

Geometry Design of Railway Track for High-Speed Railways Bandung-Cirebon KM 00+000 - KM 33+850

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ABSTRACT

Efficiency, comfort, speed and timeliness are the main factors humans need in mobilisation and transportation. In providing a theoretical basis and technical reference for the quality improvement of high-speed railways in Indonesia, this study comprehensively discusses the theory of geometrical design of high-speed railway tracks and the calculation of excavation and embankment volumes. By using Minister of Transportation regulations Number 7 of 2022 and TB 10621-2014, which contains technical planning for high-speed railway tracks, an alternative route is planned across Bandung to Cirebon Phase I (Rancaekek-Cimalaka) with an operating speed of 350 km/hour, there are 5 horizontal curves and 16 vertical curves calculated using TB 10621-2014 and AutoCAD Civil 3D software. The results obtained from this study are alternative planning of the high-speed railway route along 33,850 meters from Bandung to Cirebon Phase I (Rancaekek- Cimalaka).

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1. INTRODUCTION

In today's world, railways have become one of the most advanced and rapidly developing forms of transportation. The reasons are relatively low air pollution per passenger, compared to cars, and the very high speeds that can be achieved by the most advanced modern trains, e.g. China's Maglev trains, whose maximum speed is recorded to be 623 km/h. The construction of the Jakarta Bandung High-Speed Train is both an icon and a momentum for Indonesia to modernise mass transportation in an era of continuous progress.

The Jakarta Bandung High-Speed Train will cross several stations, starting from Halim Station - Karawang Station - Padalarang Station - Tegalluar Station, which will take approximately 36-45 minutes, then from Padalarang station will be a meeting station between the fast train and the Jakarta Bandung High-Speed Train feeder train which will go to Bandung Station (using the feeder train) with a travel time of approximately 22 minutes. The speed of the Jakarta Bandung High-Speed Train can be set between 250-350 kilometres per hour. However, with modern technology, namely high-speed trains that PT Kereta Cepat Indonesia China will operate, it is necessary to conduct a study to extend the high-speed rail line to streamline and maximise the performance of high-speed rail facilities and infrastructure. Based on information from the government, the high-speed rail line has a master plan to cross from Jakarta to Surabaya, which cuts the time to only 4 hours.

The future development of the critical technologies of high-speed rails, such as dynamic technology, structural safety technology, passive safety protection technology, fluid-structure combined technology, traction and brake technology, intelligent control safety technology, prognostic and health management technology, comprehensive energy-saving technology, etc. [2]. Based on the National Railway Master Plan, fast train technology development is relatively rapid and no longer exclusive, as shown by the increasing number of countries that use fast trains as a mainstay mode choice [3].

Through continuous technological innovation, critical technological breakthroughs have been made in a series of crucial high-speed rail technologies, and independent research and development capabilities have been established, continuously improving high-speed rail safety, reliability, economy, environmental friendliness, and intelligence. The high-speed rail produced by China has excellent comprehensive performance indicators, such as operating speed, comprehensive comfort, safety, reliability, energy conservation, environmental protection, etc [2].

Railroad tracks must be built with proper geometry and be solid and stable enough to ensure the safety of train travel. In addition, the ballastless track is now widely applied in high-speed and urban rail transit. It uses concrete slabs with good integrity to replace bearings and ballasts, continuously maintain track geometry, and substantially reduce the level of repair and maintenance work required [5].

The high-speed rail safety management system consists of four main components. First, System Assurance provides a legal and regulatory basis for high-speed rail safety related to technical aspects. As the third component, Personnel Organization provides qualified and well-trained human resources. Finally, the fourth component is Emergency Rescue, which has an emergency support program to deal with emergencies [7].

2. RESEARCH METHOD

The data processing method in this research consists of three stages. The first stage is data reduction, where surveys are conducted on the existing high-speed railway line across Bandung to record line coordinates and plot them on topographic maps. The second stage is data presentation, where the survey data is analysed and used to create a new trajectory. Furthermore, geometry calculations were carried out based on the guidelines of Minister of Transportation Regulation No. 7 of 2022, considering the field's topography. The third stage is ecclesia drawing, where initial conclusions are drawn based on the planning, calculations, and depictions that have been done. These provisional conclusions may change with strong evidence in the following data collection stage.

In the data analysis stage of this research, several steps were taken. First, alternative trajectories were selected by considering RTRW data from the West Java Provincial Government, Bandung Regency, and Sumedang Regency to avoid interfering with local planning. Then, a survey was conducted on the Bandung-Cirebon Phase I (Rancaekek – Cimalaka) high-speed rail line to obtain direct information about the field conditions that will be used as a trace and the coordinate data from the survey was used for plotting the trace area. Analysis was performed on topographic maps to obtain contours of the specified area. Contour data is obtained from DEMNAS. After obtaining the contours, the planning and calculation of railroad geometry, including horizontal alignment, vertical alignment, slope, railroad structure, maximum speed, and calculation of excavation and embankment volume, are carried out. Guidelines for calculating railroad geometry refer to Transportation Regulation No. 7 Year 2022 and TB 10621-2014.

Furthermore, the upper structure of the railway line was drawn using AutoCAD Civil 3D software to obtain the details of the line's persecution. Finally, conclusions are drawn from the data analysis and depiction of the railway line, and suggestions are given in planning the Bandung-Cirebon Phase I (Rancaekek-Cimalaka) high-speed railway line.

3. RESULTS AND DISCUSSION

3.1. Alternative trace plan based on RTRW and RIPNAS

The Bandung-Cirebon high-speed railway line has been planned in RIPNAS and Bappenas. The Ministry of Transportation has planned the construction of a fast train that can serve passengers from Jakarta to Surabaya. However, the plan has changed due to funding constraints; the route has changed from Jakarta to Bandung [9]. In planning the Bandung-Cirebon railway line, researchers considered the Bandung Regency and West Java Province Spatial and Regional Plans (RTRW) to avoid clashes with infrastructure development planned by the local government. Researchers chose an alternative route primarily adjacent to the Cisumdawu toll road.

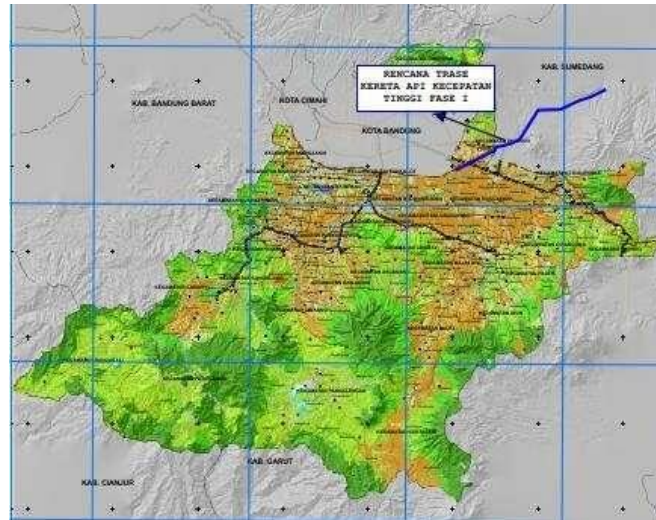


Figure 1. Bandung Regency RTRW Map

The Bandung Regency RTRW map in Figure 1 shows several areas traversed by the alternative plan for the Bandung-Cirebon Phase I high-speed railway line. Researchers planned alternative trajectories that were adjusted to field and traffic conditions in Bandung Regency. The planned trajectory passes through Rancaekek District and Cileunyi District. Data on the field conditions of the alternative trajectory were obtained through surveys by exploring based on the planned coordinate plots. Data collected in the field included photo documentation and GPS location coordinate capture.

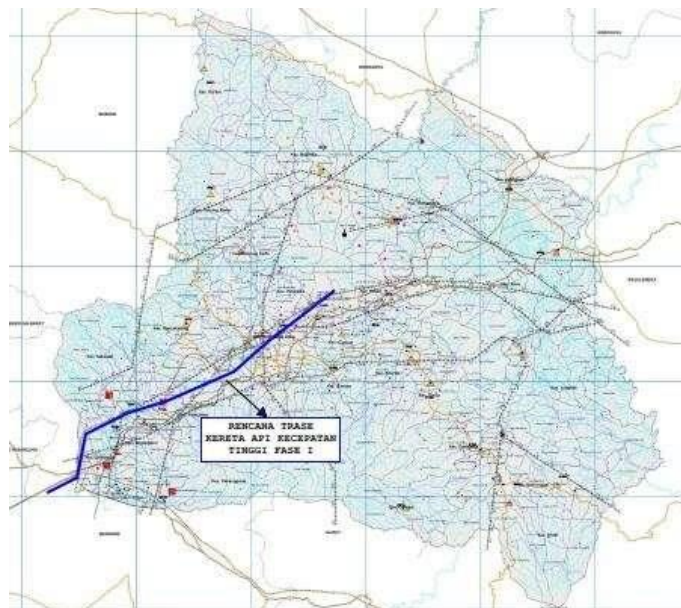


Figure 2. Sumedang Regency RTRW Map

Figure 2 shows some areas traversed by the planned high-speed railroad trajectory for Bandung-Cirebon Phase I. Researchers suggest alternative trajectories adapted to field and traffic conditions in Sumedang Regency. The majority of the trajectory is adjacent to the operating Cisumdawu toll road. Hence, it crosses several areas of Sumedang Regency, including Jatininggor District, Tanjungsari District, Pamulihan District, North Sumedang District, and Cimalaka District. This alternative trajectory can be considered for further research.

3.2. Geometry planning

Before geometry planning, researchers used contour data from the DEMNAS website to obtain a more accurate contour map. The National DEM data comes from several data sources, including IFSAR (5m resolution), TERRASAR-X (5m resampling resolution from the original 5-10m resolution), and ALOS PALSAR (11.25m resolution). Researchers also added mass point data from the Indonesian Rupabumi map (RBI).

The geometry planning of the Bandung- Cirebon railway line refers to the Minister of Transportation Regulation No. 7 Year 2022 on Technical Requirements for High-Speed Railways and TB 10621-2014. The operating speed is planned to be 350 km/h, while the maximum is 400 km/h. The width of the railroad used is 1435 mm. A lower operating speed than the maximum speed was chosen to avoid travel disruptions caused by too high a speed. The track design plan uses a double track with a width of 1435 mm for high-speed trains.



Figure 3. Topography of Alternative Track

Figure 3 shows that the topography on the alternative route passes through a relatively high area with the lowest elevation of 465 meters above sea level and the highest elevation of 935 meters above sea level. With the different topography, it is one of the challenges for researchers to design a path plan that is quite efficient and economical. Then, the maximum slope that has been planned is 30%.

3.3. Horizontal alignment Calculation

Table 1. Horizontal curvature

		Start	End	(m)	Transition (m)	(Km/h)
1	Spiral	01+719,475	02+179,475		460	300
	Circle	02+179,475	02+209,042	3000		300
	Spiral	02+209,042	02+669,042		460	300

2	Spiral	02+998,278	03+258,278		260	160
	Circle	03+258,278	04+737,500	1500		160
	Spiral	04+737,500	04+997,500		260	160
3	Spiral	05+972,272	06+242,272		270	200
	Circle	06+242,272	08+754,936	2500		200
	Spiral	08+754,936	09+024,936		270	200
4	Spiral	21+460,241	22+010,241		550	300
	Circle	22+010,241	24+367,454	5500		300
	Spiral	24+367,454	24+967,454		600	300
5	Spiral	25+670,215	25+910,215		240	200
	Circle	25+910,215	26+326,989	2500		200
	Spiral	26+326,989	26+566,989		240	200

Table 1 shows the horizontal curve data on the Bandung-Cirebon Phase I alternative high-speed railroad line. Based on the table above, it is known that the alternative high-speed railway line across Bandung-Cirebon Phase I has 5 curves with the smallest radius of 1500 meters and the largest radius of 5500 meters. The horizontal curve used uses a transitional curve (Spiral - Circle - Spiral) with the following formula:

$$R_{min} = 11,8 \frac{v^2}{(h_r + h_q)} \quad (1)$$

$$V_{max} = \sqrt{\frac{R_r(h_r + h_d)}{11,8}} \approx 0,29 \sqrt{R_r(h_r + h_d)} \quad (2)$$

$$L_{min \text{ peralihan}} \geq \frac{v}{3,6} \times \frac{h_q}{[\beta]} \quad (3)$$

$$h_r = 11,8 \frac{v^2}{R} - h_q \quad (4)$$

$$\alpha A - P1 = \arctan \frac{\Delta X}{\Delta Y} \quad (5)$$

$$\alpha P1 - P2 = \arctan \frac{\Delta X}{\Delta Y} \quad (6)$$

$$\Delta P1 - 1 = (\alpha P1 - P2) - (\alpha A - P1) \quad (7)$$

$$d = \sqrt{\Delta X^2 - \Delta Y^2} \quad (8)$$

$$\theta_s = \frac{90 \times Ls}{\pi \times R \text{ planning}} \quad (9)$$

$$\alpha P1 - P2 = \arctan \frac{\Delta X}{\Delta Y} \quad (10)$$

$$Xs = Ls \left(1 - \frac{Ls^2}{40 \times R \text{ planning}^2} \right) \quad (11)$$

$$Lc = \left(\frac{\Delta - 2\theta}{180} \right) \quad (12)$$

$$Ys = \frac{Ls^2}{6 \times R \text{ planning}} \quad (13)$$

$$p = \frac{Ls^2}{6 \times R \text{ planning}} - R (1 - \cos \theta s) \quad (14)$$

$$k = Ls - \frac{Ls^3}{6 \times R \text{ planning}} - R \sin \theta s \quad (15)$$

$$Ts = (R + p) \times \tan \frac{\Delta s}{2} + k \quad (16)$$

$$Es = (R + p) \times \sec \left(\frac{\Delta s}{2} \right) - R \text{ planning} \quad (17)$$

Table 2. Horizontal curve calculation

Horizontal Alignment		Curve 1	Curve 2	Curve 3	Curve 4	Curve 5
V (Km/h)		200	160	200	300	200
hr (mm)		175	175	130	175	130
hq (mm)		60	60	60	60	60
Rmin (m)		2008,511	1285,447	2484,211	4519,149	2484,211
Curved Vmax (Km/h)		243,496	172,178	200,000	329,696	200,000
L min Switching (m)		313,620	250,896	232,975	470,430	232,975
hr (mm)		97,333	141,387	128,800	133,091	128,800
R plan (m)		3000	1500	2500	5500	2500
Ls plan (m)		460	260	270	550	240
A1	X	801294,577	803682,914	805144,837	806947,980	821301,065
	Y	9230116,152	9231299,283	9232870,265	9236141,270	9242726,975
P1	X	804426,034	803637,347	807731,747	816787,378	823776,344
	Y	9228380,672	9232869,133	9233762,193	9245888,718	9241829,918
A2	X	803682,914	805144,837	806947,980	821301,065	822373,670
	Y	9231299,283	9232870,265	9236141,270	9242726,975	9243903,973
αA-P1 (rad)		-1,065	-0,029	1,239	0,790	-1,223
αP1-P2 (rad)		-0,249	1,570	-0,318	-0,960	-0,595
ΔPI-1 (rad)		0,815	1,599	-1,557	-1,750	0,628
d (m)		3580,211	1570,511	2736,355	13850,144	2632,815
Θs (m)		4,395	4,968	3,096	2,866	2,752
Xs (m)		459,730	259,805	269,921	549,863	239,945
Lc (m)		230	130	135	275	120
Ys (m)		11,756	7,511	4,860	9,167	3,840
p (m)		2,939	1,878	1,215	2,292	0,960
k (m)		229,839	129,902	134,918	274,838	119,930
Ts (m)		886,844	391,833	403,720	822,094	360,242
Es (m)		271,058	115,698	110,941	311,532	13,367

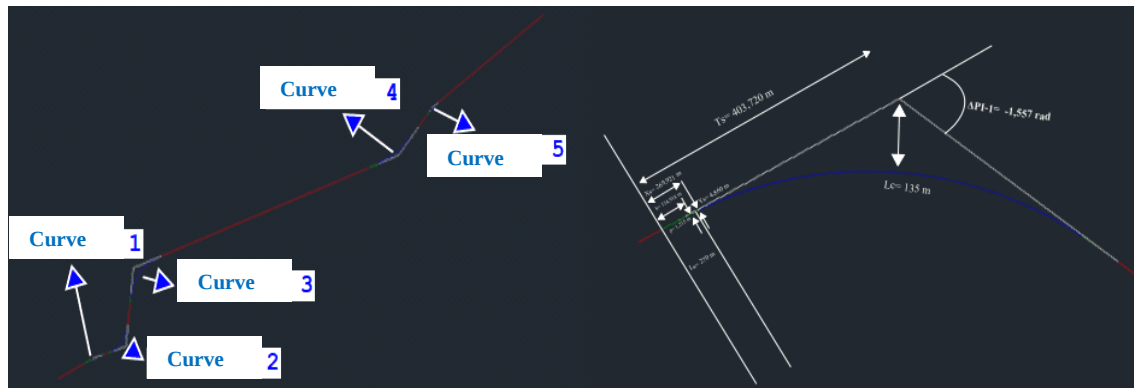


Figure 4. Schematic of Horizontal Curve

Table 2 shows that the calculation results based on Permenhub Number 7 of 2022 and TB 10621-2014 obtained the results as above. The formula researchers use is TB 10621-2014, the code used in calculating high-speed rail planning in China.

Figure 4 (i) shows that the horizontal curve scheme totals 5 curves designed through Autocad and calculations with formulas. An example of a detailed curve scheme can be seen in Figure 4 (ii). In the figure, there are 3 horizontal curves designed with a plan speed of 200 km / h, a maximum speed of 200 km / h, actual rail elevation of 128.8 mm, a maximum rail height 130 mm, 60 mm rail deficiency, plan radius 2500 m, minimum radius 2484.211 m, plan intermediate curve length 270 m, minimum intermediate curve length 232.975 m, $\Delta PI-1$ or curve angle -1.557 rad, $d = 2736.355$ m, $\Theta_s = 3.096$ m, $X_s = 269.921$ m, $L_c = 135$ m, $Y_s = 4.86$ m, $p = 1.215$ m, $k = 134.918$ m, $T_s = 403.720$ m, and $E_s = 110.941$ m. The use of formulas in the design affects the length of the transitional arch to the radius of the planned horizontal arch.

Conclusion The first to fifth horizontal curves have the highest planned speed of 300 km/h, the highest maximum speed on the curves is 329.696 km/h, the maximum rail height is 175 mm, the highest actual rail height is 141.397 mm, largest plan radius 5,500 m, largest minimum radius 4,519.149 m, the largest intermediate curve length of 550 m, and the largest minimum intermediate curve length of 470.430 m. The horizontal arch scheme can be seen in Figure 4 (ii). After obtaining the horizontal curve calculation, calculate the superelevation in the 5 curves with the following formula [1].

$$\text{Point 1} = \frac{\frac{1}{4}L_s}{L_s} \times hr \quad (18)$$

$$\text{Point 2} = \frac{\frac{2}{4}L_s}{L_s} \times hr \quad (19)$$

$$\text{Point 3} = \frac{\frac{3}{4}L_s}{L_s} \times hr \quad (20)$$

$$\text{Point 4} = \frac{L_s}{L_s} \times hr \quad (21)$$

Table 3. Superelevation

Superelevation	Curve 1	Curve 2	Curve 3	Curve 4	Curve 5
Plan Ls (m)	460	260	270	550	240
Lc (m)	230	130	135	275	120
hr (mm)	97,333	141,387	128,800	133,091	128,800
Point 1 (mm)	24,333	35,347	32,200	33,273	32,200
Point 2 (mm)	48,667	70,693	64,400	66,545	64,400
Point 3 (mm)	73,000	106,040	96,600	99,818	96,600
Point 4 (mm)	97,333	141,387	128,800	133,091	128,800

In Table 3, there are calculations of superelevation in 5 horizontal curves, which obtained the highest actual elevation data of 141.387 mm in curve 2 and the lowest actual elevation of 97.333 mm in curve 1.

3.4. Vertical alignment Calculation

Calculation of vertical alignment has been calculated by researchers based on TB 10621-2014; the formula is the code used to calculate high-speed train planning in China. Vertical alignment planning uses the following formula.

$$A = (g_1 \pm g_2) < 0\% \quad (22)$$

$$L_v = A \times R_v \quad (23)$$

$$E_v = \frac{A \times L_v}{800} \quad (24)$$

$$L_p = (\Delta i_1 + \frac{\Delta i_2}{2} \times R_v + 0,4 v) \quad (25)$$

Table 4. Vertical Alignment

Vertical Alignment	Curve 1	Curve 2	Curve 3	Curve 4	Curved 5	Curve 6	Curve 7
Rv	17268,075	30000	28000	25000	25000	25000	25000
V plan	300	160	200	300	300	300	300
g1 (%)	0,800	2,170	2,870	2,770	0,420	-0,600	-1,400
g2 (%)	2,170	2,870	2,770	0,420	-0,600	-1,400	-1,360
A (%)	1,370	0,700	0,100	2,350	1,020	0,800	0,040
Lv (m)	23657,263	21000	2800	58750	25500	20000	1000
Ev (m)	40,513	18,375	0,350	172,578	32,513	20,000	0,050
lp	11948,63138	10564	1480	29495	12870	10120	620

Table 5. Vertical Alignment curve 8 – curve 16

Vertical Alignment	Curved 8	Curved 9	Curved 10	Curved 11	Curved 12	Curved 13	Curved 14	Curved 15	Curved 16
Rv	25000	25000	25000	25000	25000	30000	12060,009	19444,444	15918,997
V plan	300	300	300	300	350	350	300	300	300
g1 (%)	-1,360	-2,300	-2,500	-2,800	-2,950	-2,700	-0,700	1,400	2,300
g2 (%)	-2,300	-2,500	-2,800	-2,950	-2,700	-0,700	1,400	2,300	3,000
A (%)	0,940	0,200	0,300	0,150	0,250	2,000	2,100	0,900	0,700
Lv (m)	23500	5000	7500	3750	6250	60000	25326,019	17500	11143,298
Ev (m)	27,613	1,250	2,813	0,703	1,953	150,000	66,481	19,687	9,750
lp	11870	2620	3870	1995	3265	30140	12783,01	8870,00	5691,65

Planning vertical alignment curves, a grade line with an uninterrupted height shape, i.e. a non-linear grade line or a line with a constant line shape, is inserted between the non-inclined section of the rail and the inclined section of the same rail [10]. In Table 4, it can be seen that there are 16 vertical curves designed on the Bandung- Cirebon Phase I high-speed rail line. The vertical curve is more because of the field's significant topographic differences. With these differences, it is necessary to do quite a lot of design to get a smooth slope. The planned vertical alignment has the largest planned radius of 30,000 m in curves 2 and 13 and the smallest planned radius of 12,060.009 m in curve 14 [11] [12].

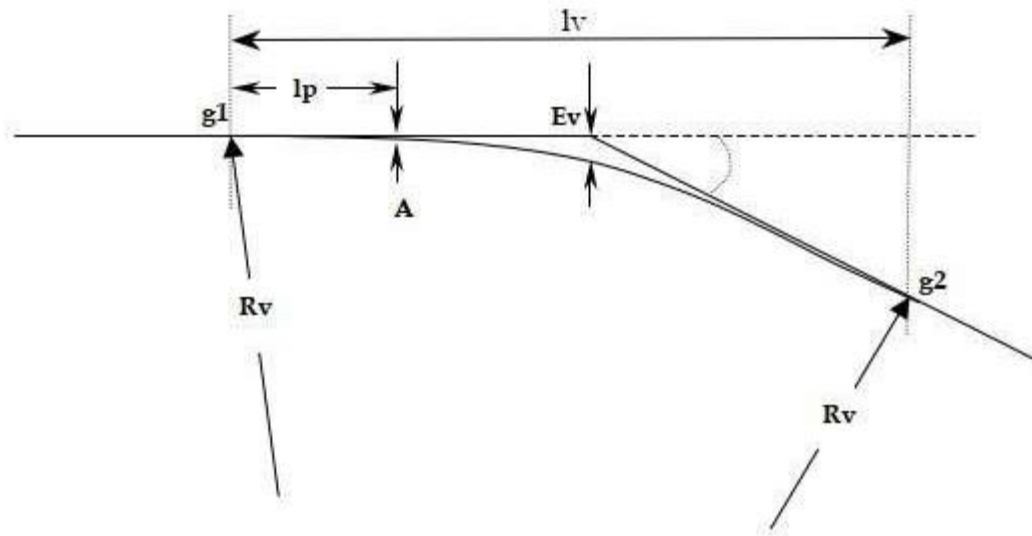


Figure 5. Vertical Alignment Schematic

3.5. Vertical alignment Calculation

The high-speed railroad components' design was depicted in *AutoCad Civil 3D* software. The drawing is done on the *Assembly* menu, as seen in the following figure.

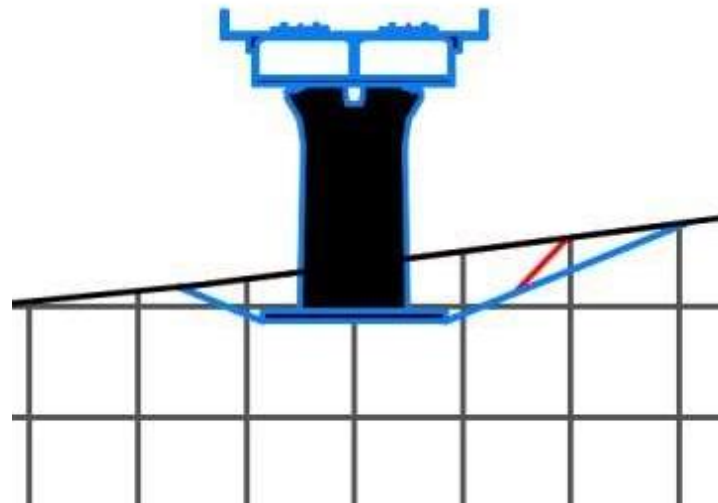


Figure 6. Cross Section of Upper Structure Components

In Figure 6, there is a *cross-section* image of the high-speed railroad line; in the cross-section, it can be seen that the researchers designed the line with an *elevated* type without *ballast* (*ballastless*) because, in the Bandung-Cirebon Phase I crossing, there is a topography that is high enough to require a high and sturdy bottom structure. Therefore, the researchers designed the line to be fully *elevated*. The designed line uses double or two lanes to match the existing line, namely the Jakarta-Bandung crossing. Structural depictions of visible line components are rail, *ballasted*, pillars and pieces of existing land. The depiction of the pillar is only designed with the same or typical height. With this design depiction, further research must be carried out to plan the lower structure. A *ballasted* track is necessary for the train to reach high speeds, while ballasted tracks tend to be more restricted due to the lower structure. With this design, the maximum speed of high-speed trains can reach 350 km/h. Using railroad components using R.60 rail and ballasted is typical of the existing Jakarta-Bandung crossing [14] [15] [16] [17].

3.6. Calculation of excavation and backfill volume

In calculating the volume of excavation and embankment of the railway line, researchers determine it using an average of every 250 meters, according to the cross-section table. Table 5 shows cross sections at km 00+000 and km 00+250. By looking at the table, researchers get the area of the embankment, so the data that can be processed is:

At km 00+000:

Excavation area = 422.54 m²

Stockpile area = 0.00 m²

At km 00+250:

Excavation area = 145.39 m²

Stockpile area = 0.00 m²

Excavation calculation:

Average excavation area :

$$A_{average} = \frac{422.54 + 145.39}{2} = 283.965 \text{ m}^2$$

Average excavation volume:

$$\begin{aligned} Vol_{galian} &= A_{average} \times \text{Track length} \\ &= 283.965 \times 250 = 70,991.30 \text{ m}^3 \end{aligned}$$

Embankment Calculation:

Average stockpile area:

$$A_{average} = \frac{0 + 0}{2} = 0.00 \text{ m}^2$$

Average excavation volume:

$$\begin{aligned} Vol_{galian} &= A_{average} \times \text{Track length} \\ &= 0.00 \times 250 = 0.00 \text{ m}^3 \end{aligned}$$

The excavation and embankment volume calculation above is one example and will be calculated through Table 6.

Table 6. Excavation and Backfill Volume STA 00+000 – 04+000

Station	Cut Area (Sq.M.) (m) ²	Cut Volume (m) ³	Fill Area (Sq.M.) (m) ²	Fill Volume (m) ³	Cum. Cut Vol. (m) ³	Cum. Fill Vol. (m) ³
0+000.00	422.54	0.00	0.00	0.00	0.00	0.00
0+250.00	145.39	70,991.30	0.00	0.00	70,991.30	0.00
0+500.00	107.13	31,565.13	0.00	0.00	102,556.44	0.00
0+750.00	39.12	18,281.14	0.08	9.80	120,837.57	9.80
1+000.00	104.46	17,946.90	0.00	9.80	138,784.47	19.60
1+250.00	324.08	53,567.64	0.00	0.00	192,352.12	19.60
1+500.00	146.64	58,840.62	0.00	0.00	251,192.73	19.60
1+750.00	74.32	27,619.61	0.00	0.00	278,812.34	19.60
2+000.00	53.92	16,027.76	0.00	0.00	294,840.11	19.60
2+250.00	106.17	20,007.75	0.00	0.00	314,847.86	19.61
2+500.00	84.85	23,879.58	0.00	0.00	338,727.44	19.61
2+750.00	25.92	13,845.21	0.00	0.03	352,572.65	19.63
3+000.00	24.33	6,280.38	0.00	0.03	358,853.02	19.66
3+250.00	0.00	3,041.03	81.00	10,122.05	361,894.06	10,141.71

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