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The Geometric Design of Horizontal Alignment: A Case of Serpong – Balaraja Toll Road, Indonesia

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ABSTRACT

Rapid economic growth and a significant population necessitate efficient road functioning to facilitate community needs in terms of time, costs, income, health, comfort, and safety. Geometric road design serves as the cornerstone of road safety considerations and places significant emphasis on the strategic placement of symmetrical physical road components. This research is about planning the geometric design of the Serpong - Balaraja toll road, especially the horizontal alignment and this aims to know the planning of the toll road, the research conducted on Serpong – Balaraja Toll Road, located in Tangerang Regency in South Tangerang City. The road starts from STA 0+000 to 5+150. This study employs a measurable approach, where the data collected is derived mathematically using established formulas. The data utilized consists of primary data, specifically situation maps, road traffic information, and topographical details extracted from Google Earth. The results of the planning showed that there are four bends in this road. The first and the fourth bend is full circle type with a radius of 850 m; the curved length (Lc) for the first bend is 86.37 m, and the second bend is 45.994 m. Second is the spiral-spiral (SS) type, with a 160 m radius and a curved length (Ls) of 122.690 m. third is the spiral-circle-spiral (SCS) type with a 350 m radius, with a curved length (Ls) of 40 m. The calculation of this planning bases on road geometric design guidelines 2021.

1. Introduction

Roads are infrastructure vital to human activities because roads can link regions. Roads also play an essential role in economic, social, tourism, and cultural growth. Rapid economic growth and a significant population necessitate efficient road functioning to facilitate community needs in terms of time, costs, income, health, comfort, and safety [1]. Safety is the main element that needs to consider in road construction. Highways are required to ensure user consolation and safety, to allow effective traffic movement [2]. Geometric road design, which forms the foundation of road safety considerations, primarily focuses on strategically placing symmetrical physical road components. It encompasses cost-effectiveness analysis, minimizing adverse environmental effects, accommodating traffic volume, ensuring road accessibility, and more [3].

Along with economic development, road construction in Indonesia is continuously developed, especially toll roads. The construction of toll roads is a government action to distribute facilities throughout Indonesia. From 2014 to 2019, 1,235 km of new toll roads were built throughout the country [4]. Toll roads continue to be built because they have many benefits; improving goods and services distribution services that support economic growth is one of many other benefits of toll roads. The traffic movement on toll roads, specifically freeways, exhibits intriguing characteristics that require continuous observation. Toll road conditions differ in dynamics compared to non-toll roads, making monitoring and

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analyzing traffic patterns continually essential. This ongoing observation helps to understand and address the unique aspects and challenges associated with toll road systems [5].

Banten Province is a province located in the westernmost part of Java Island. Tangerang Regency is a regency with the largest population in Banten Province, with a density of 3,736 people/km2 in 2017 [6]. With the breadth of the area and the continued increase in population, proper access roads have to build so that people can mobilize quickly and comfortably. The Serpong – Balaraja toll road is a toll road that was built from the Rawa Buntu interchange to the Balaraja interchange. This toll road plans to have a length of 39.4 km. Serpong - Balaraja Toll Road is a toll road that connects South Tangerang City with Tangerang Regency. This toll road will cross areas including Rawabuntu – BSD Timur – Cicayur – Legok – Mekar Jaya – Pasir Barat – Jambe – Cileles – Tigaraksa - Balaraja Interchange. The construction of the Serpong - Balaraja toll road will improve the community's economy, and logistics service relations in Jakarta, Tangerang, and Banten will be smoother. In planning a road, the safety of road users is the main thing that needs to consider. A way to improve road safety is improving geometric road design to mitigate accident occurrence and severity on roadways [7].

This journal aims to design geometric roads that are safe to pass on the Serpong - Balaraja toll road. Most research involving the road design component of safety has focused on understanding the relationships between geometric, other design components, and safety and using accident records as indices and driver's perception under varying geometric [8]. The scientific research process must be systematic and use the proper method. The method used in this planning uses the manual calculation method and refers to the 2021 Road Geometric Design Guidelines as guidelines and standards.

2. Literature Review

2.1 Toll Roads

Compared to regular routes, toll roads offer a distinct advantage, like freeways. This difference expects to provide better quality considering the increasing level of community mobility [9]. Roads provide the essential infrastructure for industrial and agricultural growth [10]. Toll roads can also support economic growth in an area. In addition, toll road users will also facilitate by increasing existing accessibility and mobility. The time saved on toll roads compared to non-toll roads, along with the return on investment for businesses generated through toll revenues, relies on the predictability and stability of toll rates [11]. With the existence of toll roads, regional development will likely be more evenly distributed and can better support the distribution of goods and services in the area.

Road construction is the government's effort to assist people in Indonesia, especially in the province of West Java, in carrying out their mobility properly and comfortably, both economically and socially [12]. Until now, the Toll Road Regulatory Agency has recorded seven toll roads totaling 2,620 km operating throughout Indonesia. It proves that toll roads are very influential in community mobilization. With toll roads, it will be easier for people to move from one area to another. In addition, the construction of toll roads will impact regional interactions in the growing tourism sector, especially around areas affected by toll road connections.

2.2 Road Geometric Planning

The transportation network is a fundamental part of civil infrastructure and a crucial part of sustainable development, which plays a vital role in an efficient and reliable transportation system [13] [14]. Roads are a crucial component of a region's infrastructure, enabling its growth and facilitating the efficient movement of people and goods. As the local economy expands, well-developed and well-maintained roads become increasingly essential. These roads not only enhance accessibility and connectivity but

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also contribute to economic development by facilitating trade, commerce, and the transportation of goods. Recognizing the significance of robust road infrastructure is paramount in accommodating the needs and demands of a growing economy, ensuring smooth and efficient transportation networks to support continued progress. There are three primary goals in the design of geometric roads: ensuring driver comfort and safety in terms of visibility design, adequate road surface friction coefficient, and free space for maneuvering vehicles. Another objective is to provide an economically efficient method while aiming for uniformity of road geometry concerning the terrain type [15] [16] [17].

To meet the road infrastructure, geometric road planning is needed. User safety is the main goal in the geometric planning of a road [18]. The aspect of road planning that concentrates on the physical layout can effectively serve the main purpose of the road, which is to ensure optimal traffic flow and maximize the cost-effectiveness ratio of implementation while delivering a sense of safety and comfort for road users. Planning the geometric aspects of roads is an initial stage in constructing interconnected or access roads. Furthermore, geometric road planning incorporates various elements tailored to the accuracy and available primary data derived from field surveys. These data have undergone thorough analysis and are aligned with relevant regulations and guidelines [19] [20] [21].

2.3 Alignment Road

Road alignment is an arc that is contained in the road geometric. The geometric design of the road consists of horizontal alignment and vertical alignment. Horizontal alignment is usually perpendicular to the map plane or can include twists and turns. Meanwhile, vertical alignment is a line formed by vertical planes such as the peaks of slopes and valleys of their derivatives. Road alignment is a primary concern for road designers and researchers because accidents often occur on road alignments. Therefore, the need to quantify, using a suitable safety parameter in the road design element, the design's effect on road users' safety [8].

Vertical alignment is a projection of the road axis on a vertical plane that passes through the road axis. The vertical alignment consists of a vertical slope and arc sections. Vertical alignment has two types of slumps: positive (climb) and negative (derivative). There are also two types of curvature: concave and convex arch [22]. The larger the circular curve/radius, the more comfortable the driver passes through the horizontal alignment [23].

The horizontal alignment or alignment of a road is the projection of the vertical axis of the straight road plane of paper consisting of straight lines and curved lines. A horizontal line arch is the curved part of the road between two straight lines. In planning horizontal alignment need to know the relationship between design speed and curvature and the relationship between the two with superelevation. The bend is the most crucial aspect of horizontal alignment as it subjects vehicles to centrifugal forces that can push them out of the corner. Therefore, ensuring the safety of road users requires careful consideration in the planning of curved sections. Factors to be considered include the maximum transverse slope, transition curve, visibility, side-free area, and widening of traffic lanes within the bend area. These considerations aim to enhance safety and provide an optimal driving experience for motorists [24].

3. Method

Data is one of the main strengths in compiling research and scientific modeling **[25]**. The commencement of systematic scientific investigation necessitates the initial recognition of the appropriate problem **[26]**. The research was conducted on Serpong – Balaraja Toll Road, located in Tangerang Regency in South Tangerang City. This road is divided into two sections, and this study will

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discuss the 1A section (STA 0+000 – 5+150). This study employs a measurable approach, where the data collected is derived mathematically using established formulas. The data utilized consists of primary data, specifically situation maps, road traffic information, and topographical details extracted from Google Earth. The location of the work can be seen on the location map can be seen in Figure 1.

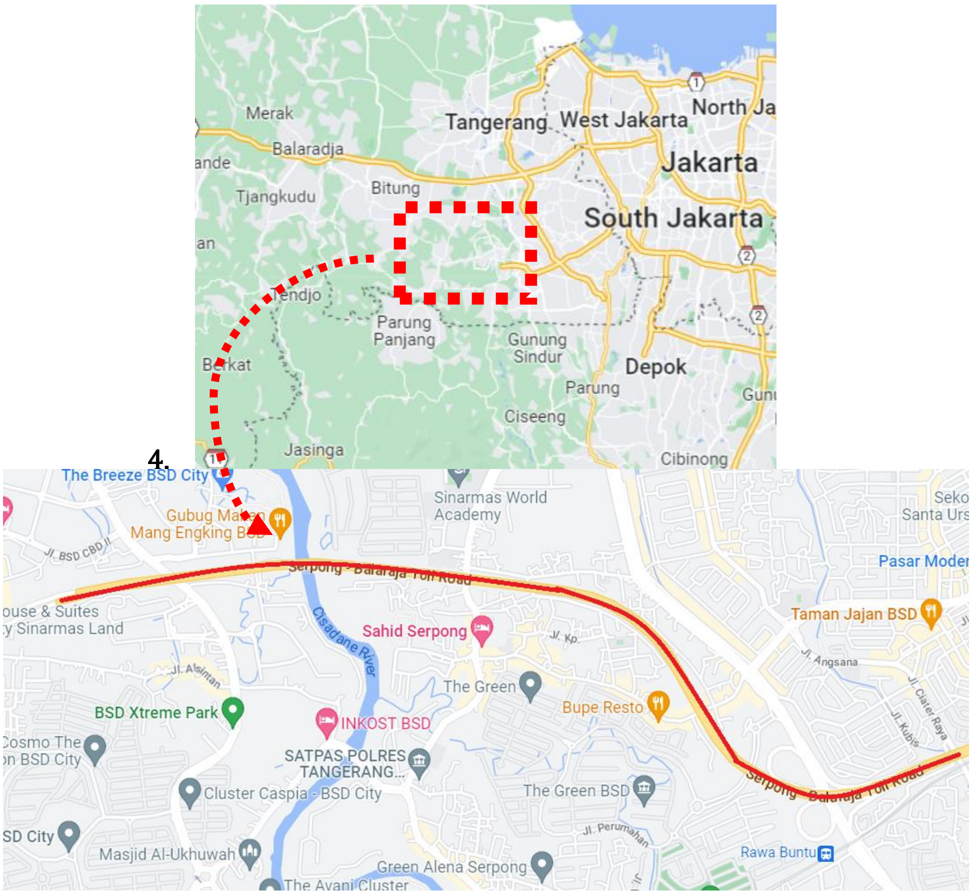

Figure 1 The Location of Serpong – Balaraja Toll Road Section 1A

The road geometric design guidelines mentioned are associated with the 2021 Road Geometric Design Guidelines. These guidelines will generate information on road types and classes, slopes, and plan speeds. This data will be utilized to design the horizontal alignment. This study uses road class regulations based on road functions and classifications referring to Road Geometric Design Guidelines 2021, page 30, Table 4-1, page 42, Table 5-1, and page 49, Table 5-3. The calculated geometric elements will be presented as data tables and superelevation drawings.

4. Result and Discussion

Based on the Road Geometric Design Guidelines 2021 issued by the Ministry of PUPR, the Serpong – Balaraja Toll Road is a primary road with a 4/2 road type, the road is designed for a speed of 60 - 100 km/h, and the maximum superelevation is 8%. The design criteria of the Serpong – Balaraja toll road can be seen in Table 1 below.

Table 1. Design Criteria

No	Variable of Design	Value of Main Design Variable		
1	Connection Purpose	Toll Road		
2	Road Attribute	SJJ	=	Primary
		Status	=	National Toll Road

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	Functions	=	Artery Primary
	Class	=	I
	SPPJ	=	JBH
3	Design Speed Range		60 – 100 km/hour

Source: Road Geometric Design Guidelines 2021

4.1 Horizontal Alignments

To calculate the horizontal alignment, it is essential to acquire the contour of the land surface to determine the coordinate points for constructing the connecting road. Here are the coordinates of the road route. The coordinates for the road alignment are derived through the processing of data generated using applications such as Google Earth, Global Mapper, and AutoCAD. The coordinates can be seen in Table 2.

Table 2. Coordinates of The Road Route

Point	X	Y
Start	681918.7035	9302620.876
1	681725.6561	9302332.457
2	681595.4316	9302175.146
3	681573.9528	9302459.7
4	681546.5268	9302612.631
End	681574.7224	9302840.094

Based on the coordinates above, the theta angle (θ) is as follows:

1) Coordinate Difference

Δx start – 1 = coordinate point x 1 – coordinate point x start
= 681918.7035-681725.6561
=193.0474 m

Δx 1 – 2 = coordinate point x 1 – coordinate point x 2
= 681725.6561-681595.4316
=130.2245 m

Δy start – 1 = coordinate point y 1 – coordinate point y start
= 9302620.8757-9302332.4569
=288.4188 m

Δy 1– 2 = coordinate point y 1 – coordinate point y 2
= 9302332.4569 – 6,305.189
=157.3107 m

2) Long Internodes Before Curved

The calculated differences in coordinates are further utilized to determine the distances between points, enabling the determination of the total length of the path:

$D = \sqrt{\Delta x^2 + \Delta y^2}$

Information:

Δx^2 = x coordinate difference

Δy^2 = y coordinate difference

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$$D\ start - 1 = \sqrt{193.0474^2 + 288.4188^2} = 347.0630\ m$$
$$D\ 1 - 2 \quad = \sqrt{130.2245^2 + 157.3107^2} = 204.2182\ m$$

3) Azimuth Angle (Z)

The results of the calculation of coordinate differences are also processed into azimuth angle calculations as follows:

$$Z = \text{arc tan}\,\frac{\Delta x}{\Delta y}$$

Information:

Δx^2 = x coordinate difference

Δy^2 = y coordinate difference

$$Z\ awal - 1 \quad = \arctan\frac{193.0474}{288.4188} = 58.9°$$

$$Z\ 1 - 2 \quad = \arctan\frac{5.07}{5.381} + 90 = 133.3°$$

4) Theta Corner (θ)

$$\theta 1 \quad = \quad (Z1{-}2) - (Zstart{-}1) = (133.3°) - (58.9°) = 74.4° \text{in}$$

The calculations' outcomes are in the table below Table 3.

Table 3. Coordinates Calculation Route

Point	X	Y	ΔX	ΔY	Length (m)	Azimuth	θ	STA
Start	681918.703	9302620.876						
			193.047	288.419	347.063	33.796		347.063
1	681725.656	9302332.457					5.823	
			130.225	157.311	204.218	39.618		551.281
2	681595.432	9302175.146					43.935	
			21.479	-284.554	285.363	-4.317		836.644
3	681573.953	9302459.7					14.484	
			27.426	-152.931	155.371	-10.167		992.015
4	681546.527	9302612.631					3.101	
			-28.196	-227.462	229.203	7.066		1221.219
End	681574.722	9302840.094						

After acquiring the coordinate data and determining the arc length, the subsequent step calculates the horizontal curve utilizing the guidelines outlined in PDGJ 2021. The subsequent calculations determine the design of Full Circle, Spiral-Spiral (SS), and Spiral-Circle-Spiral (SCS).

a. Start Point 1-2 (Full Circle)

Plan speed 60 km/hour

e normal = 2%

e max = 10%

θ = 5.823

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R = 850 m

e = 2,7%

L's = 40 m

fm = 0,155

$$Rmin = \frac{v^2}{127(emax+fm)} = \frac{60^2}{127(0.1+0.155)} = 111.163\ m$$

$$Dmax = \frac{1432.4}{Rmin} = \frac{1432.4}{111.163} = 12.8855$$

$$D = \frac{1432.4}{R} = \frac{1432.4}{850} = 1.6852$$

$$e = -\left(\frac{emax}{Dmax^2} \times D^2\right) + \left(\frac{2.emax}{Dmax} \times D\right)$$

$$e = -\left(\frac{0.1}{12.8855^2} \times 1.6852^2\right) + \left(\frac{2 \times 0.1}{12.8855} \times 1.6852\right) = 0.024$$

$$L's = (e + en)\frac{1}{2}B.m$$

$$L's = (0.024 + 0.02)\frac{1}{2}7.125 = 19.25\ m$$

$$L's = 0.022\frac{v^3}{R.c} - 2.727\frac{v.e}{c}$$

$$L's = 0.022\frac{60^3}{850 \times 0.4} - 2.727\frac{60 \times 0.024}{0.4} = 4.1593\ m$$

Using L's = 40 m

$$Lc = 0.01745 \times \theta \times R$$

$$Lc = 0.01745 \times 5.8230 \times 850 = 86.37\ m$$

$$Tc = R \times tan\frac{1}{2} \times \theta$$

$$Tc = 850 \times tan\frac{1}{2} \times 5.8320 = 43.2971\ m\text{the}$$

$$Ec = \frac{R}{cos\frac{1}{2} \times \theta} - R$$

$$Ec = \frac{850}{cos\frac{1}{2} \times 5.8320} - 850 = 1.1020\ m$$

Check the value of Ec

$$Ec = Tc \times tan\frac{\theta}{4}$$

$$Ec = 43.2971 \times tan\frac{5.8320}{4} = 1.1020\ (\text{OK!})$$

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The type of bend designed for the first bend is a full circle (FC) match with the fourth bend. The second bend was designed with a spiral-spiral (SS) type, and the third bend was designed with a spiral-circle-spiral (SCS) type. The calculation for this bend can be seen in Tables below.

Table 4. Calculation of Spiral-Spiral (SS) Bend

The result of the calculation		
Rmin	=	111.163
Dmax	=	12.886
D	=	8.953
e	=	0.095
θs	=	21.968
Ls	=	122.690

Table 5. Calculation of Spiral-Circle-Spiral (SCS) Bend

The result of the calculation		
Rmin	=	111.163
Dmax	=	12.886
D	=	4.093
e	=	0.053
θs	=	3.274
Ls	=	11.210

Table 6. Calculation of Full Circle (FC) Bend

The result of the calculation		
Rmin	=	111.163
Dmax	=	12.886
D	=	1.685
e	=	0.024
Tc	=	23.007
Lc	=	45.996

5. Conclusion

The results of the planning research for the Serpong – Balaraja toll road based using the Road Geometric Design Guidelines 2021 showed that there are four bends in this road, the first and fourth bend is full circle (FC) type, the second bend is spiral-spiral (SS) type. The third bend is the spiral-circle-spiral (SCS) type. The main design criteria obtained by the road was a class I primary arterial road with 4/2-T type. Based on the calculations, the first and second full circle (FC) bend possess a radius of 850 m, the curved length (Lc) for the first bend is 86.37 m, and the second bend is 45.994 m. The spiral-spiral (SS) bend has a 160 m radius, and the curved length (Ls) is 122.690 m. The radius of the spiral-circle-spiral (SCS) bend is 350 m, and the curved length (Ls) is 40 m. This computation employs the road class regulation derived from the functions and classifications outlined in Indonesia's Road Geometric Design Guidelines 2021.

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