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Analysis of Road Geometrics on Curves (Case Study: Cisumdawu Toll Road KM 202 - KM 208)

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A B S T R A C T

Road safety is an important issue in land transportation, with the number of accidents in Indonesia increasing as the number of roads and vehicles increases. This study aims to evaluate the suitability of the geometric design of bends on the Cisumdawu Toll Road at KM 202-208 with the latest standards that can accommodate the safety and comfort aspects of road users. The bend design generally refers to the old standard and is not fully compliant with Road Geometric Design Guidelines (PDGJ 2021). There are significant differences between existing data and idealized calculations, especially in vehicle comfort. Therefore, design improvements, such as spiral and superelevation lengths, as well as safety facilities, are highly recommended to optimize road geometric performance and improve the safety of toll road users.

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INTRODUCTION

Road safety is one of the main issues in land transportation that continues to be of concern to various parties, including the government, academics, and the public.The case of accidents in Indonesia tends to increase with the addition of roads and the number of vehicle movements (DataIndonesia.id, 2023). In general, the causes of traffic safety are divided into three main factors, namely human factors (human error), vehicle factors, and road environmental factors (Artiani, 2016), In this case, one important aspect that needs to be considered in the aspect of road safety is road geometric planning, especially in the bend area.

Bend is part of the horizontal alignment of the road in the form of a curve, functioning to change the direction of the vehicle gradually within the limits of comfort and safety of road users (Directorate General of Highways, 2021). Many accidents occur in the bend area, especially on high-speed highways. Unqualified geometric design (on existing roads) has the potential to cause accidents, such as bends that are too sharp, unqualified pavement conditions (surfaces that are too slippery) contribute to causing accidents (Artiani, 2016). For example in Ethiopia (Mettu-Gore Road), the cause of accidents is because horizontal bends and sharp vertical curves limit the driver's visibility (Mulugeta Tola and Gebissa, 2019).

Road geometric planning is part of the road planning, which focuses on planning the form itself to fulfill the basic function of the road, which is to provide services to the movement of traffic flow (vehicles) optimally. While the goal of road geometric planning is to produce a plan or design of highway infrastructure that is safe, efficient in the service of traffic flow and maximize the ratio of the level of use / cost of implementation (Sukirman n.d.). This planning must consider various aspects such as design speed, bend radius, superelevation, lane width, and visibility, in order to be able to serve the traffic flow optimally (Oktania et al. 2025)), (Jima and Sipos 2022.

Roads are one type of land transportation that connects regions and helps improve the economy and living conditions of the community. Road infrastructure is the most important issue to consider, especially in terms of mobility. A good, safe, and smooth road infrastructure service is possible if it meets the technical criteria of route geometry (Dhaniarti Raharjo, 2022). In the context of Indonesia, toll roads as strategic infrastructure have a major role in improving inter-regional connectivity and supporting economic growth. However, toll roads also demand high safety standards due to the greater speed of vehicles compared to ordinary roads (Government of the Republic of Indonesia, 2009).

The Cileunyi-Sumedang-Dawuan (Cisumdawu) Toll Road is one of the national strategic projects that aims to improve connectivity between Bandung and Kertajati International Airport. With a total length of more than 61.6 km, there are 6 sections on the Cisumdawu toll road Section I: Cileunyi-Tanjungsari (11.45 km), Section II: Tanjungsari-Sumedang (17.05 km), Section III: Sumedang-Cimalaka (4.05 km), Section IV: Cimalaka-Legok (8.20 km), Section V: Legok-Ujungjaya (14.90 km), Section VI: Ujungjaya-Kertajati (6.065 km) and passing through hilly areas, this toll road has many sharp bend segments (Kompas.com, 2003.). Analysis of the geometric shape of the bends is crucial, given that the highway is traversed by fast-moving vehicles. Inappropriate bend design can reduce driving comfort and increase the risk of accidents, especially on sections with significant height and curvature.

From the description above, it is the background that the author feels interested in conducting road geometric research with bends focused on KM 202 - 208 which includes areas with hilly topography and many road bends. Based on the geometric report document by PT Yodya Karya (2021).

LITERATURE REVIEW

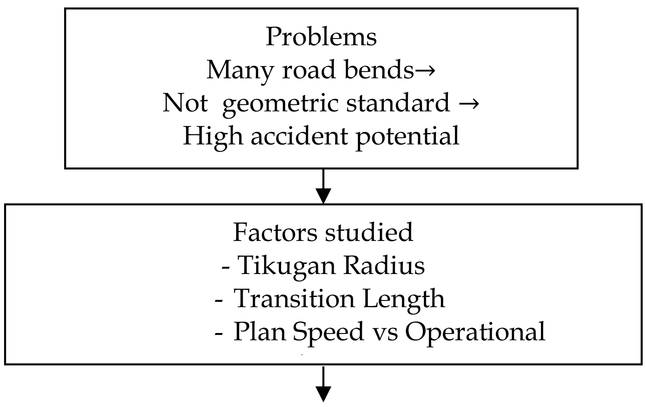
Research on the planning and analysis of toll road geometrics has been carried out by many previous researchers. Most of these studies focus on the initial planning stage of toll roads and interchanges, with approaches based on Bina Marga, AASHTO standards, and some studies utilize AutoCAD Civil 3D software.

Research by Ilham Rizky Darmawan and Giri Danuarto (No. 1 & 4), for example, focuses on geometric planning and rigid pavement on the Probolinggo-Banyuwangi Toll Road. The result is a proposed new road geometric design based on old standards. Meanwhile, Wisnu Hardian Pradito (No. 3) and Muhammad Bergas Wicaksono (No. 5 & 15) compiled geometric and flexible pavement planning for the Pandaan-Malang and Malang-Kepanjen toll roads. Their main focus was on adjusting the alignment to the local topography and soil structure.

Some studies such as Achmad Pahrul Rodji's (Nos. 2 & 6 & 19) examine the geometric analysis of roads and interchanges, especially in urban areas such as Jakarta and Bekasi. These studies are more concerned with the need to adjust ramp bends and interchanges to traffic density.

Research by Tri Tjahjono (Nos. 14 & 18) used a statistical approach to assess the relationship between geometric variables and crash risk. This is an important reference that road geometrics should not only be viewed from the technical side, but also the real safety in the field.

METHODOLOGY



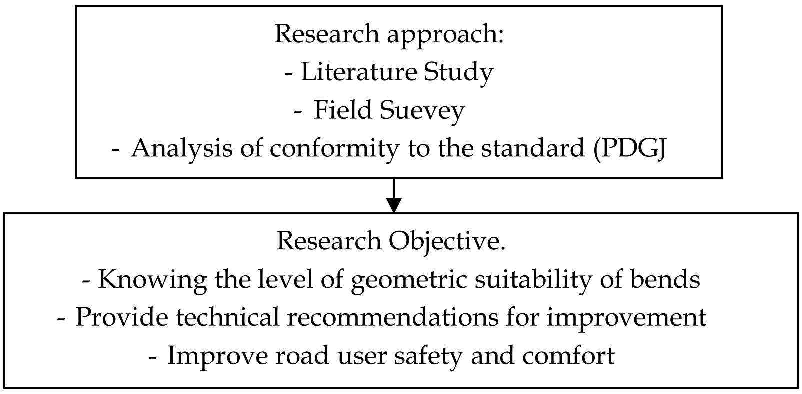


Figure 1. Framework of Thought

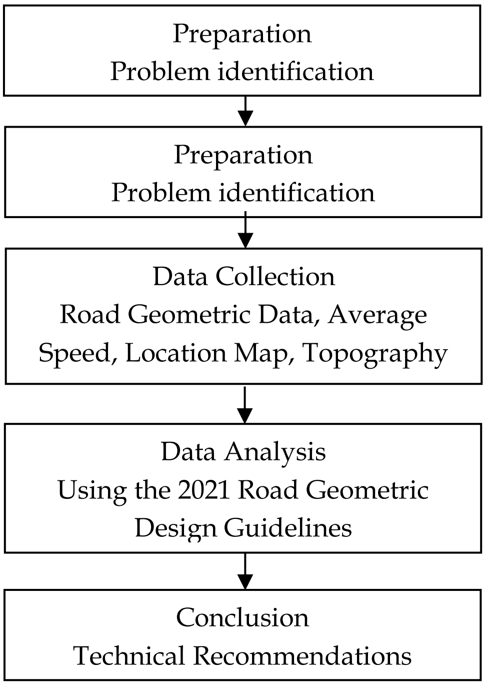


Figure 2. Research Flowchart

This research uses quantitative methods to analyze road geometric design on the level of safety and comfort of road users. This research was conducted on the Cisumdawu Toll Road at KM 202-208 using secondary data in the form of road geometric data, road class functions, average speed and bend location maps. As well as providing recommendations for improvement and design recommendations in accordance with the 2021 Road Geometric Design Guidelines.

RESEARCH RESULTS

To analyze toll road geometrics, several important aspects need to be considered. Design criteria, road trajectory, horizontal and vertical alignment need to be taken into account so as to get improvement recommendations and design recommendations in accordance with the 2021 Road Geometric Design Guidelines.

Design Criteria

The adjustments we make refer to the provisions listed in the 2021 Road Geometric Design Guidelines. Design Criteria Table Secondary data results refer to the guidelines of the Standard *Specifications For Geometric Design of Urban Road,* Department of Public Works Directorate of Highways 1992.

Table 1. Design Criteria

No.	Geometric Parameters	Unit	Proposed Design Criteria
1	Plan Speed	Km/hour	80
2	Traffic Lane Width	m	3.6
	Outer Shoulder Width	m	3
	Inside Shoulder Width	m	1.5
	Median Width	m	2.5
	Normal Transverse Slope of Traffic Lane	%	2
	Normal Transverse Slope of Outer Shoulder	%	4
	Maximum Superelevation	%	8
	Minimum Vertical Free Space Height	m	5.1
	Height of Free Space above Railroad Track	m	6.5
	Air Duct Vertical Clearance Height		
	- 66 kV SUTT	m	8
	- SUTT 150 kV	m	9
	- SUTET 500 kV	m	15
3	Minimum Stop Length	m	110
4	Minimum Bend Radius	m	230
	Minimum recommended Bend radius	m	400
	Minimum Bend Radius with Normal Slope	m	3500
	Minimum Curve Length	m	1000/Θ and or 140
	Minimum Transitional Arch Length	m	70
	Minimum Bend Radius Without Transitional Curve	m	1000
	Maximum Relative Landi	%	8
5	Maximum Landi	%	4
	Vertical Curve Radius		
	- Convex	m	4500
	- Concave	m	3000
	Minimum Length of Vertical Curve	m	70

Road Trace

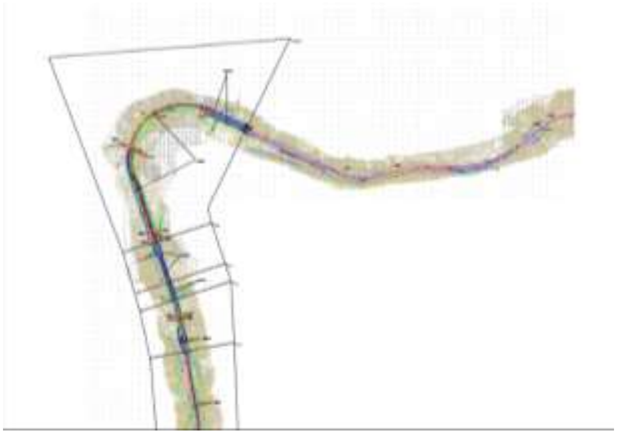


Figure 3. Cisumdawu Toll Road Trace at KM 202-208 Bend P11-P15

This research specifically limits the analysis to the P11 to P15 bend segments on the Cisumdawu Toll Road (KM 202-208). The selection of these segments is based on preliminary findings that indicate potential geometric design discrepancies

Horizontal Alignment

Table 2: Horizontal alignment

NO.P1	PI-01	PI-02	PI-03	PI-04	PI-05
V (Km/h)	80	80	80	80	80
TYPE	S-C-S	S-C-S	F-C	S-C-S	S-C-S
STA					
X	832339.562	835407.574	836192.8	837374.134	838236.68
Y	925.782.144	9254011.063	9254213.262	9254179.686	9254945.479
D	119.997	75.560	91.628	48.400	90.089
R (m)	280	280	315	315	280
Ts/Tc (m)	413.634	390.099	0.025	604.815	340.487
Lc (m)	529.33	494.456	210.23	1.110.696	362.322
Ls (m)	126	126	21	21	147
Ltotal (m)	781.33	746.454	-	1.152.696	362.322
qs (m)	4.813	4.512	-	9.622.383.985	6.016
Es (m)	78.721	65.058	-	113.458	50.399
emax (%)	6	6	6	6	6
Widening	-	-	-	-	-

Point PI-01 has a turning angle of 119.997° and a radius of 280 meters, with a total bend length of 781.33 meters and a spiral superelevation of 78.721 meters. PI-02 has a turning angle of 75.56° and a bend length of 746.456 meters, with a superelevation of 65.058 meters. PI-03 uses the F-C type with a radius of 315 meters and a curve length of 210.23 meters, no transition spiral, and a maximum superelevation of 6%. PI-04 has a turning angle of 48.4° and a total length of 1152.696 meters, with a 21-meter spiral and a high superelevation of 113.458 meters. Finally, PI-05 has a turning angle of 90.089°, a radius of 280 meters, and a bend length of 362.322 meters, with a spiral of 147 meters and a superelevation of 50.399 meters. All points do not require bend widening.

Vertical Alignment

Table 3. Vertical Alignment

DESCRIPTION	**STA PLV**	**PVI 1** STA PVI	**STA PTV**	**STA PLV**	**PVI 2** STA PVI	**STA PTV**	**STA PLV**
Curve Type	-	CEMBUNG	-	-	CEKUNG	-	-
Lvc (m)	-	25.53	-	-	25.53	-	-
K	-	51	-	-	51	-	-
Ev (m)	-	0.064	-	-	0.064	-	-
STA (m)	40745.26	40770.76	40770.79	42109.65	42135.15	42135.18	42568.62
Elevation / Z (m)	460.43	461.193	461.19	421.03	420.261	420.26	422.43

PVI 3 **STA PVI**	**STA PTV**	**STA PLV**	**PVI 4** STA PVI	**STA PTV**	**STA PLV**	**PVI 5** STA PVI	**STA PTV**	**STA PLV**
CEMBUNG	-	-	-	-	-	-	-	-
25.53	-	-	639.42	-	-	2207.84	-	-
51	-	-	51	-	-	51	-	-
0.064	-	-	0.064	-	-	0.064	-	-
42594.12	42594.15	45820.03	45845.525	46459.44	46433.91	46459.412	48641.75	48616.22
422.558	422.56	293.52	292.502	292.50	289.56	289.432	289.43	203.16

PVI 6 **STA PVI**	**STA PTV**	**STA PLV**	**PVI 7** STA PVI	**STA PTV**	**STA PLV**	**PVI 8** STA PVI	**STA PTV**	**STA PLV**	**PVI 9** STA PVI	**STA PTV**
CEKUNG	-	-	CEMBUNG	-	-	CEKUNG	-	-	CEMBUNG	-
563.94	-	-	521.29	-	-	1575.72	-	-	25.53	-
51	-	-	51.00	-	-	51.00	-	-	51.00	-
0.064	-	-	0.06	-	-	0.06	-	-	0.06	-
48641.72	49180.17	51080.16	49180.13	51601.45	51575.92	51105.66	53151.64	53126.11	51601.42	53151.64
202.140	202.14	127.739	203.47	126.72	129.07	126.72	129.20	83.46	129.20	82.70

PVI 1 is a convex curve with a vertical curve length (Lvc) of 25.53 m and a curvature of K = 51, located at STA 40776.79 with an elevation of 461.19 m, experiencing a change from 460.43 m to 461.93 m. PVI 2 is a concave curve with the same parameters, located at STA 42135.15 and elevation 420.26 m, with a change in elevation from 421.03 m to 420.261 m. PVI 3 is also convex curved at STA 42568.62 with an elevation of 422.43 m, and an elevation change from 422.558 m to 422.56 m. PVI 4 is located at STA 639.42 with K = 51 and a change in elevation from 293.52 m to 292.502 m, using the standard parameter Ev = 0.064. PVI 5 has an Lvc of 2207.84 m and a PTV elevation of 289.432 m. PVI 6 is a concave curve with a Lvc of 563.94 m, K = 51, and an elevation change from 203.16 m to 202.14 m. PVI 7 is a convex curve with Lvc 521.29 m, K = 51, and elevation transition from 127.74 m to 126.72 m at STA 49180.13 m. PVI 8 is a concave type with Lvc 1575.72 m, experiencing an elevation transition from 129.07 m to 126.23 m at STA 51575.92 m. Finally, PVI 9 is a short convex curve with Lvc 25.53 m at STA 53105.61 m, showing a sharp elevation change from 129.22 m to 82.70 m.

Bend Comparison P11-P15

Table 4. Comparison of Bend P11-P12

No.	Bend	Parameters	Calculation Result	2021 PDGJ requirements (Vd 80 km/h)	Compatibility
1	PI-01	R (m)	250	≥ 280 m	Not suitable
		Ls (m)	126	≥ 130 m	Nearly Compliant
		Ice (%)	9%	Max 8% (hilly highway)	Not suitable
2	PI-02	R (m)	270	≥ 280 m	Nearly Compliant
		Ls (m)	126	≥ 130 m	Nearly Compliant
		Ice (%)	8%	Max 8%	As per
3	PI-03	R (m)	200	≥ 280 m	Not suitable
		Ls (m)	126	≥ 130 m	Not suitable
		Ice (%)	10%	Max 8%	Not suitable
4	PI-04	R (m)	315	≥ 280 m	As per
		Ls (m)	21	≥ 130 m	Not suitable
		θs(°)	9,622°	Normal 10-20°	Marginal
		Ice (%)	11,3%	Max 8%	Not suitable
5	PI-05	R (m)	280	≥ 280 m	As per
		Ls (m)	147	≥ 130 m	As per
		Ice (%)	7%	Max 8%	As per

Based on the geometric analysis of the five bend segments (PI-01 to PI-05) of the Cisumdawu Toll Road, comparison with the 2021 Road Geometric Design Guidelines shows that the bend radii of PI-01 (250 m), PI-02 (270 m), and PI-03 (200 m) are below the minimum limit of 280 m, increasing the potential danger due to centrifugal force, while PI-04 (315 m) and PI-05 (280 m) meet the standard. The length of the transitional spirals at PI-01, PI-02, and PI-03 is 126 m, almost meeting the minimum requirement of 130 m, while PI-04 is only 21 m and PI-05 is ideal with 147 m. The maximum recommended superelevation is 8%, but PI-01 (9%), PI-03 (10%), and PI-04 (11.3%) exceed the limit, while PI-02 (8%) and PI-05 (7%) comply. The overall evaluation showed that only PI-05 met all parameters, while PI-04 became the most critical segment with a short spiral and high superelevation, and PI-01 to PI-03 had problems with almost all elements.

DISCUSSION

Based on the results of the analysis of the geometrics of bends PI1 to PI5 on the Cisumdawu Toll Road KM 202–208, there are several aspects that need attention in order to improve the quality of road design in terms of safety and user comfort.

The length of the transition spiral (Ls) used, which is 126 meters, is still below the minimum recommended limit in PDGJ 2021, which is 130–140 meters for a plan speed of 80 km/hour. A spiral that is too short has the potential to cause a rapid and sudden transfer of lateral forces, which can impact the stability of the vehicle when entering a curve. This is reinforced by research (Hari et al., 2024) which shows that spiral lengths that do not meet standards can trigger sudden high centrifugal forces, increasing the risk of losing vehicle control.

The superelevation value at the bend has also not reached the maximum allowable limit, which is 8%, as permitted on toll roads with hilly terrain conditions. Non-optimal superelevation, especially on bends with small radii, will reduce the road's ability to balance the centrifugal forces that arise when vehicles turn. Literature from (Setiawan, 2020) states that adequate superelevation is very important to maintain vehicle stability, especially for heavy vehicles traveling at high speeds.

In terms of comfort, the arc length (Lc) of 529.33 meters is considered too long for the bend radius. The duration of the vehicle in the turning condition should not be too long to avoid driver fatigue and disorientation effects. (Tamin, 2015) explains that bends that are too long can create a sense of saturation and disrupt driver focus, especially if not accompanied by adequate visual changes along the trajectory.

Visibility aspects and road safety equipment are also important concerns. The addition of bend warning signs, delineators, guardrails, and rumble strips before bends is highly recommended to provide warnings to road users, especially at night or during heavy rain that reduces visibility. Research by (Nasution, 2021) shows that the application of passive safety equipment can significantly reduce the number of accidents on the bend road segment.

Periodic evaluation of geometric conditions and traffic behavior is necessary. Collecting data such as actual operating speed, accident frequency, and road user response can be used as a basis for further engineering decisions. Although the initial design was based on technical guidelines, validation based on field conditions is a more responsive and adaptive approach to real needs.

CONCLUSIONS AND RECOMMENDATIONS

Based on the geometric analysis of the bend segment of the Cisumdawu Toll Road at KM 202–208, it can be concluded that the geometric design generally refers to the old planning standard, Geometric Planning Standard for Urban Roads 1992, but has not fully met the provisions of the 2021 Road Geometric Design Guidelines, with several parameters such as the spiral length (Ls) of 126 meters, which almost meets the minimum 130 meters according to the 2021 Road Geometric Design Guidelines, and the circular arc length (Lc) of 529.33 meters, which is at the lower limit of comfort and thus reduces driver comfort.

There is a significant difference between the existing data calculation and the ideal calculation, which indicates that although it is still functionally usable, design improvements are highly recommended to reduce the risk of accidents and improve comfort, especially for vehicles traveling at high speeds. Therefore, design adjustments such as increasing spiral length, adding superelevation, and improving visual and physical safety facilities are highly recommended to optimize road geometric performance.

This research confirms the importance of periodic evaluation of road infrastructure to remain adaptive to the latest regulations and developments in transportation technology. Periodic evaluation of bend geometry on highways is essential, especially on segments with hilly topography or small radii, to anticipate changes in traffic conditions and adjust to the latest standards. Reconstruction of geometry elements such as spirals, superelevation, and visibility needs to be done to comply with the more stringent provisions of the 2021 Road Geometric Design Guidelines. In addition, it is important to equip curves with additional safety facilities such as warning signs, reflective markings, and guardrails, especially in risky areas.

ADVANCED RESEARCH

Geometric analysis of Toll Road bends for future research needs to integrate aspects of safety, comfort, and the latest technology. Safety evaluation should focus on critical parameters such as bend radius and superelevation using 3D scanning and vehicle dynamics modeling. Comfort aspects can be analyzed through vehicle vibration measurements and road user perception surveys. The application of cutting-edge technologies such as Artificial Intelligence for crash prediction and Vehicle-to-Infrastructure (V2I) systems for early warning at dangerous curves is important. This approach aims to create geometric standards that meet the latest regulations. The result is expected to improve the safety and comfort of toll road users.

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