Jurnal Impresi Indonesia (JII)
p-ISSN: 2828-1284 e-ISSN: 2810-062x
Vol. 5. No. 5. 2026

Geometry Analysis of the Horizontal Curved Alinyemen Rail Road Cikampek – Cirebon Corridor

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Keywords:
track geometry;
horizontal curve;
curve radius;
superelevation;
160 km/h;
PT FOOD;
Cirebon.

Abstract

The development of railway transportation in Indonesia requires continuous improvement in infrastructure quality to support higher train speeds while maintaining safety and comfort. PT Kereta Api Indonesia (Persero), through the Directorate General of Railways, plans to increase the maximum train speed from 120 km/h to 160 km/h. This study aims to analyze the railway track geometry on horizontal curve alignment in relation to the planned speed upgrade. The research was carried out on horizontal curve No. 21 at KM 201+064 to KM 201+584, located on the down track between Kertasmaya and Arjawinangun Stations in the Cikampek–Cirebon corridor (Operational Area 3 Cirebon), with a 1067 mm track gauge. The analysis includes curve radius, curve length, tangent angle, mid-ordinate, and rail superelevation, referring to PD No. 10A (2016) and Ministry of Transportation Regulations No. 32/2011 and No. 60/2012. The results show that the existing curve radius of 750 meters does not meet the minimum requirement of 800 meters for the 160 km/h design speed. Adjustments to superelevation and mid-ordinate values are required to ensure stability and ride comfort. Therefore, a realignment or redesign of the curve geometry is needed to achieve safe and efficient operation. This study is expected to serve as a technical reference for future railway speed enhancement projects and contribute to the advancement of railway engineering, particularly in track geometry analysis and design.

INTRODUCTION

Trains are one of the modes of land transportation that has an important role in supporting the mobility of passengers and goods. The quality of rail infrastructure greatly determines the safety, comfort, and smooth travel of trains (Gao et al., 2023; Zhu et al., 2023). One of the Important Assets in rail infrastructure is Vertical and Horizontal Curves, which function to direct the railway wheels from the Straight Track to the Cornering Track or called Curve (Rinaldi, 2021).

The development of railway transportation in Indonesia continues to increase in line with the high demands of mobility and the need for fast, safe, and efficient modes of transportation (Adya Aghasta, 2024; Afif R H, 2022; Arief et al., 2024; Fajriati et al., 2020). One of the efforts made by the government through the Directorate General of Railways is a plan to increase the speed of train operations to reach 160 km/h. This speed increase is expected to shorten travel time between cities, increase the competitiveness of rail transportation modes, and encourage economic growth in various regions (Fiqih et al., 2023; Indonesia, 2012; Karyanto et al., 2020; Nurdianto, n.d.; Prabowo et al., 2023).

PT. KAI Reviewed the Plan to Increase the Speed of the Train from the original maximum speed of 120 km/h to the maximum speed of the Train of 160 km/h, The increase in the speed of travel time planned by PT. KAI is a form of improving the quality of service-to-service users (Khosravi et al., 2021; Sy & Drajat, 2022; Widyaningsih & Ayuningtyas, 2022).

The specific issue addressed in this research is the horizontal curve geometry at Curve No. 21, KM 201+064 to KM 201+584, on the downstream track between Kertasmaya and Arjawinangun Stations in the Cikampek–Cirebon corridor. The existing curve radius is reported as approximately 750–760 meters, while the manuscript indicates that a higher radius is required to support the planned speed of 160 km/h. This condition shows that the existing alignment may not yet meet the technical requirements for speed upgrading and therefore needs recalculation, redesign, or realignment based on applicable railway standards (Li et al., 2019; Wang et al., 2018; Zhang et al., 2020).

Actual technical data from the manuscript show that the horizontal curve consists of several interrelated geometric elements, including curve radius, curve length, tangent angle, mid-ordinate or arrow, and curve height or superelevation. The results indicate that the existing curve radius can only support a lower operational speed, while the recommended design for 160 km/h requires a larger curve radius, longer transition curve, and adjusted superelevation. This confirms that speed improvement cannot be evaluated only from train performance, but must also consider track geometry, lateral forces, centrifugal effects, ride comfort, and structural readiness of the railway body.

Previous studies have emphasized the importance of geometric design in railway speed improvement. Aghastya's study on the Bandung–Cirebon high-speed railway corridor proposed horizontal curve radii ranging from 2,500 to 12,000 meters for a much higher operational speed, showing that larger radii are essential in high-speed railway design. Another study on high-speed railway track geometry in the Bandung–Cirebon section discussed geometric planning by referring to Indonesian railway regulations and Chinese technical standards, indicating the importance of combining national and international standards in railway alignment planning.

Other international studies also show that horizontal curve design must consider safety and ride comfort, not merely mathematical compliance (Cárdenas-Gallo et al., 2017; Xu et al., 2013). Alqatawna's study proposed a graphical method for designing high-speed railway horizontal alignment by analyzing can't, radius, and colthood parameters from several technical standards. Kurhan and colleagues also emphasized that reconstruction of existing railways requires optimization of curve parameters such as radius, transition curves, and superelevation based on measurement and design data.

Despite the growing number of studies on high-speed railway alignment, there remains a research gap in the evaluation of existing conventional railway corridors planned for moderate speed enhancement, especially on narrow-gauge tracks in Indonesia. Many previous studies focus on new high-speed railway lines, while fewer studies examine whether existing corridors such as Cikampek–Cirebon can technically accommodate speed increases through curve geometry adjustment. Therefore, this research fills a practical and academic gap by evaluating an existing horizontal curve using field measurement data, curve register data, and technical calculations for a planned speed of 160 km/h.

The urgency of this research lies in the fact that increasing train speed without ensuring adequate curve geometry can reduce safety, comfort, and infrastructure reliability. If the curve radius, superelevation, and transition length are insufficient, trains may experience excessive lateral acceleration and centrifugal force when passing through curved sections. This condition may affect ride comfort, track wear, maintenance needs, and operational safety. Therefore, before the 160 km/h speed plan is implemented, technical verification of the existing curve alignment is necessary to determine whether redesign or realignment is required.

The novelty of this research is its focus on the horizontal curve geometry of Curve No. 21 in the Cikampek–Cirebon corridor using actual field and register data to assess readiness for a 160 km/h speed plan. Unlike general studies on railway geometric design, this research provides a location-specific technical evaluation involving radius calculation, superelevation analysis, transition curve length, curve length, tangent angle, and curve arrow. The study also connects geometric changes with practical consequences, such as track axis adjustment, infrastructure modification, and potential travel time reduction between Kertasmaya and Arjawinangun Stations.

The purpose of this research is to analyze whether the existing horizontal curve geometry on the Cikampek–Cirebon corridor meets the technical requirements for increasing train speed to 160 km/h. The research aims to identify the main geometric factors forming the horizontal curve, evaluate the existing curve register, and recommend suitable curve geometry values for safe and comfortable train operation. The contribution of this study is both practical and academic: practically, it can serve as a technical reference for PT KAI and railway infrastructure planners in evaluating speed improvement projects; academically, it enriches railway engineering studies related to horizontal curve geometry, speed planning, and infrastructure readiness on existing Indonesian railway corridors.

RESEARCH METHODS

This research employed a quantitative descriptive approach to analyze the geometry of horizontal railway curve alignment on the Cikampek–Cirebon corridor in relation to the planned increase in train operating speed from 120 km/h to 160 km/h. The population of this research consisted of all horizontal curve segments located along the Kertasmaya–Arjawinangun railway section within Operational Area 3 Cirebon. The research sample focused specifically on Horizontal Curve No. 21 at KM 201+064 to KM 201+584 on the downstream track, selected using purposive sampling because the curve has an existing radius below the minimum requirement for the planned operational speed. The main research instruments included a Total Station device for coordinate measurement, railway curve register documents, Google Earth imagery, technical calculation sheets, and AutoCAD software for geometric visualization and alignment processing. Instrument validity was ensured through coordinate verification between field measurements and existing railway register data, while reliability was assessed through repeated measurements and consistency checks of curve geometry calculations based on applicable railway standards and regulations.

The data collection process was conducted through several stages, including literature study, field observation, technical documentation review, and direct geometric measurement (Li et al., 2019). Literature studies were carried out using journals, railway engineering references, government regulations, and technical standards related to railway horizontal curve geometry and operational speed planning. Secondary data were obtained from the Railway Road Resort 3.7 Arjawinangun office, including existing curve register data, railway alignment information, and infrastructure specifications. Primary data collection involved direct field measurements using Total Station equipment to obtain coordinate points consisting of Easting (X), Northing (Y), and Elevation (Z) values. The collected coordinate data were then processed and visualized using AutoCAD software to identify the existing alignment pattern, curve radius, tangent angle, transition curve length, superelevation, and other geometric components associated with railway operational performance.

The research procedure began with identifying the research problem related to the feasibility of increasing train speed on the selected curve segment, followed by field survey preparation and coordinate measurement activities. The measured data were processed through geometric calculations based on Indonesian railway regulations, including PD No. 10A of 2016, Ministry of Transportation Regulation No. 32 of 2011, and Regulation No. 60 of 2012. Data analysis techniques used in this study included quantitative geometric analysis, comparative analysis between existing and planned curve conditions, and technical evaluation of curve suitability for 160 km/h train operation. The analysis focused on calculating curve radius, curve length, tangent angle, mid-ordinate, transition curve length, and superelevation values to determine whether the existing curve geometry fulfilled the required safety and operational standards. The results of the analysis were then interpreted to formulate technical recommendations regarding curve redesign, infrastructure adjustment, and railway alignment improvement for future speed enhancement implementation.

RESULTS AND DISCUSSION

From the research process that has been carried out on horizontal curve number 21 at KM 201 + 064 to KM 201 + 584 the downstream line between Kertasmaya Station – Arjawinangun Station, Cikampek-Cirebon Corridor (Daop 3 Cirebon) with a track width of 1067 mm. Thus, the results are as follows:

Main Factors of Horizontal Curved Alignment

Horizontal Curve Alignment is two lines that when extended to each other will form an angle connected to a curve in the form of a circle with or without a transitional curve, the main factors that form a curve include Value: Radius, Arrow, Curved Angle, Curved Length, Curve Height.

These data are very important; must be known to know what the Speed of the Railway Plan is when crossing the curve or can even be used as a basis for calculations to design the Curve Alignment.

1. Research Analysis Data of Existing Curved Registers Three-Point Method

Based on the results of the curved alinyemen research, there is a difference in value between the existing register and the register in the field. At km 201+064 to km 201+584, the downstream line between Arjawinangun and Kertasemaya stations has a curved radius of 760 meters.

The difference in the value of the curved radius is caused by the presence of centrifugal force, the centrifugal force tends to push to the outside side of the track or side Where there is a value of elevation on the curve, resulting in the radius of the curve can change according to conditions in the field.

On the curve of km 201+064 to km 201+584 of the downstream line between Arjawinangun Station and Kertasemaya Station, there is a maximum speed limit of 105 km/h that is allowed.

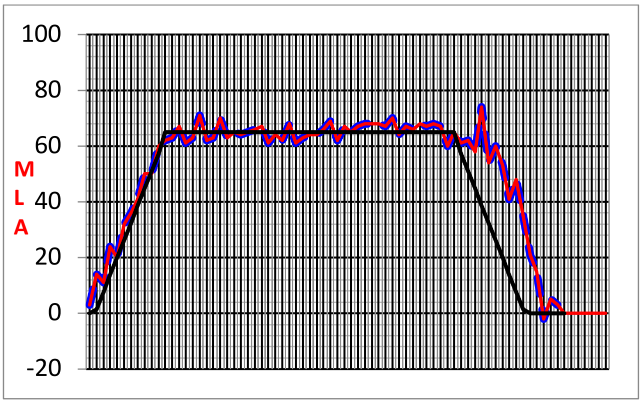

Figure 1 Horizontal Curve Diagram of Arrow Design

2. Analysis Data of Existing Curve Registers Total Station Measurement Method

Curve geometry measurements were carried out using Total Station on the existing curve of Km 200+064 to 201+584. From the measurement activities, hundreds of coordinate points were obtained consisting of Easting (X), Northing (Y), and Elevation (Z) components, as examples of the data produced are as follows.

Table 1 Research Results with Total Station

No	Easting (X)	Northing (Y)	Elevation (Z)	No	Easting (X)	Northing (Y)	Elevation (Z)
1	212863.032	9266358.861	6.822	36	212885.914	9266314.498	6.598
2	212862.583	9266358.660	6.629	37	212885.118	9266314.201	7.091
3	212862.372	9266358.550	6.560	38	212884.144	9266313.767	7.095
4	212862.263	9266358.518	6.517	39	212883.561	9266313.514	6.715
5	212862.218	9266358.498	5.653	40	212883.089	9266313.255	6.502
6	212860.453	9266357.711	4.992	41	212882.624	9266313.089	6.628
7	212858.144	9266356.682	4.763	42	212882.502	9266313.035	6.630
8	212855.939	9266355.700	4.785	43	212882.453	9266313.013	5.640
9	212875.444	9266354.196	6.128	44	212882.155	9266312.880	5.639
10	212860.686	9266353.640	4.770	45	212881.724	9266312.688	5.435
11	212849.916	9266353.073	4.764	46	212880.815	9266312.319	5.150
12	212834.583	9266346.241	4.720	47	212879.066	9266311.504	4.728
13	212816.910	9266338.366	4.716	48	212877.855	9266310.931	4.662
14	212937.227	9266337.420	4.123	49	212877.521	9266310.816	4.576
15	212934.123	9266336.037	4.123	50	212872.727	9266308.680	4.450
16	212931.848	9266335.023	4.185	51	212856.115	9266301.277	4.423
17	212930.049	9266334.221	3.762	52	212903.991	9266295.939	5.220
18	212914.450	9266327.271	3.747	53	212837.529	9266292.996	4.396
19	212888.229	9266325.268	6.234	54	212952.081	9266289.574	3.577
20	212902.372	9266321.889	3.770	55	212936.494	9266282.628	3.564
21	212895.227	9266318.705	4.833	56	212926.880	9266277.994	3.422
22	212894.929	9266318.572	4.902	57	212924.640	9266277.032	3.666
23	212894.080	9266318.100	5.078	58	212922.689	9266276.216	4.021
24	212893.176	9266317.791	5.484	59	212919.967	9266274.977	4.014
25	212892.686	9266317.573	5.587	60	212917.893	9266274.109	3.962
26	212892.588	9266317.529	6.187	61	212917.595	9266273.976	3.587
27	212891.858	9266317.204	6.170	62	212916.349	9266273.421	3.587
28	212891.814	9266317.184	6.027	63	212916.199	9266273.354	3.841
29	212890.389	9266316.566	6.590	64	212916.054	9266273.290	4.246
30	212889.788	9266316.304	6.847	65	212915.182	9266272.901	4.937
31	212888.786	9266315.835	6.869	66	212912.976	9266271.918	5.490
32	212888.204	9266315.549	6.584	67	212912.964	9266271.913	6.076
33	212887.683	9266315.319	6.294	68	212912.246	9266271.593	6.077
34	212887.207	9266315.131	6.303	69	212912.124	9266271.539	5.999
35	212886.831	9266314.964	6.232	70	212910.928	9266270.966	6.377

Based on these data, the pattern of horizontal coordinate changes shows the shape of the alignment that follows the curved configuration. The shift of the X and Y values between points occurs gradually, indicating that the transition from the straight to the curve and back to the next trajectory can be well identified.

In general, the results of shooting the total station can provide the coordinates of the curved components by producing Easting (X), Northing (Y), and Elevation (Z) values, so that the data can be processed with Autocad, the results of the data that have been input into Autocad produce the following picture:

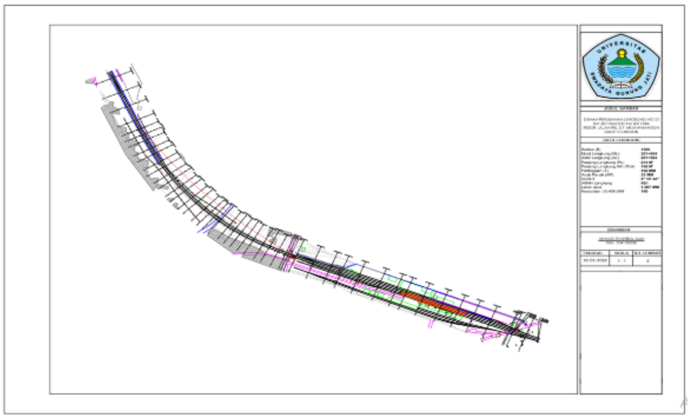

Image 1 Total Station Data Input Results to Autocad

3. Recommended Amount of Horizontal Curved Register Value

The Plan to Increase the Speed of Railways from the initial speed of 120 km/h to a speed of 160 km/h is a form of improving the quality of service to users of Railway passenger services, before the plan is officially enforced, there needs to be technical studies, especially on the feasibility of Railway Infrastructure, especially on the Geometry of Curved Rail Roads, Analysis of technical studies in the form of calculations of Curved Radius, Curved Length, Curved Angles, Arrows and Curved Heights Based on Official Regulation Number 10A of 2016 in accordance with the Railway Plan Speed of 160 km/h.

a. Curvature Radius

Radius Calculation Using the Formula: 4.3 $\sqrt{R}$ with the Value of the Plan Speed Equation = Maximum Speed of the Train at the time of Crossing the Curve, in this case the planned speed of the train uses 160 km/h.

Cast :

Plan Speed = 4.3 $\sqrt{R}$

160 km/h = 4.3 $\sqrt{R}$

$$\sqrt{R} = \frac{160}{4,3} = 37 \text{ (R min = 1.385 meter)}$$

b. Elevation of Curve (H Theoretical)

The Height of the Curve / Slope of the Curve must have a correlation relationship / conformity with the Radius Calculation of a curve, in accordance with the Guidelines of the Official Regulation Number 10A of 2016 concerning the Maintenance of Railway Lines Width

of 1067 mm The maximum limit of a Allowed Height of a Curve is 110 mm. The calculation is as follows:
Normal H: maximum 110 mm
V Plan : 160 km/h
R (Radius) : 1385 meters (according to initial calculation)

$$\text{H normal} = 5{,}95 \times \frac{V^2}{R}$$

$$\text{H normal} = 5{,}95 \text{ x } \frac{(160 \text{ x } 160)}{1385 \text{ m}}$$

H normal = 110 mm
(The height is still appropriate but too close to the tolerance limit. Ideal radius of 1500 meters for a speed of 160 km/h)

c. Switching Curve Length

The Switching Curve serves as a smoothing when the Train crosses the Curve Peak, the Switching Curve has a Height Value and Arrows that vary according to the Switching Curve calculation formula itself. The calculation is as follows:
(PLA) = $0{,}01\ X\ V\ X\ H$
PLA = 0.01 X 160 km/jam x 102 mm
PLA = 163 m ≈ 165 m (rounded up).

d. Curved Length

Planning the Curve Length Design must know what is the speed of the plan to be used, what is the value of the Design Curve Radius, the Curve Design Value is known, namely: 1500 meters for the Plan speed of 160 km/h then you can get a Curve Length using the following Calculation Formula:
Known a Rail Road Curve
Radius = 1500 Meter
Mark;
Tangent Angle

$$(PL) = \frac{a^0 \text{ x } \pi r}{180^0}$$

$$(PL) = \frac{8^0 11'50'' \times 3.14 \times 1500}{180^\circ}$$

= 214 meters

e. Tangent Angle Alpha (a^0)

The Tangent Alpha angle is very important to know because it has a relationship in determining the design of the plan Radius and the Curve Length of the plan, from the previous calculation data it is known that to plan a railway speed of 160 km/h requires an arch radius of 1500 meters and a curve length of 214 meters.

Formula for Finding Curved Tangent Angles:
Mark;

$$\text{Tangent Angle } (a^\circ) = \frac{PL \times 180^o}{3.14 \times r}$$

$$(a^\circ) = \frac{(214\ Meter) \times 180^o}{(3.14 \times 1500)}$$

$$= 8^\circ 10'42''$$

f. Curved Arrow

Based on previous research data, a Radius value of 1500 meters was obtained to support the speed of a railway of 160 km/h, from this data was developed to find the value of the curved arrow

Formula for Finding Arrows
Description :
R = Curvature Radius
F (AP) = Curved Arrow

$$F = \frac{50{,}000\ mm}{R}$$

$$F = \frac{50{,}000\ mm}{1500\ m}$$

$$F = 33\ mm/meter$$

g. The Effect of Changes on the Curved Register

Based on the results of the analysis in the field, in order to support the plan to increase the speed of the railway from the speed of 120 km/h to the speed of the Plan of 160 km/h, there are several things that must be fulfilled, as attached is the Curved Register comparison data.

Table 2 Changes to the existing curved register to the 160 km/h register plan

Curved Parts	Value of Existing Register	Value of Research Register	Nilai Register Kec. 160 km/jam	Units
Radius	770	760	1500	meter
Curved Length (PL)	520	520	214	meter
Sudut a°	38°42’46”	39°13’20”	8°10’42”	Degrees
Elevation (T)	94	98	102	millimetre
Start Curve	65	66	33	millimetre
Start Curve (ML)	201+064	201+064	201+064	meter
Curved End (AL)	201+584	201+584	201+584	meter

h. The Effect of the Railway Improvement Plan on the Structure of the Railway Road

Changes in the Design of the Radius of the Curve which originally had a radius of 760 meters must be changed to a Radius of 1500 meters. The change in Radius affects the change in the existing Curve Register and also has an impact on the change in the US Track point.

With the change of the AS Track (AS Track), it is necessary to make a new body by ploughing or making a new ground according to the needs of the location. These changes are shown in the following table.

Table 3 US Track Point Change (US Track)

Topographic Points	U.S. Track Point Upstream to Downstream Line	Change of US Point Track Downstream to US Point Plan	Units
KM 201+004	5	16	meter
KM 201+104	5	17	meter
KM 201+204	6	26	meter
KM 201+304	6	31	meter
KM 201+404	6	31	meter
KM 201+504	6	22	meter
KM 201+604	6	7	meter

i. The Effect of the Railway Improvement Plan on Train Travel Time

Table 4 Comparison of Travel Time Between Kertasmaya Station - Arjawinangun Cikampek - Cirebon Corridor

No	Train Name	TRAIN Code	Train Speed 105 Km/h Entrance St.Awn	Train Speed 105 Km/h Entering St.Ktm	Train Speed 160 Km/h Entrance St.Awn	Train Speed 160 Km/h Entrance St.Ktm
1	Sawunggalih	113B	00.03.00	00.05.30	00.03.00	00.04.50
2	Harina	95	00.32.00	00.34.30	00.32.00	00.33.50
3	Gajayana	35	00.41.00	00.43.30	00.41.00	00.42.50
4	Taksaka	45	01.01.00	01.03.30	01.01.00	01.02.50
5	Argo Dwipangga	15	01.16.00	01.19.30	01.16.00	01.17.50
6	Argo Sindoro	19	01.27.00	01.29.30	01.27.00	01.28.50

The travel time of the train from Arjawinangun Station to Kertasmaya Station with a train speed of 105 Km/H can be reached in 2 minutes and 30 seconds and if the Train Speed Increase Plan can be realized, then the travel time from Arjawinangun Station to Kertasmaya Station can be traveled with a time of 1 minute 50 seconds or faster 1 minute 20 seconds than the time before.

CONCLUSION

The conclusion of the study shows that the curved geometry of No. 21 Km 201+064 to 201+584 has not fully met the requirements to support the plan to increase the speed of train operations to 160 km/h. This is due to the existing curved radius of 760 meters which is only able to support a maximum speed of around 105 km/h, so adjustments are needed if the speed increase is to be realized. In addition, the formation of horizontal curved lines is influenced by several main factors such as curved radius, curved length, angle, curved arrows, and height, which are interrelated and affect the safety, comfort, and stability of train travel. Based on the results of the research, a recommendation for a curved register was also obtained as a technical reference if an increase in speed of up to 160 km/h will be implemented. Suggestions that can be given include the need to comprehensively adjust the height value and length of the switching curve so that the lateral and centrifugal forces that occur when the train crosses the curve can be smoother, safer, and more comfortable. In addition, if the speed increase is to be realized, it is necessary to conduct a thorough evaluation of the condition of the infrastructure such as ballast thickness, bearing condition, rail anchoring system, and surrounding environmental factors to ensure the stability of the line in the long term. The results of this research are also expected to be a technical and academic reference for various parties in the development of rail road infrastructure. On the other hand, there needs to be a policy adjustment related to the plan to increase the speed up to 160 km/h, considering that the current regulations still limit the maximum speed to 120 km/h.

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