flow of heavy vehicles and adverse geometric conditions.

Horizontal alignment features several elements that require adjustments. In particular, 194 of 505 curves (38.42%) have a radius lower than the absolute minimum allowed (30 m), which affects traffic safety and comfort. In addition, it was determined that none of the curves analyzed has the minimum overwidth necessary to guarantee adequate performance of the vehicle on the track, which can generate instability when performing maneuvers in sharp curves.

Regarding the vertical alignment, it was evident that several vertical curves have insufficient lengths, which affects the visibility and smoothness of the route. In addition, slopes higher than the values recommended by the regulations were found, which can represent difficulties for the transit of heavy vehicles and affect the stability of vehicles in adverse weather conditions.

Regarding the cross-section, it was identified that the width of the roadway complies with the standards established in the regulations, which is a favorable point of the design. However, the berms are inadequately dimensioned, which reduces the safety margin for drivers and limits the space available for emergency maneuvers or controlled stops.

Another important finding is that the cant transition is not correctly designed in multiple curves, which can generate negative effects on the stability of vehicles when traveling through these sections. The cant ramp, in several cases, has values that are very high or lower than the recommended ranges, which can cause slippage or loss of grip in high-speed conditions or wet pavement.

Given the impact that these deficiencies can have on road safety and the operational efficiency of the road, the implementation of corrective measures in the most critical sectors of the route is recommended. Some of the proposed solutions include:

- Improve horizontal alignment, increasing the radii of curvature in the sections that have values below the minimum allowed.
- Implement adequate overwidths in sharp curves to improve traffic stability and safety.
- Optimise the visibility distance for stopping and overtaking, through interventions in the geometry of the route and the elimination of visual obstacles.

• Adjust slopes and improve cant transition to ensure that the geometric design meets road safety and comfort parameters.

• Widen and standardize the berms in the sections where there are deficiencies, ensuring a safe space for emergency maneuvers.

In conclusion, although the geometric design of the El Encano - Santiago road complies with some regulatory parameters, it has multiple deficiencies that affect its safety and functionality. The implementation of improvements in the layout is essential to guarantee a safer, more efficient road in accordance with current road standards.

Recommendations

• Carry out an exhaustive study and provide adequate overtaking distances, because they have high percentages of elements that do not comply with this parameter, which can become a severe accident factor when traveling on the road.

• Review the parameter of absolute minimum radii, since it is not met in a considerable percentage for the sector under study, due to the importance of this, with respect to the accident rate, these sectors of the road being the most critical when traveled by the user.

• Correct the overwidth of the roadway, taking into account that it is one of the parameters that provides a margin of safety to the user when traveling on the road, however, for the sector under study it is not complied with in the entire section analyzed, being a critical factor.

• Make corrections to provide a road in better conditions because the transition from cant to curve can be a direct factor at a technical level of the accident rate when the user travels on the road, presenting a danger of slipping or overturning.

• Carrying out modifications where intertangent lengths are not adequately complied with, because the capacity and level of the road are limited since the user when traveling on the road adopts behavior patterns according to the conditions that are presented.

• Build a third lane for heavy cargo vehicles to circulate on it (lane for slow traffic), in sectors where there are critical slope lengths.

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