JOS - MRK *Volume 5, Nomor 2, Juni 2024, Page 262-269*

JURNAL ONLINE SKRIPSI
MANAJEMEN REKAYASA KONSTRUKSI POLINEMA

Journal homepage: http://jos-mrk.polinema.ac.id/ **ISSN: 2722-9203 (media online/daring)**

EVALUATION OF ROAD GEOMETRIC DESIGN IN THE CANGAR HOT SPRING TOURIST AREA OF BATU CITY

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ABSTRACT

±12-km Jalan Arjuno – Jalan Sumberbrantas Batu is a collector road with quite busy traffic. There are a lot of bends, climbs and also quite sharp descents that make this road uncomfortable for users. The purpose of this article is to redesign the road geometric to comply with applicable design criteria. The results of direct surveys and calculations using existing coordinate data showed that Jalan Arjuno – Jalan Sumberbrantas has ±93 bends consisting of 26 F-C types and 67 S-C-S types. Having calculated the radius of the bends according to the design criteria, it turns out that the existing R value does not meet the minimum R, and the existing road width also does not meet the PDGJ 2021 design criteria. After redesigning according to the Road Geometric Design Guidelines (or PDGJ 2021), it was found 31 S-C-S bends, and 28 vertical curves consisting of 15 sag vertical curves, and 13 crest vertical curves.

keywords : geometric evaluation, redesign, road geometric

1. BACKGROUND

Road is one of the most important facilities for the community that is used as a means of connecting one region to another, therefore the importance of good road geometric design to support community activities to run safely and comfortably. If a road has good geometric and pavement conditions, it greatly affects the safety of road users. Because there are so many cases of traffic accidents caused by improper geometric conditions and road pavement that has been damaged. So this triggers a lack of safety and comfort for motorists which results in traffic accidents. These problems occur in the Cangar Hot Springs Tourism Area where accidents often occur. Because the road geometric design is not good and not in accordance with the standards and design criteria. With this geometric re-planning is expected to reduce traffic accidents and provide safety and comfort for motorists who pass through it. Where this re-planning refers to the 2021 Road Geometric Design Guidelines (PDGJ) and the 2017 Road Pavement Design Manual.

2. METHOD

The research study location is located on the Jalan Raya Arjuno – Jalan Raya Sumberbrantas section at STA 0+000 - STA 11 + 998.

Figures 1. Study Area
Source: Research Data

In this study, geometric replanning of roads using the 2021 Indonesian Road Geometric Design Guidelines with the help of the AutoCAD Civil 3D 2024 application. The following is a flow chart in road geometric replanning:

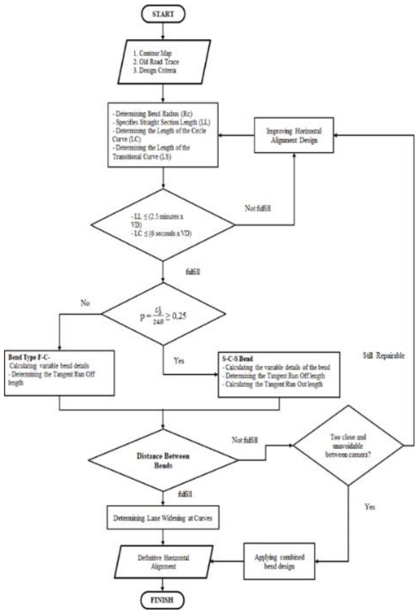
a. Evaluation of Existing Conditions

The stages of evaluating existing conditions are:

1. Research site survey (Jalan Raya Arjuno – Jalan Raya Sumberbrantas)

2. Data Collection
3. Comparing one of the existing technical criteria with the provisions of the 2021 Road Geometric Design Guidelines.

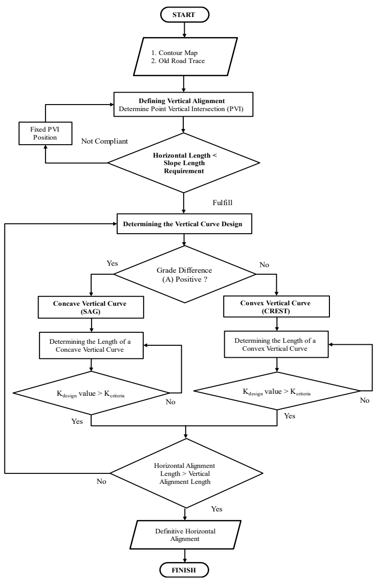
b. Horizontal Alignment Redesign



Figures 2. Horizontal Alignment Flowchart

Source: PDGJ 2021

c. Vertical Alignment Redesign



Figures 3. Vertical Alignment Flowchart
Source: PDGJ 2021

3. RESULT & DISCUSSION

- **Evaluation of Horizontal Alignment**

To get the value of the existing bend radius of the road, the planner tries to get the existing R from the measurements on Google Earth by drawing tangent lines on both sides of the bend (the starting point of the bend and the end point of the bend) until they intersect at one point. Furthermore, to get the Radius value, namely by drawing a radius line right on the tangent line that coincides with both sides of the bend by paying attention to the end of the curve of the bend taken. Of the total 93 bends in the study location, it turns out that all bends do not meet the standards in the aspect of the bend radius.

The results of the horizontal alignment evaluation are presented in the following table.

Table 1. Evaluation of Rexisisting

PI No	P (meter)	Type of Bend	Rmin (m) (V_D=60 km/jam)	R (m) (Existing)	Description
PI 1	0.786	Ok S-C-S	122.000	55.4	Not Fulfill
PI 2	0.176	Not Ok F-C	122	40	Not Fulfill
PI 3	1.0917	Ok S-C-S	122	68.4	Not Fulfill
PI 4	1.0765	Ok S-C-S	122	81.9	Not Fulfill
PI 5	0.6934	Ok S-C-S	122	40	Not Fulfill
PI 6	0.119	Not Ok F-C	122	35	Not Fulfill
PI 7	1.3572	Ok S-C-S	122	53.3	Not Fulfill
PI 8	1.1136	Ok S-C-S	122	66	Not Fulfill
PI 9	0.6445	Ok S-C-S	122	34.5	Not Fulfill
PI 10	0.6089	Ok S-C-S	122	41.3	Not Fulfill
PI 11	0.5724	Ok S-C-S	122	32.1	Not Fulfill
PI 12	0.9081	Ok S-C-S	122	25.7	Not Fulfill
PI 13	1.1045	Ok S-C-S	122	31	Not Fulfill
PI 14	0.972	Ok S-C-S	122	46.4	Not Fulfill
PI 15	0.6168	Ok S-C-S	122	32.2	Not Fulfill
PI 16	0.6962	Ok S-C-S	122	43.2	Not Fulfill
PI 17	0.4995	Ok S-C-S	122	22.8	Not Fulfill
PI 18	0.6136	Ok S-C-S	122	22	Not Fulfill
PI 19	0.293	Ok S-C-S	122	32	Not Fulfill
PI 20	0.381	Ok S-C-S	122	28	Not Fulfill
PI 21	0.1067	Not Ok F-C	122	25	Not Fulfill
PI 22	0.1437	Not Ok F-C	122	29	Not Fulfill
PI 23	0.5097	Ok S-C-S	122	10.5	Not Fulfill
PI 24	0.2521	Ok S-C-S	122	20	Not Fulfill
PI 25	0.3525	Ok S-C-S	122	23.5	Not Fulfill
PI 26	0.3388	Ok S-C-S	122	21	Not Fulfill
PI 27	0.4167	Ok S-C-S	122	10	Not Fulfill

PI 28	0.0167	Not Ok F-C	122	10	Not Fulfill
PI 29	0.0167	Not Ok F-C	122	10	Not Fulfill
PI 30	0.3159	Ok S-C-S	122	20.5	Not Fulfill
PI 31	0.182	Not Ok F-C	122	15.3	Not Fulfill
PI 32	0.391	Ok S-C-S	122	13.7	Not Fulfill
PI 33	0.463	Ok S-C-S	122	19	Not Fulfill
PI 34	0.326	Ok S-C-S	122	18.4	Not Fulfill
PI 35	0.333	Ok S-C-S	122	18	Not Fulfill
PI 36	0.323	Ok S-C-S	122	7.98	Not Fulfill
PI 37	0.375	Ok S-C-S	122	16	Not Fulfill
PI 38	0.245	Not Ok F-C	122	11.8	Not Fulfill
PI 39	0.309	Ok S-C-S	122	13.5	Not Fulfill
PI 40	0.278	Ok S-C-S	122	10.4	Not Fulfill
PI 41	0.354	Ok S-C-S	122	18.9	Not Fulfill
PI 42	0.201	Not Ok F-C	122	12.7	Not Fulfill
PI 43	0.311	Ok S-C-S	122	15.7	Not Fulfill
PI 44	0.237	Not Ok F-C	122	13.2	Not Fulfill
PI 45	0.404	Ok S-C-S	122	16.8	Not Fulfill
PI 46	0.411	Ok S-C-S	122	29.3	Not Fulfill
PI 47	0.278	Ok S-C-S	122	15	Not Fulfill
PI 48	0.536	Ok S-C-S	122	20.3	Not Fulfill
PI 49	0.285	Ok S-C-S	122	14.6	Not Fulfill
PI 50	0.185	Not Ok F-C	122	10.8	Not Fulfill
PI 51	0.230	Not Ok F-C	122	11.6	Not Fulfill
PI 52	0.378	Ok S-C-S	122	20	Not Fulfill
PI 53	0.300	Ok S-C-S	122	15.8	Not Fulfill
PI 54	0.347	Ok S-C-S	122	12	Not Fulfill
PI 55	0.436	Ok S-C-S	122	15	Not Fulfill
PI 56	0.231	Not Ok F-C	122	18	Not Fulfill
PI 57	0.315	Ok S-C-S	122	17	Not Fulfill
PI 58	0.044	Not Ok F-C	122	15	Not Fulfill
PI 59	0.107	Not Ok F-C	122	14	Not Fulfill
PI 60	0.167	Not Ok F-C	122	16	Not Fulfill
PI 61	0.140	Not Ok F-C	122	19	Not Fulfill
PI 62	0.148	Not Ok F-C	122	18	Not Fulfill
PI 63	0.358	Ok S-C-S	122	20.7	Not Fulfill
PI 64	0.386	Ok S-C-S	122	24.3	Not Fulfill
PI 65	0.280	Ok S-C-S	122	18	Not Fulfill
PI 66	0.306	Ok S-C-S	122	15	Not Fulfill
PI 67	0.297	Ok S-C-S	122	17	Not Fulfill
PI 68	0.183	Not Ok F-C	122	19.1	Not Fulfill
PI 69	0.371	Ok S-C-S	122	14	Not Fulfill
PI 70	0.335	Ok S-C-S	122	14.6	Not Fulfill
PI 71	0.443	Ok S-C-S	122	24.1	Not Fulfill
PI 72	0.511	Ok S-C-S	122	32.6	Not Fulfill
PI 73	0.058	Not Ok F-C	122	26	Not Fulfill
PI 74	0.351	Ok S-C-S	122	22.6	Not Fulfill
PI 75	0.419	Ok S-C-S	122	22.4	Not Fulfill
PI 76	0.321	Ok S-C-S	122	20.4	Not Fulfill
PI 77	0.340	Ok S-C-S	122	24	Not Fulfill
PI 78	0.198	Not Ok F-C	122	21	Not Fulfill
PI 79	0.274	Ok S-C-S	122	21.3	Not Fulfill
PI 80	0.309	Ok S-C-S	122	19.4	Not Fulfill
PI 81	0.280	Ok S-C-S	122	20.6	Not Fulfill
PI 82	0.262	Ok S-C-S	122	18.1	Not Fulfill
PI 83	0.474	Ok S-C-S	122	19	Not Fulfill
PI 84	0.310	Ok S-C-S	122	18.3	Not Fulfill
PI 85	0.217	Not Ok F-C	122	11.3	Not Fulfill
PI 86	0.337	Ok S-C-S	122	14.5	Not Fulfill
PI 87	0.033	Not Ok F-C	122	20	Not Fulfill
PI 88	0.382	Ok S-C-S	122	19.5	Not Fulfill
PI 89	0.254	Ok S-C-S	122	13.3	Not Fulfill
PI 90	0.239	Not Ok F-C	122	16.3	Not Fulfill
PI 91	0.478	Ok S-C-S	122	12.2	Not Fulfill
PI 92	0.140	Not Ok F-C	122	8.46	Not Fulfill
PI 93	0.208	Not Ok F-C	122	20	Not Fulfill

From the evaluation of the Resksisting value and the p value above, it is obtained that 93 existing bend radius do not meet the Rminimum design criteria of 122m. of the 93 bends there are 26 F-C type bends and 67 S-C-S type bends.

- **Redesign**

After being evaluated according to the geometric planning standards of inter-city roads, it must be re-planned on its own horizontal alignment and vertical alignment. And the next step is to establish design criteria to serve as a reference in the geometric re-planning stage.

1) Design Criteria

These design criteria refer to the technical data of roads that have been built with adjustments to the latest guidelines in the 2021 Road Geometric Design Guidelines.

Tabel 2. Main Design Criteria

No.	Elemen Kriteria Desain Utama	Nilai Kriteria Desain Utama
1	Peran menghubungkan	Titik Start Point ke Titik Ending Point sebagai bagian dari peran menghubungkan IKK ke IKK

2	Penggolongan Jalan (Atribut Jalan)	Jalan Umum
		SJJ : Primer
		Status : Jalan Provinsi
		Fungsi : Jalan Kolektor Primer
		Kelas : III
		SPPJ : JSD
3	Rentang Vd, Km/Jam	30-70

Source : PDGJ 2021

Tabel 3. Technical Design Criteria

No	Elemen Kriteria Desain Teknis Geometrik Jalan		Nilai Kriteria
1	V_D, Km/Jam		50
2	Grade max, %		8
3	Kekesatan Melintang paling besar (f max)		0.160
4	Superelevasi paling besar (e max), %		8%
5	R min lengkung horizontal, m		83
6	L min lengkung vertikal, m, atau nilai K		Kcembung > 7 Kcekung > 13
7	Panjang bagian lurus paling panjang, m		2083
8	Tipe jalan dan Dimensi jalan	Tipe Jalan	2/2-TT
		Lebar lajur, m	5
		Lebar bahu, m	2
9	Kelandaian Melintang	Lajur Jalan, %	3
		Bahu, %	5
10	Jenis Perkerasan		AC (Asphalt Concrete)
11	Ruang Jalan	Rumaja, m	11
		Rumija, m	15
		Ruwasja, m	10

Source : PDGJ 2021

2) Road Trace

The following are the trajectory coordinates in the previous planning:

Tabel 4. Trace Coordinate

No	POINT	X-AXIS	Y-AXIS
1	Starting Point	668493	9136280
2	PI 1	668375	9137351
3	PI 2	667951	9137535
4	PI 3	668068	9137899
5	PI 4	667670	9138007
6	PI 5	667846	9138338
7	PI 6	667804	9138581
8	PI 7	668013	9138698
9	PI 8	667997	9139011
10	PI 9	668310	9139214
11	PI 10	668071	9139551
12	PI 11	668485	9139532
13	PI 12	668364	9139825
14	PI 13	668575	9140016
15	PI 14	668438.52	9140306
16	PI 15	668696	9140384
17	PI 16	668718	9140624
18	PI 17	668963	9140722
19	PI 18	669005	9140939
20	PI 19	668597	9140989
21	PI 20	668737	9141266
22	PI 21	668411	9141390
23	PI 22	668394	9141867
24	PI 23	668927	9141969
25	PI 24	668668	9142603
26	PI 25	668920	9142808
27	PI 26	668703	9143113
28	PI 27	668935	9143315
29	PI 28	668749	9143582
30	PI 29	668785	9143816
31	PI 30	668990	9143779
32	PI 31	668859	9144034
33	Ending Point	669020	9144227

Source: Research Data

3) Horizontal Alignment Redesign

The following is an example of horizontal alignment calculation on PI.4:

1. Distance calculation

$$d_{4-5} = \sqrt{(X_5 - X_4)^2 + (Y_5 - Y_4)^2} \quad (1)$$

$$= \sqrt{(667846 - 667670)^2 + (9138338 - 9138007)^2} = 374.882 \text{ m}$$

2. Calculation of azimuth angle

$$\alpha_{PI.4} = \arc\tan\left(\frac{X_5 - X_4}{Y_5 - Y_4}\right) \quad (2)$$

$$= \arc\tan\left(\frac{667846 - 667670}{9138338 - 9138007}\right) = 28^o$$

3. Deflection angle calculation

$$\Delta_{PI.4} = \alpha_{PI.3} - \alpha_{PI.4} \quad (3)$$

$$= 74.818 - 28 = 46.818^o$$

4. Calculation of plan radius of curvature

$$R_{min} = \frac{V_D{}^2}{127\,(e_{max} + f_{max})} \quad (4)$$

$= \frac{40^2}{127\ (8\% +\ 0{,}166)} = 51$ m

5. Calculation of transitional arch length (Ls)

- Based on superelevation Runoff

$L_{r\,min} = \frac{wn_1\ e_{max}}{\Delta}(b_w)$ (5)

$= \frac{5\ \times\ 1\ \times\ 8\%}{0{,}70\%} \times 1 = 57\ m$

- Based on driving comfort:

$L_{s\,min} = \sqrt[2]{24(P_{min})R}$ (6)

$= \sqrt[2]{24 \times\ 0{,}2\ \times\ 52} = 16\ m$

- Based on Shortt's formula:

$L_{s\,min} = \frac{0{,}0214\ V_D{}^3}{R_C \times C}$ (7)

$= \frac{0{,}0214 \times 40^3}{52 \times 1{,}2} = 22\ m$

Based on the three Ls formulas above, the Ls value of 22 m was chosen..

Check Ls

$L_s \leq 0{,}5\ (6\ \text{second} \times\ V_D\ )$ (8)

$22\ \leq \frac{1}{2} \times \left(6\ \times \left(\frac{40\times1000}{3600}\right)\right) = 33$ m → OK

6. Calculation of the bend shift value. If p ≥ 0.25 then the bend is of type SCS.

$p = \frac{22^2}{24\times52} = 0{,}39\ \text{m} \geq 0{,}25\ \text{m}$ → **OK S-C-S** (9)

7. Calculation of transitional bend angle.

$\theta_S = \frac{90\ Ls}{\pi\ Rc} = \frac{90\times22}{\pi\times52} = 12.120°$ (10)

8. Calculation of perpendicular distance from point TS to point SC.

$X_s = L_S\ - \frac{L_s{}^3}{40.R_C{}^2} =\ 22 - \frac{22^3}{40\times52^2} = 21.901$ m (11)

9. Calculation of perpendicular distance to point SC on the curve.

$Y_S = \frac{L_s{}^2}{6.R_C} = \frac{22^2}{6\times52} = 1.551$ m (12)

10. Calculation of distance from TS point to bend shift point.

$k = X_s - R_C \text{Sin}\theta_S$ (13)

$= 21.901 - 52 \times \text{Sin}(12.120) = 10.983$ m

11. Calculation of tangent length from point PI to TS.

$T_S = (R_C\ +\ p)\ \tan\frac{1}{2}\Delta\ + k$ (14)

$= (52\ +\ 0{,}39\ )\ \tan\left(\frac{46.818}{2}\right) + 10.983 = 33.664$ m

12. Calculation of distance from PI to circular arc.

$E_S = (R_C\ +\ p)\ \sec\frac{1}{2}\Delta\ -\ R_C$ (15)

$= (52\ +\ 0{,}39) \times \sec\left(\frac{46.818}{2}\right) - 52 = 5.088$ m

13. Circular arch bend angle calculation.

$\theta_C\ =\ (\Delta\ -\ 2\theta_S)$ (16)

$= (46.818 -\ 2 \times 12.120) = 22.578°$

14. Calculation of the arc length of a circle.

$L_C = \frac{2\pi}{360} \times\ \theta_C \times\ R_C$ (17)

$= \frac{2\pi}{360} \times\ 22.578 \times 52 = 20.491$ m

Check Lc

- $L_C\ \leq 6$ detik $\times\ V_D$ (18)

  $20.491\text{m} \leq 6 \times \left(\frac{40 \times 1000}{3600}\right)$

  20.491 m ≤ 66.67 m → **Fulfill**

- Lc > 20 m

  20.491 m > 20 m → **Fulfill**

15. Calculation of total arch length.

$L_{total} =\ L_C\ +\ 2L_S$ (19)

$=\ 20.491\ +\ 2 \times 22 = 64.491$ m

16. Distance between bends.

Length of tangent PI.2 ($Ts_{PI.2}$) = 63.31 m

Distance between curves $= d_{2-3} - Ts_{PI.2} - Ts_{PI.3}$ (20)

$= 382.342\ - 63.31 - 63.36$

= 255.67 m

Distance between curves ≥ 20 m

255.67m ≥ 20 m → **OK**

17. Lane width at curves.

Type of vehicle = 3 Axle Truck

P = 7,18 m

A = 1,28 m

Number of lanes = 2

– Width of front protrusion

$T_d =\ \sqrt{R^2 + A(2P + A)} - R$ (21)

$=\ \sqrt{}(52^2 + 1{,}28(2 \times 7{,}18 + 1{,}28)) - 52 = 0.19$ m

– Total pavement width at the corner

$B = b + R - \sqrt{R^2 - P^2}$ (22)

$= 2{,}49 + 52 - \sqrt{}(52^2 - [[7{,}18]]^2\ ) =\ 2.99$ m

– Additional width due to driving difficulty

$Z = 0{,}104 \times \frac{V}{\sqrt{R}}$ (23)

$= 0{,}104 \times 40/\sqrt{52} = 0{,}58$ m

– Pavement width at curves

$B_t = n(B + C) + (n - 1)T_d + Z$ (24)

$= 2(2{,}99 + 0{,}8) + (2 - 1) \times 0{,}19 + 0{,}580$

$= 8.35$ m

– Additional pavement width at curves

$\Delta b = B_t - B_n$ (25)

$= 8.35\ - 10 = -1.655$ m

– Check for additional width at corners

$\Delta b \leq 0{,}5$ m (26)

-1.655 m $\leq 0{,}5$ m

From the results of the above calculations, it is obtained that the bend widening of -1.655 m is smaller than the requirement of 0.5 m, so for the PI bend point. 2 no widening is required at the bend.

Tables 5. Horizontal Alignment Result

NO. PI	PI 1	PI 2	PI 3	PI 4	PI 5	PI 6	PI 7
V (Km/jam)	60	40	40	40	50	40	40
TYPE	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S
Δ (º)	60	84	93	103	38	71	64
R (m)	123	52	52	52	85	52	52

Ts/Tc (m)	51.787	30.129	35.374	42.588	15.086	22.277	18.671
Lc (m)	98.033	54.614	62.126	71.366	29.862	42.095	35.851
Ls (m)	31	22	22	22	26	22	22
Ltotal (m)	161	99	106	115	82	86	80
θs (m)	0.127	0.211	0.211	0.211	0.154	0.211	0.211
e_{max} (%)	8	8	8	8	8	8	8
Pelebaran	-	-	-	-	-	-	-

Source: Calculation Results

NO. PI	PI 8	PI 9	PI 10	PI 11	PI 12	PI 13	PI 14
V (Km/jam)	40	40	40	40	40	40	40
TYPE	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S
Δ (º)	60	92	128	115	70	73	98
R (m)	55	52	52	52	52	52	52
Ts/Tc (m)	19.122	35.203	66.304	52.807	22.128	23.625	39.302
Lc (m)	36.806	61.891	94.195	82.483	41.842	44.350	67.310
Ls (m)	21	22	22	22	22	22	22
Ltotal (m)	78	106	138	126	86	88	111
θs (m)	0.189	0.211	0.211	0.211	0.211	0.211	0.211
e_{max} (%)	8	8	8	8	8	8	8
Pelebaran	-	-	-	-	-	-	-

Source: Calculation Results

NO. PI	PI 15	PI 16	PI 17	PI 18	PI 19	PI 20	PI 21
V (Km/jam)	40	40	40	40	40	40	40
TYPE	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S
Δ (º)	68	63	57	94	110	96	67
R (m)	52	55	52	52	52	52	52
Ts/Tc (m)	20.864	20.752	15.433	36.264	48.188	37.644	20.457
Lc (m)	39.684	39.687	30.005	63.333	77.726	65.167	38.980
Ls (m)	22	21	22	22	22	22	22
Ltotal (m)	84	81	74	107	122	109	83
θs (m)	0.211	0.189	0.211	0.211	0.211	0.211	0.211
e_{max} (%)	8	8	8	8	8	8	8
Pelebaran	-	-	-	-	-	-	-

Source: Calculation Results

NO. PI	PI 22	PI 23	PI 24	PI 25	PI 26	PI 27
V (Km/jam)	40	40	40	40	40	40
TYPE	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	S-C-S
Δ (º)	81	101	73	86	84	84
R (m)	52	52	52	52	52	52
Ts/Tc (m)	28.247	41.513	23.648	31.318	30.144	29.800
Lc (m)	51.753	70.067	44.388	56.377	54.637	54.121
Ls (m)	22	22	22	22	22	22
Ltotal (m)	96	114	88	100	99	98
θs (m)	0.211	0.211	0.211	0.211	0.211	0.211
e_{max} (%)	8	8	8	8	8	8
Pelebaran	-	-	-	-	-	-

Source: Calculation Results

NO. PI	PI 28	PI 29	PI 30	PI 31
V (Km/jam)	40	40	40	40
TYPE	S-C-S	S-C-S	S-C-S	S-C-S
Δ (º)	44	91	127	67
R (m)	57	52	52	52
Ts/Tc (m)	11.846	34.615	65.652	20.400
Lc (m)	23.360	61.080	93.696	38.882
Ls (m)	20	22	22	22
Ltotal (m)	63	105	138	83
θs (m)	0.176	0.211	0.211	0.211
e_{max} (%)	8	8	8	8
Pelebaran	-	-	-	-

Source: Calculation Results

4) Vertical Alignment Redesign

The following are the Point Vertical Intersection (PVI) points in the vertical re-planning of the alignment.

Tables 6. PVI Point

Titik	STA	Elevation
STA Awal	0.0000	1470.0000
PVI 1	566	1460
PVI 2	926	1465
PVI 3	1336	1463
PVI 4	1719	1470
PVI 5	2070	1465
PVI 6	2420	1475
PVI 7	2720	1468
PVI 8	3200	1476
PVI 9	3550	1473
PVI 10	3950	1480
PVI 11	4270	1475
PVI 12	4875	1490
PVI 13	5140	1485
PVI 14	5660	1498
PVI 15	6150	1520
PVI 16	6425	1530
PVI 17	6745	1550
PVI 18	7340	1570
PVI 19	7525	1586
PVI 20	8050	1610
PVI 21	8300	1630
PVI 22	8500	1641
PVI 23	8780	1638
PVI 24	9000	1639
PVI 25	9300	1636
PVI 26	9665	1644
PVI 27	9980	1638
PVI 28	10850	1658
STA Akhir	10972	1656

Source: Determination Result

The following is an example of vertical alignment calculation on PVI.2:

1. **Longitudinal slope**

$$g_2 = \frac{\text{Elevasi}_{akhir} - \text{Elevasi}_{awal}}{\text{STA}_{\text{akhir}} - \text{STA}_{\text{awal}}} \times 100\% \quad (27)$$

$$= \frac{1465 - 1463}{1336} \times 100\% = 0.5\%$$

Algebraic Differences (A)

A = │g2 – g1│ (28)

= │-0.07% – (0.5%)│= -0.57% (Negative) → **Crest**

Based on the four formulas, the largest L value of **230 m** was selected.

2. **Critical slope length**

g1 = 0.5%

Critical slope length = 900m

Critical slope length control:

360 m ≤ 900 m → OK

g2 = -0.07%

Critical slope length = 900m

Critical slope length control:

410m ≤ 900 m → OK

3. **Determine the minimum stopping sight distance (J_{PH})**

Design Speed (V_D) PVI 9 = 40 km/jam

Tabel 7. Vertical Curve Design Based on J_{PH}

V_D (km/jam)	J_{PH} (m)	K
20	20	3
30	35	6
40	50	9
50	65	13
60	85	18
70	105	23
80	130	30
90	160	38
100	185	45
110	220	55
120	250	63

Source: PDGJ, 2021

So we get JPH of 50 m and Kref of 9.

4. **Sag Vertical Curve Length**

To calculate the length of the sag vertical arch, it is calculated based on the following four conditions

- Based on stopping sight distance (J_{PH})

L = K × A (29)

= 9 × 4.5 = 41 m

- Based on passenger comfort

$$K = \frac{V_D^2}{1296\ a} \quad (30)$$

$$= \frac{40^2}{1296 \times (0{,}05 \times 9{,}81)} = 2.517$$

L = K × A (31)

$$= 2.517 \times 4.5 = 11.326 \text{ m} \approx 12 \text{ m}$$

- Based on appearance factors

$L = K_{min} \times A$ (32)

= 30 × 4.5 = 135 m

- Berdasarkan faktor drainase

$L = K_{max} \times A$ (33)

= 51 × 4.5 = 230 m

Check $K_{desain} > K_{ref}$,

51 > 9 → **OK**

5. Curved Shift Value

$$Ev = \frac{A \times L}{800} \quad (34)$$

$$= \frac{4.5 \times 230}{800} = 1.294 \text{ m}$$

6. Vertical Curve Stationing

STA PVI 9 = 350 m

STA PLV = STA PVI 9 – ½ x L (35)

= 350 – ½ x 230 = 3435 m

STA PTV = STA PVI 9 + ½ x L (36)

= 350 + ½ x 230 = 3665 m

7. Vertical Curve Elevation

Elevasi PVI 9 = 1473 m

$$\text{Elevasi PLV} = \text{Elevasi PVI9} - \left(\frac{g_1 \times L}{2}\right) \quad (37)$$

$$= 1473 - \left(\frac{(-2\%)\% \times 230}{2}\right) = 1475 \text{ m}$$

$$\text{Elevasi PTV} = \text{Elevasi PVI9} + \left(\frac{g_2 \times L}{2}\right) \quad (38)$$

$$= 1473 + \left(\frac{(2.5\%) \times 230}{2}\right) = 1463 \text{ m}$$

4. CONCLUSION

Based on the results of the analysis and discussion that has been carried out, the following conclusions can be drawn:

(1) After evaluating the existing conditions based on the radius value, it is obtained that all existing R values are less than Rminimum ($R_{Existing} < R_{minimum}$ = 122m) with an average speed of 60km / hour. Therefore, there is a need for re-design at all existing coordinate points.

(2) The results of geometric replanning of roads using the latest standard, namely the 2021 Road Geometric Design Guidelines, obtained bends consisting of 31 Spiral-Circle-Spiral type bends for horizontal alignment. As for the vertical alignment, the results of 28 vertical arches consist of 15 sag vertical curve and 13 crest vertical curve

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