

HORIZONTAL ALIGNMENT ANALYSIS BASED ON COORDINATE DATA ON THE STATE JAYA-SIMPANG KALIAWI INDAH ROAD SECTION, WAY KANAN REGENCY

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Abstract

Horizontal alignment is an important part of road geometry because it is related to changes in direction and bends on the road trajectory. On the Jalan Negara Jaya-Simpang Kaliawi Indah section, Way Kanan Regency, analysis was carried out based on STA data and the coordinates of available control points. Data processing included calculation of distance between points, azimuth, azimuth change as deflection angle, and radius estimation based on three consecutive coordinate points. The data analyzed consisted of 14 control points from STA 0+000 to STA 9+732. The results of the analysis showed 12 changes in direction, with 9 locations having a deflection angle of more than 5° and 3 locations showing small changes. The largest change in direction was found at STA 1+500 at 62.31° to the left, followed by STA 3+750 at 58.86° to the left. The smallest indicative radius was obtained at STA 1+500 of 596.43 m and STA 3+750 of 669.72 m. This value is an indicative radius and not a bend radius of the existing design. The evaluation refers to the Road Geometric Design Guidelines Number 13/P/BM/2021, but the suitability of the minimum radius and other bend parameters cannot be determined as more detailed PC, PI, PT, plan speed, and centerline data have not been carried out. The results of the analysis can be used as a basis for determining locations that require further geometric surveys.

Keywords: Deflection Angle, Horizontal Alignment, Indicative Radius, Road Geometry, UTM Coordinates.

INTRODUCTION

The geometric condition of the road is one of the aspects that need to be considered in road operation because it is related to the characteristics of the trase and the operation of the vehicle. Horizontal alignment describes the road trajectory on a horizontal plane consisting of a straight and curved section. Parameters related to horizontal alignment include the trajectory direction, deflection angle, corner radius, curve length, superelevation, as well as the relationship between the planned speed and the geometry of the curve (Directorate General of Highways, 2021; Himes et al., 2019). These geometric characteristics are also related to safety aspects, especially in horizontal corners because the corner radius, vehicle speed, and superelevation can affect the condition of the vehicle when passing corners (Himes et al., 2019).

The Road Geometric Design Guidelines (PDGJ) Number 13/P/BM/2021 are technical guidelines of the Directorate General of Highways which include criteria, technical provisions, and geometric design procedures, including horizontal alignment (Directorate General of Highways, 2021). These guidelines are used in this study as a frame of reference to understand the geometric parameters that need to be examined. However, this study does not assess the fulfillment or non-fulfillment of standards if the required design parameters are not available.

This study is different from the geometric evaluation which directly uses Point of Curve (PC), Point of Intersection (PI), and Point of Tangent (PT) data as well as curve design parameters. The data available in this study are in the form of control points with relatively large intervals. Therefore, the analysis is focused on identifying the change in the direction of the trase and estimating the indicative radius based on three consecutive coordinate points as the initial stage to determine the location that requires a more detailed geometric survey.

The objectives of this study are: (1) to identify the characteristics of changes in the direction of horizontal alignment; (2) to calculate the indicative deflection angle based on coordinate data; (3) to calculate the indicative

radius based on three consecutive coordinate points; and (4) to determine the location that needs to be examined further through a geometric survey with a tighter point interval.

LITERATURE REVIEW

Horizontal alignment is the shape of road trajectory on a horizontal plane consisting of straight and curved parts. In geometric design, the bend radius, deflection angle, superelevation, curve length, and plan speed are interrelated parameters. The Road Geometric Design Guidelines Number 13/P/BM/2021 are used as a technical reference in understanding road geometric design parameters and procedures (Directorate General of Highways, 2021).

In general, the shape of the horizontal curve can be in the form of Full Circle (FC), Spiral–Circle–Spiral (SCS), and Spiral–Spiral (SS). The determination of the bend type requires more detailed geometric information, especially the position of the PC, PI, PT points, tangent length, arc length, and spiral parameters. Since the data is not yet available in the data used in this study, the classification of the type of bend is not performed. In coordinate-based analysis, the direction of each segment can be determined using the azimuth. The difference of azimuth between two consecutive segments is used to determine the change in direction or angle of indicative deflection. Furthermore, if the three coordinate points are not in a straight line, the radius of the circle passing through the three points can be calculated using geometric relationships:

$$R = \frac{abc}{4A}$$

With R being the radius of the circle through three points, a, b, and c are the length of the sides of the triangle formed by the three points, while A is the area of the triangle (Weisstein, n.d.). In this study, the result is called a three-point indicative radius because the available control points are relatively large and do not directly represent the PC, PI, and PT points. The criterion of deflection angle of more than 5° is used as an operational criterion to separate relatively more prominent changes in direction from minor changes in the data filtering stage. This criterion is not used as a standard limit of geometric design and is not used to declare a bend meets or does not meet geometric requirements.

Previous Research

Previous research has shown that existing geometric data can be used to identify horizontal alignment parameters such as corner length, deflection angle, radius, and superelevation. Drakopoulos and Örnek (2000) developed a vehicle data-based approach to obtain existing road geometry parameters, including corner length, deflection angle, and superelevation. The approach suggests that existing geometric data can be systematically analyzed to evaluate a set of alignment elements.

Liu (2021) used field data and vehicle-based measurement systems to identify horizontal curve parameters, including PC, PT, curve length, radius, and corner direction. These results demonstrate the importance of the availability of fairly tight centerline data when the evaluation is directed at the actual geometry of the road.

Studies of superelevation, side friction, and road consistency show that radius, velocity, superelevation, and lateral friction force requirements are interrelated parameters in horizontal bend design (Nicholson, 1998). Therefore, radius alone is not sufficient to declare that a bend meets the design requirements. A more complete evaluation requires plan speed and superelevation as well as other curved parameters.

Research on the relationship between speed and lateral friction forces in horizontal bends also shows that frictional force needs are influenced by approach speed, corner speed, radius, and superelevation (Bonneson, 1999). These findings reinforce the argument that the indicative radius in this study is only used as a location screening indicator, not as a single basis for assessing safety or design compliance.

Research Conceptual Framework

The conceptual framework of the study was constructed from the relationship between the coordinate data, the change in trase direction, and the need for geometric examination. The coordinates were used to obtain the azimuth of the segment; the azimuth difference was used to determine the indicative deflection angle; three consecutive points were used to calculate the indicative radius; then the combination of the deflection angle and the indicative radius was used to determine the priority location of the survey. The final stage is not intended as a test of compliance with the standard, but rather as an initial screening of the site.

Research Position and Novelty

The position of this study lies in the use of secondary road road data to conduct an initial screening of horizontal lines on the district section when PC–PI–PT data are not yet available. This approach does not replace topographic surveys, but can help determine a more efficient location for advanced geometric measurements. The novelty of the study is the use of a combination of direction change angles and three-point indicative radius to compile inspection priorities on the Negara Jaya–Simpang Kaliawi Indah section.

METHOD

The research uses secondary data from the Leger Document of Jalan Negara Jaya–Simpang Kaliawi Indah, Section 169, Way Kanan Regency, Lampung Province, 2025 Leger Document. The data used includes STA and X-Y coordinates of control points available on the main road card.

The stages of data processing include: (1) STA and coordinate inventory; (2) calculation of distance between points based on coordinates; (3) calculation of azimuth of each segment; (4) calculation of azimuth changes between segments; (5) identification of major direction changes using operational criteria $>5^\circ$; and (6) estimation of indicative radius using three consecutive coordinate points.

The calculation is done on a flat plane based on UTM coordinates. The three-point radius is not treated as the actual design radius. Therefore, the radius results are used only as an indicator to filter out locations that need to be examined further.

The evaluation of the suitability of the geometric design parameters according to PDGJ 13/P/BM/2021 has not been carried out in full because the available data does not fully list the points of PC, PI, PT, plan speed, curve length, and numerical superelevation parameters at each corner. Thus, this study is placed as an initial analysis of horizontal alignment based on coordinate data.

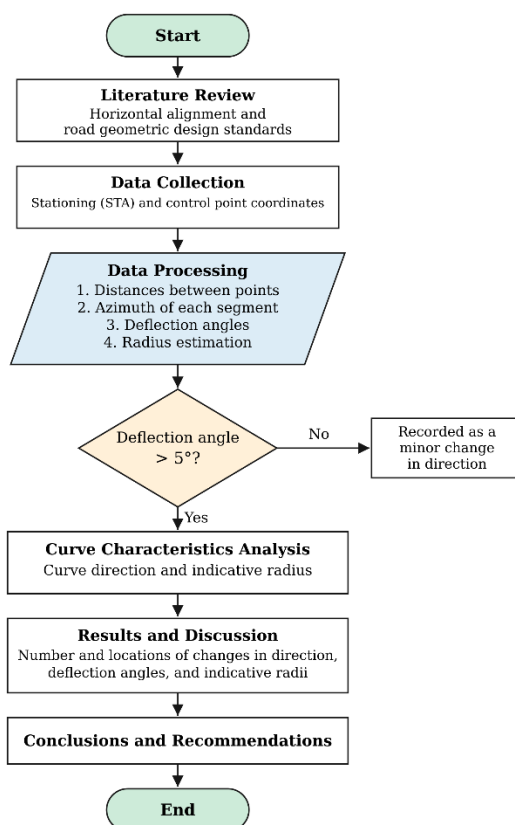


Image 1. Horizontal alignment analysis flow chart.

RESULTS AND DISCUSSION

The horizontal alignment analysis was carried out based on 14 coordinate control points on the Jalan Negara Jaya–Simpang Kaliawi Indah section, Way Kanan Regency. The coordinate data was used to describe the road trajectory and identify changes in direction in each segment. The trajectory description based on the control points used in the analysis is shown in image 2.

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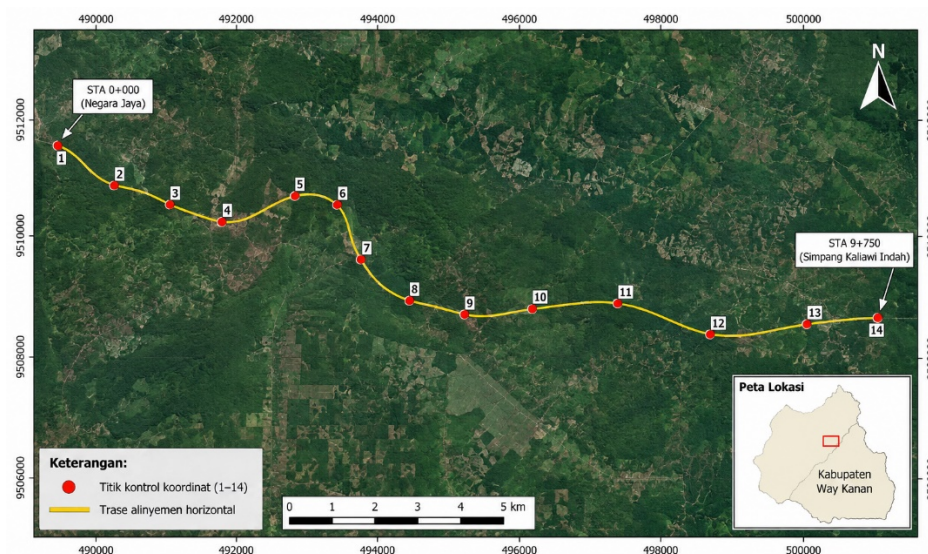


Image 2. Horizontal alignment tracing based on 14 coordinate control points.

Road Identity and Data

Table 1. Road Identity and Data

No	STA	Azimuth Changes (°)	Deflection Angle (°)	Directions	R indicative (m)	Classification
1	0+750	-20.55	20.55	Right	1,683.16	Main*
2	1+500	-62.31	62.31	Left	596.43	Main*
3	2+250	-1.34	1.34	Right	28,259.20	Small
4	3+000	10.24	10.24	Left	4,094.19	Main*
5	3+750	58.86	58.86	Left	669.72	Main*
6	4+500	-13.78	13.78	Right	2,418.76	Main*
7	5+250	2.20	2.20	Left	16,474.21	Small
8	6+000	22.13	22.13	Left	1,615.41	Main*
9	6+750	37.34	37.34	Left	996.19	Main*
10	7+500	-13.47	13.47	Right	3,012.20	Main*
11	8+250	0.70	0.70	Left	57,154.41	Small
12	9+000	27.70	27.70	Left	1,182.57	Main*

The data on the road map lists several geometric parameters, including RUMIJA width, flatness, cross fall, superelevation, radius, horizontal alignment, and vertical alignment. However, for the calculation needs of this study, the parameters that can be used consistently are STA and control point coordinates.

Control Point Coordinate Data

Table 2. Control Point Coordinate Data

No	STA	Direction	Deflection Angle (°)	R indicative (m)
1	0+750	Right	20.55	1,683.16
2	1+500	Left	62.31	596.43
3	3+000	Left	10.24	4,094.19
4	3+750	Left	58.86	669.72
5	4+500	Right	13.78	2,418.76
6	6+000	Left	22.13	1,615.41
7	6+750	Left	37.34	996.19
8	7+500	Right	13.47	3,012.20
9	9+000	Left	27.70	1,182.57

There are 14 control points from STA 0+000 to STA 9+732. The distance between the points from the coordinate calculation ranges from 440.48–745.19 m. The relatively large interval is the main limitation in determining the geometry of the bend in detail. Therefore, the result of the three-point radius must be understood as an indicative radius and not an existing bend radius.

Angle of Change of Direction of Horizontal Alignment

Table 3. Angle of Change of Direction of Horizontal Alignment

No	STA	Direction	Δ (°)	Rc (m)	$T = T_c$ (m)	Ec (m)	Lc (m)
1	0+750	Right	20.55	1,683.16	305.12	27.43	603.69
2	1+500	Left	62.31	596.43	360.57	100.52	648.63
3	3+000	Left	10.24	4,094.19	366.84	16.40	731.72
4	3+750	Left	58.86	669.72	377.83	99.23	688.00
5	4+500	Right	13.78	2,418.76	292.27	17.59	581.73
6	6+000	Left	22.13	1,615.41	315.91	30.60	623.94
7	6+750	Left	37.34	996.19	336.61	55.33	649.22
8	7+500	Right	13.47	3,012.20	355.72	20.93	708.16
9	9+000	Left	27.70	1,182.57	291.56	35.41	571.72

*Note: "Main" is the study's operational criterion for screening locations with a deflection angle of $>5^\circ$, not a bend-level classification according to geometric design standards.

Based on azimuth calculations, there are 12 points of change in direction at the intermediate point. With the operational criteria of deflection angle of more than 5° , there are 9 locations that are prioritized for further examination. The largest change in direction is found at STA 1+500 at 62.31° to the left, while the next major change is at STA 3+750 at 58.86° to the left. Minor changes in direction are found at STA 2+250, STA 5+250, and STA 8+250.

Indicative Geometric Radius

The indicative radius of the three points is calculated from three consecutive coordinates. The smallest value is found at STA 1+500 at 596.43 m, followed by STA 3+750 at 669.72 m, STA 6+750 at 996.19 m, and STA 9+000 at 1,182.57 m.

A large radius value at a point with a small change in direction indicates that the change in trase direction based on three points is relatively sloping. In contrast, a smaller indicative radius indicates a location that needs attention on a follow-up geometric survey. Such an interpretation is only filtering because the radius value is strongly influenced by the position and distance of the three control points used.

Table 4. Indicative Geometric Radius

No	STA	Direction	Deflect Angle (°)	R indicative (m)
1	0+750	Right	20.55	1,683.16
2	1+500	Left	62.31	596.43
3	3+000	Left	10.24	4,094.19
4	3+750	Left	58.86	669.72
5	4+500	Right	13.78	2,418.76
6	6+000	Left	22.13	1,615.41
7	6+750	Left	37.34	996.19
8	7+500	Right	13.47	3,012.20
9	9+000	Left	27.70	1,182.57

Indicative Calculation of Corner 1 Element

To provide a more detailed calculation stage as in the reference study, STA 1+500 is used as an example of calculating curve elements with a Full Circle (FC) approach. This calculation is indicative because the existing PI, PC, and PT points are not yet available. Therefore, the results are not used to determine the existing curve type.

Known Data

- P1 = STA 0+750
- P2 = STA 1+500
- P3 = STA 2+250

Calculate from the coordinates:

$$P_1 = (491745,600, \text{ } 9508914928)$$

$$P_2 = (492366,417, \text{ } 9508979442)$$

$$P_3 = (492592,563, \text{ } 9509546013)$$

Distance P1–P2

$$a = \sqrt{(492366,417 - 491745,600)^2 + (9508979,442 - 9508914928)^2}$$

$$a = \boxed{624,16 \text{ m}}$$

Distance P2–P3

$$b = \sqrt{(492592,563 - 492366,417)^2 + (9509546,013 - 9508979442)^2}$$

$$b = \boxed{610,04 \text{ m}}$$

Distance P1–P3

$$c = \sqrt{(492592,563 - 491745,600)^2 + (9509546,013 - 9508914928)^2}$$

$$c = \boxed{1.056,23 \text{ m}}$$

Triangle area

With the coordinates of the three points:

Radius (Rc) Calculation

The radius formula of a circle that passes through three points:

$$R = \frac{a \times b \times c}{4A}$$

Substitution:

$$R = \frac{624,16 \times 610,04 \times 1.056,23}{4 \times 168.573,66}$$

$$R = \boxed{596,43 \text{ m}}$$

Thus, Rc = 596.43 m. This value is the radius of the circle that passes through the three control points and not the radius of the existing design.

Tangent Length Calculation (T or Tc)

For the Full Circle approach, the tangent length is calculated by the equation:

$$T = 596,43 \tan \frac{62,31^\circ}{2}$$

$$T = 596,43 \tan 31,155^\circ$$

$$\boxed{T = 360,57 \text{ m}}$$

So, the length of the tangent is indicative T = Tc = 360,57 m.

Calculation of External Distance (Ec)

$$Ec = T \tan \frac{\Delta}{4}$$

$$Ec = 360,57 \tan 15,5775^\circ$$

$$\boxed{Ec = 100,52 \text{ m}}$$

So, $E_c = 100,52$ m.

Arc Length Calculation (L_c)

The arc length of a circle is calculated by equation:

$$L_c = \frac{\Delta}{360^\circ} \times 2\pi R_c$$

$$L_c = \frac{62,31}{360} \times 2\pi(596,43)$$

$$\boxed{L_c = 648,63 \text{ m}}$$

So, the length of the arc is indicative $L_c = 648,63$ m.

Arc Center Distance Calculation (M_c)

As an additional parameter, the center distance of the arc can be calculated by equation:

$$M_c = R_c \times [1 - \cos(\Delta/2)]$$

$$M_c = 596,43 \times [1 - \cos(31,155^\circ)] = 86,02 \text{ m}$$

Arc Center Distance Calculation (M_c)

As an additional parameter, the center distance of the arc can be calculated by equation:

$$\text{STA PC} = \text{STA PI} - T = 1+500 - 360,57 = 1+139,43$$

$$\text{STA PT} = \text{STA PC} + L_c = 1+139,43 + 648,63 = 1+788,06$$

The values of PC and PT are only the result of a mathematical reconstruction based on the assumption that PI is at STA 1+500. Both cannot be declared as existing PCs and PTs without a centerline/topography survey.

Recapitulation of Indicative Curve Elements

The same calculation can be applied to the nine main directional change locations. The following recapitulation uses the three-point indicative radius and deflection angle in Table 5.

Table 5. Rekapitulasi Elemen Tikungan Indikatif

No	STA	Direction	Δ (°)	R_c (m)	$T = T_c$ (m)	E_c (m)	L_c (m)
1	0+750	Right	20.55	1,683.16	305.12	27.43	603.69
2	1+500	Left	62.31	596.43	360.57	100.52	648.63
3	3+000	Left	10.24	4,094.19	366.84	16.40	731.72
4	3+750	Left	58.86	669.72	377.83	99.23	688.00
5	4+500	Right	13.78	2,418.76	292.27	17.59	581.73
6	6+000	Left	22.13	1,615.41	315.91	30.60	623.94
7	6+750	Left	37.34	996.19	336.61	55.33	649.22
8	7+500	Right	13.47	3,012.20	355.72	20.93	708.16
9	9+000	Left	27.70	1,182.57	291.56	35.41	571.72

T, E_c , and L_c in the table are geometric elements resulting from the Full Circle approach to the three-point indicative radius. These values cannot be used to determine the existing bend type or for R_{min} examination because data on plan speed, superelevation, and other design parameters are not yet available.

Discussion of Geometric Parameters

PDGJ Number 13/P/BM/2021 is used as a frame of reference for road geometric design parameters. In the context of horizontal alignment, design assessment in principle requires information regarding the plan speed, bend radius, superelevation, and curved elements. The available research data has not allowed all of these parameters to be calculated or verified.

The values of 596.43 m in STA 1+500 and 669.72 m in STA 3+750 cannot be directly compared with the minimum design radius to declare that it meets or does not meet the standard. This is because the radius obtained is not the design bend radius determined from PC–PI–PT, but the radius of the circle that passes through three control points. Thus, the results of the study are used to determine locations that require tighter centerline measurement. STA locations 1+500, 3+750, 6+750, and 9+000 can be designated as follow-up inspection priorities because they have a relatively large combination of deflection angles and smaller indicative radius than some other locations. These priorities do not mean that the location has been declared to not meet the geometric requirements, but rather indicates the need to obtain more detailed geometric data.

Data Limitations and Implications for Evaluation

The main limitation of the study is the number of control points which is only 14 points on the length of the section of about 9,732 km, with a distance between points of about 440.48–745.19 m. These conditions are not enough to describe the shape of the curve in detail. In addition, the available data have not provided the position of PC, PI, PT, tangent length, arc length, spiral length, plan speed, and numerical superelevation values for each bend. On the basis of these limitations, this study does not provide a claim regarding geometric compliance with the standard. The research produced an initial map of the location of the change in direction that can be used as a basis for planning topographic surveys or centerline measurements at tighter intervals.

CONCLUSION

Based on the results of the analysis of the characteristics of the change in the direction of the horizontal alignment, of the 14 control points analyzed, there were 12 locations that experienced changes in the direction of the trase. Using the operational limit of the deflection angle of more than 5°, as many as 9 locations showed a significant change in direction, while the other 3 locations had a relatively small change in direction. The indicative deflection angle was obtained from the azimuth difference between two consecutive road segments, with values ranging from 0.70° to 62.31°. The largest change in direction occurred at STA 1+500 by 62.31° to the left, then followed by STA 3+750 by 58.86° to the left. The results of the indicative radius calculation based on three coordinate points showed that the smallest radius was found at STA 1 + 500 of 596.43 m, followed by STA 3 + 750 of 669.72 m, STA 6 + 750 of 996.19 m, and STA 9 + 000 of 1,182.57 m. The radius value is the radius of the circle that passes through three coordinate points in a row so that it is only used as a three-point indicative radius and cannot be considered as an existing design radius, considering that data on PC, PI, PT, and corner design parameters are not yet available. Based on the results of the identification of direction changes and indicative radius values, STA 1 + 500, STA 3 + 750, STA 6 + 750, and STA 9 + 000 are the locations that need to be prioritized for further geometric examination. Follow-up checks should be carried out through surveys with tighter measurement intervals to obtain the position of PC, PI, and PT as well as other geometric parameters, so that the evaluation of the suitability of horizontal alignment with road geometric design standards can be carried out more completely and accurately.

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