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Evaluation and Redesign Based on Highway Geometric Design Guidelines 2021 (Case Study of Sampakan–Singosaren Road KM 13.8, Bantul Regency)

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ABSTRACT

This study aims to : (1) evaluate the geometric design of the Sampakan–Singosaren street km 13,8 Bantul Regency based on Panduan Desain Geometrik Jalan Bina Marga 2021; (2) identify the factor considered as evaluation, (3) propose alternative design and (4) to evaluate the differences between existing geometric design and alternative geometric design. The study used trial-and-error modeling for existing, and alternative geometric using Auto cad Civil 3D Student Version and analyzed according to Bina Marga standard. Then, a comparison of the existing and alternative geometric designs is calculated based on Bina Marga Geometric Design Standard 2021. The result indicates of study that there are 2 (two) existing curves with (1) each radius range at 37 m and 30 m, respectively; (2) the horizontal sight line offset on the first curve and the second curve was 4,7 m and 0.7 m, and the driving speed of 40 km/h. Furthermore, there is some parameter that does not meet the requirements, so an alternative design is required to fulfill the requirements of Bina Marga Geometric Design Standard 2021; (3) The designed shift on the new track to ± 9 m east and ± 5 m south; (4) the radius in both curve (S-C-S) is about 44 m, (5) horizontal sight line offset on the first curve and the second curve was 8,38 m and 7,557 m. Some changes to the existing and alternative design are the larger radius, the lower super elevation, new track is more flexible, and the better JPH and horizontal sight line offset.

1. Introduction

The percentage of the population in Indonesia is very dense. One of the provinces that has a high density is Yogyakarta special region. Yogyakarta province has a population density of 1155 people/km^2, and Bantul district has 1917 people/km^2 [1].

Infrastructure development in Indonesia has undergone very rapid development. Start from the construction of buildings, infrastructure, and roads, and it continues to be developed [2]. The dense population causes an increase in the frequency of activities between individuals with high mobilization. Transfers between places with high frequency are very dependent on traffic infrastructure facilities and infrastructure in the form of roads, especially when using transportation. Various cultures, livelihoods, and daily activities demand increased traffic infrastructure facilities and infrastructure. Of course, the demand for increased traffic facilities and must-have infrastructure aspects of security and comfort.

The rapid development and distribution of residential areas in the Yogyakarta special region are influenced by several factors: Yogyakarta as a educational city, a tourist city, and rapid economic development. The specialty of Yogyakarta as a educational city is the site of many universities, colleges, and educational institutes, so civitas academics from around Indonesia and Southeast Asia settle in Yogyakarta. As a tourist city, it also attracts many visitors who are influenced by the temples and natural tourist attractions surrounding Yogyakarta. The attraction increases the frequency of large-dimension vehicles such as tourist buses. In addition, the expansion of settlements

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in the Special Region of Yogyakarta is also influenced by industry, goods, and services development. These are some of the most significant factors influencing growth in Yogyakarta.

Transportation plays a major role in the high development and growth of the Yogyakarta special region. Transportation has increased the mobilization or movement of vehicles in a relatively high number, having a reasonably dense vehicle density and large dimensions so that road infrastructure and capabilities are needed to accommodate the mobility of people, goods, and services. In addition, aspects of driver safety and comfort are also important factors in preventing accidents and hampering the activities facilitated by the road. Some roads and facilities in urban areas have been made as safe and comfortable as possible to ensure smooth traffic flow.

The 2021 Bina Marga Road Geometric Design Guidelines are a revision of the 1997 Geometric Planning Standards for Inter-City Roads. The revision includes changes to the structure of the presentation, expansion of substance, and improvement of content. It considers standards used internationally, such as the AASHTO 2018, to improves road performance to accommodate challenges and obstacles in road development in Indonesia [3].

One of the roads observed by researchers and used as the object of evaluation is the Sampakan–Singosaren road section 13.8 km, Banguntapan sub-district, Bantul district. Based on information from the Department of Public Works, Housing and Mineral Resources DI Yogyakarta, this section last experienced an increase in 2019, so it is estimated that this road section was designed using the old regulations, namely the 2004 Urban Road Geometric Guidelines (BSN). Improvement or adjustment of existing conditions is caused by several factors, namely the development of the area in this section, the very rapid development of the type of vehicle, and the fulfillment of the need for road traffic facilities [4]-[6]. Besides, material innovation is also needed to improve road performance [7]. As a result, the function and status of this section has changed so that the performance of the road has decreased. Changes in road function that are not matched by geometric changes or without evaluation result in these sections not meeting the standards. For these sections to work optimally, evaluation is needed to improve road performance services and can be used according to function or as it should be.

This study aims to: (1) Evaluate the Sampakan–Singosaren km 13.8 section based on the Road Geometric Design Guidelines; (2) Identify the factors reviewed as evaluation materials according to the Road Geometric Design Guidelines: (3) Provide alternative road geometry design solutions on the Sampakan–Singosaren km 13.8 section according to the Road Geometric Design Guidelines to meet the principles of safety, security, and comfort user; (4) Knowing the differences and making comparisons between the existing road design and alternative designs using the Road Geometric Design Guidelines [8].

2. Research Method

The research location is on the Sampakan–Singosaren road section KM. 13.8, Gunung Kidul Regency, Special Region of Yogyakarta. The road geometry design evaluation process uses the 2021 KEMENPUPR Bina Marga road geometry design guidelines. The six research stages include (1) Problem identification, (2) Data collection, (3) Existing data analysis, (4) Making alternative designs, (5) Comparison of existing and alternative data, and (6) Conclusions and suggestions. The details of the six stages of the research are as follows: [8]–[10]

The first stage in this research is to start by identifying the problem, then reviewing it again to obtain the formulation and research objectives.

The second stage is the stage of collecting data. The primary data is field geometry measurement data and existing visibility. Secondary data, namely contour mapping, traffic data, and planned vehicles. Secondary data is taken from related agencies that are directly related to the object of the study being carried out. Retrieval of primary data using a long tool for measuring long geometry. For the measurement of the existing sight distance, three trials were carried out on 2 lanes, and the largest value was taken from the sight distance. The road component can be seen in Figure 1.

The third stage is data analysis. The existing data will be analyzed using trial & error through the Auto cad Civil 3D Student Version to make the existing situation as accurately as possible. Then the current data output from the application is evaluated and analyzed using the 2021 Bina Marga Road Geometry Design Guidelines method. The parameters evaluated are visibility, bend-free space, combined bends, and horizontal and vertical alignment.

The fourth stage is making an alternative road geometry design based on the existing data recap. Making an alternative geometry design is expected to be able to provide the right solution based on the situation in the region. The alternative design begins with calculating design parameters to meet the standards, then outlined in technical drawings. The alternative design considers the parameters that must be met so that they comply with the requirements based on the 2021 Bina Marga Road Geometry Design Guidelines. One of the parameters is side free space which the graph can be seen in Figure 2.

The fifth stage is a comparison or comparison of the calculation results of the existing design and alternative designs. Comparing existing and alternative designs is a step to re-evaluate and find out changes that can be implemented in the field.

The conclusion and suggestion stage is the final stage in conducting the research. At this stage, the researcher will conclude from the results of the research that has been done. In addition, researchers will advise policymakers as organizers of the Sampakan–Singosaren road section KM.13.8, Bantul Regency, DI Yogyakarta. The Flow chart of this research shows in Figure 3.

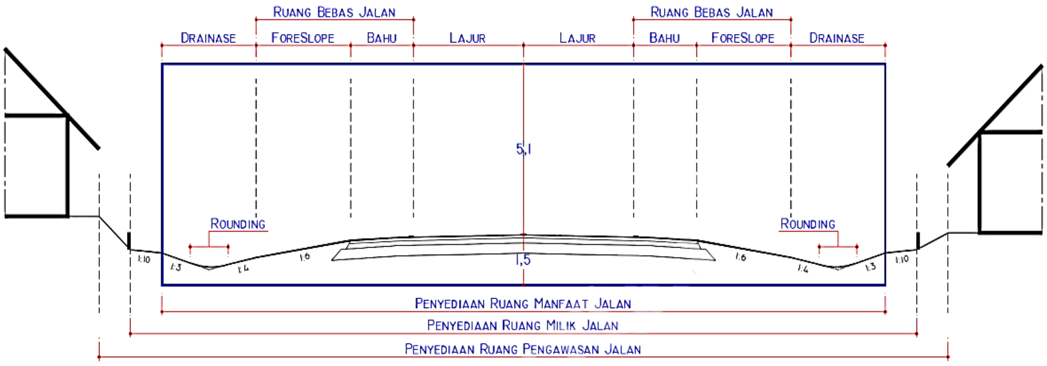

Figure 1. Road Component

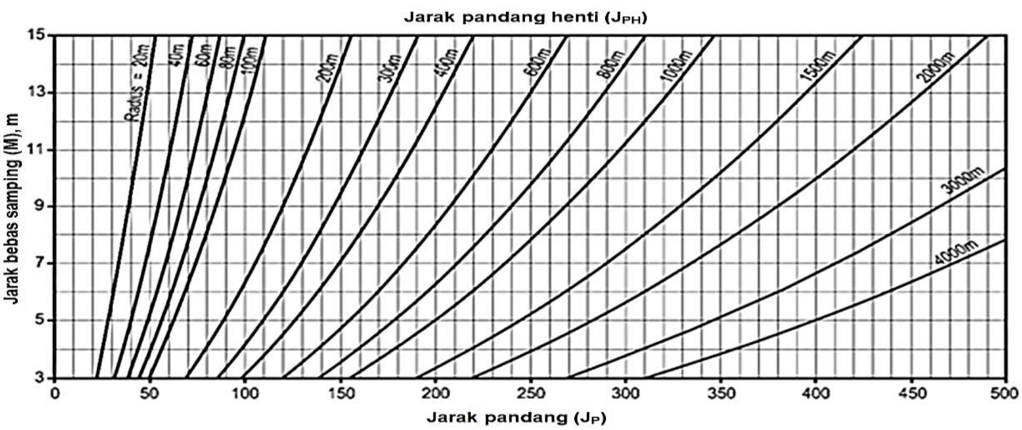

Figure 2. Side Free Space Graph

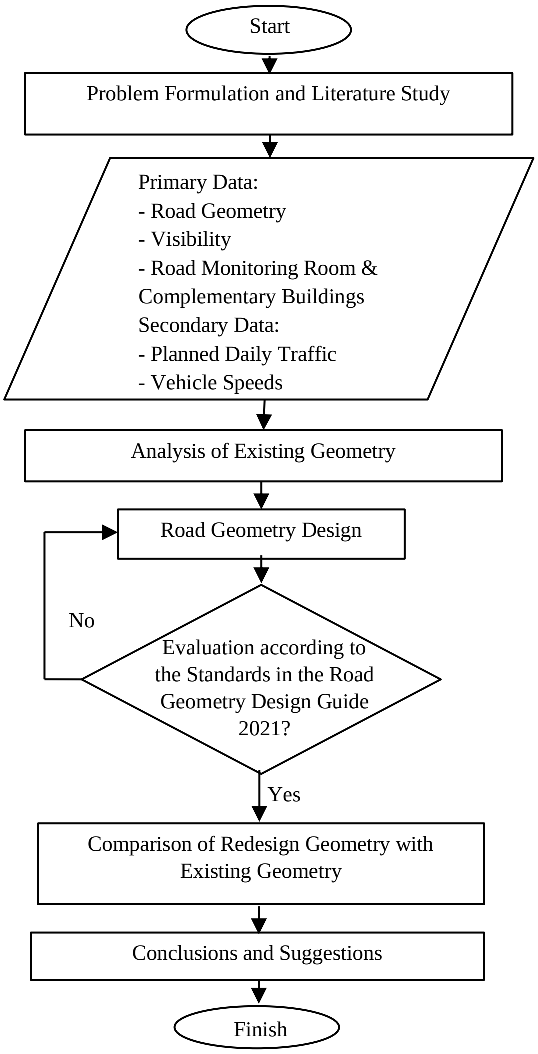

Figure 3. Research flow chart

3. Discussion

From data collection, the road segment has two lanes and two directions (2/2TT). The road width is 6 meters with no median. The super-elevation of the previous plan (*e*) is 6% and the design speed is 40 km/hour. Side free space at bend 1 is 4.7 m and at bend 2 is 0.7 m. The existing stopping sight distance can be seen in Table 1. The road using boundary markers and traffic signs.

At bend 1, side free space is calculated using a graph to obtain a minimum side free space value of 7.2 m. On the existing side, the free space is 4.7 m, so the side free space in the existing does not meet the requirements. Meanwhile, at bend 2, the existing side clear space only has 0.7 m, while the side free space based on the minimum graph is 7.8 m. It is concluded that bend 2 does not meet the side free space requirements.

Table 1. Existing Stopping Visibility

Description	Bend 1	Bend 2
Trial 1	28.92 m	21.94 m
Trial 2	25.34 m	19.20 m
Trial 3	43.70 m	20.87 m
Max	43.70 m	21.94 m

The minimum JPH required at a design speed of 40 km/h is calculated as follows:

$$JPHmin = \left(\frac{Vdxt}{3,6}\right) + \frac{VD^2}{2x3.6x9.81(\frac{a}{9.81} \pm G)} \quad (1)$$

The design vehicle speed is 40 km/h. The minimum required JPH for a speed of 40 km/h is 45.117 m, while the field JPH is 43.7 m for turn 1, while for turn 2 is 21.94 m. So that the field JPH for bend 1 and 2 do not feet the required minimum JPH. The definitive illustration of entities in Autocad Civil 3D Student Version shows in Figure 4.

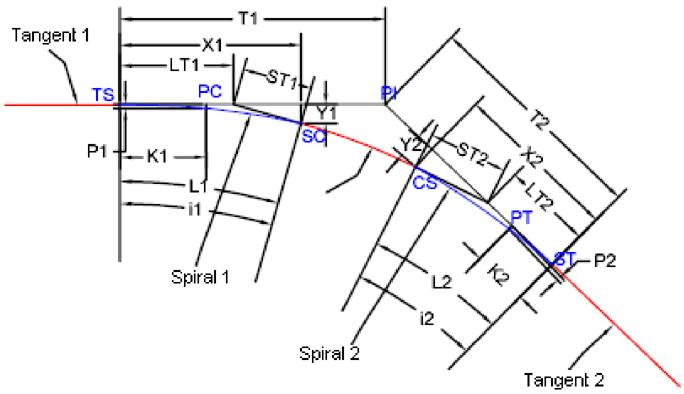

Figure 4. Definitive illustration of entities in Autocad Civil 3D Student Version [8]

3.1 Alignment Horizontal

Field measurement data is drawn or visualized using the Autodesk Civil 3D Student Version 2021 application to get bend shape results. The illustration of the existing bend is shows in Figure 5. Through trial, Autodesk Civil 3D Student Version 2021 bend data is obtained, and the results of the horizontal alignment bend calculation analysis can be seen in the calculation below.

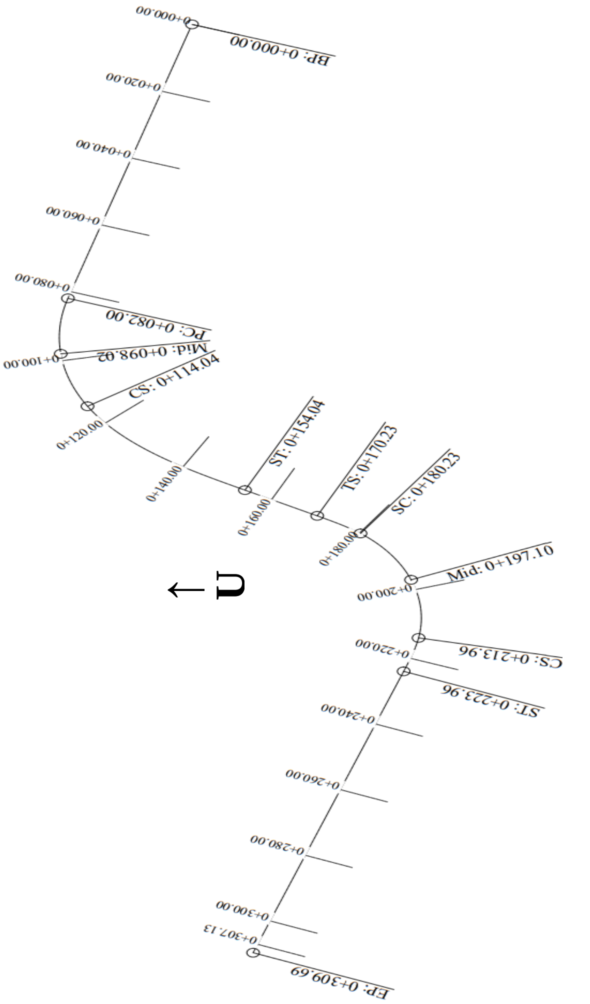

Figure 5. Illustration of the existing bend [9]

1. Bend 1 (*Circle – Spiral*) (see Figure 6)

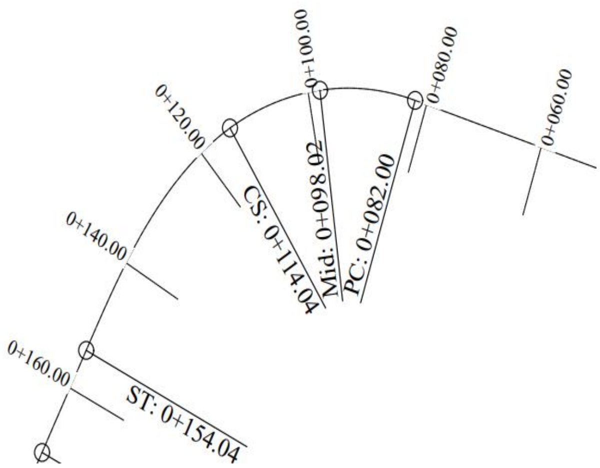

Figure 6. Existing bend 1

Is known:

V = 40 km/h
Rc = 37 m
E = 6%
Ls = 40 m
Δ = 80.574°
θs = 30.97°
θc = 49,616°
Lc = 32.041
Ltot = Lc + Ls
= 32.041 + 40
= 72.041 m
Xc = 38.847 m
Yc = 7.058 m

2. Bend 2 (*Spiral – Circle – Spiral)* (see Figure 7)

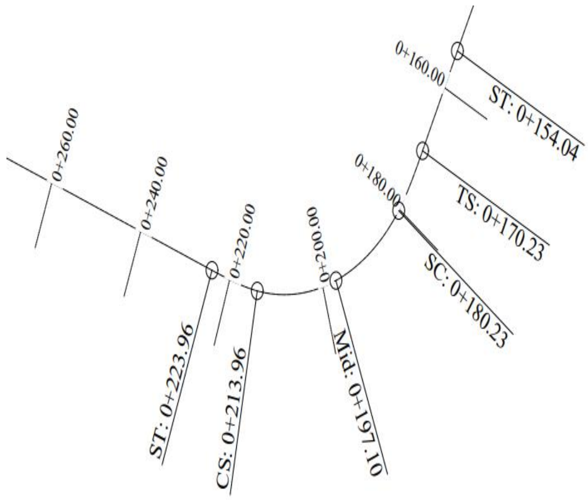

Figure 7. Existing Bend 2

Is known:

V = 40 km/h
Rc = 30 m
E = 6 %
Ls = 10 m (*spiral in* dan *spiral out*)
Δ = 83.538°
θs = 9.549°
θc = 64.430°
Lc = 33.736 m
Ltot = Lc +2xLs
= 33.736 + 2x10
= 53.736 m
Xc = 9.972 m
Yc = 0.554 m

AutoCAD Civil 3D Student Version automatically calculates the stationing of important horizontal curve points. The road alignment is divided into several segments to facilitate crossroad or super-elevation evaluation.

It should be noted that the maximum super-elevation of the past design was set at e = 6%. The slope of the bend based on the existing radius (AutoCAD Civil 3D Student Version) is calculated using the following equation:

$$e = \frac{VD^2}{127*Rmin} - f \qquad (2)$$

At bend 1, the circle radius has a value of 37 m with an existing super-elevation of 11%, but the maximum super-elevation calculation based on the 2021 road geometry design guidelines is 8%, so it can be concluded that the super-elevation analysis does not meet the requirements. Likewise, at bend 2, with a radius of 30 m and having an existing super-elevation of 18.9%, so bend 2 does not meet the super-elevation analysis requirements.

3.2 Alignment Vertical

Road elevation data is the basis for calculating the road slope at these bends. There is only 1 (one) slope at these bends because the road is relatively flat. The road slope becomes a reference for calculating vertical alignment using AutoCAD Civil 3D Student Version. The vertical alignment parameter is output by the AutoCAD Civil 3D Student Version.

Initial grade (G1)	= 1.63%
Final grade (G2)	= 0.00 %
Grade (Δ)	= 1.63%
H1 (Driver's eye height)	= 1.2 m
H2 (obstacle height)	= 0.1 m
Existing grade	= 7.91
Vertical arc length (Lv)	= 12.91 m
Elevation BVC (Beginning Vertical Curve)	= 59.11 m
Stationing BVC	= 0+143.54 m
Elevation PVI (Point Vertical Intersection)	= 59 m
Stationing PVI	= 0+150
Elevation EVC (End Vertical Curve)	= 59 m
Stationing EVC	= 0+156.46 m
K Minimum Concave for VD = 40 km/hour	= 9 (Table 2)

Existing K= Minimum K
7.91 <9 (Not eligible)

It can be concluded that the existing K value (calculation) does not meet the minimum K requirements for a concave vertical curve. (see Table 2)

The recapitulation of the analysis results of the existing bends on the Sampakan–Singosaren km 13.8 road section can be seen in Table 3, which compares the existing geometric values and the design requirements of Highways.

The Singosaren – Sampakan road section has a road function as a collector, road class III, and average daily traffic volume (ADT) of 24,596 PCU/day and continues to increase yearly. This section is also traversed by long and large vehicles. Ideally, each section should be able to serve each vehicle so that it can function as it should. However, the existing road section cannot provide sufficiently good service. Side-free space and RUMIJA, which are too close to residents' buildings, contribute to the lack of road safety in serving road users and the surrounding environment, resulting in a lack of safety and comfort for road users and the surrounding community.

Based on the recapitulation of Table 3, there are still parameters that do not meet the 2021 Road Geometric Design Guidelines standards in the curve geometry field for this road section.

Therefore, alternative planning is needed in accordance with the 2021 Road Geometry Design Guidelines so that these sections can function as they should.

Table 2. K Value in Alignment Vertical

V_D (Km/h)	J_{PH} (m)	K
20	20	3
30	35	6
40	50	9
50	65	13
60	85	18
70	105	2
80	130	30
90	160	38
100	185	45
110	220	55
120	250	63

4. Alternative Geometry

The geometry redesign was carried out to provide bend geometry parameters in accordance with the Bina Marga 2021 standard guidelines. Redesign an alternative geometric plan using AutoCAD Civil 3D *Student Version* 2021. In horizontal alignment, the redesign starts with moving the alignment, allowing the bend to get a larger radius with enough space for visibility, super-elevation, RUMIJA, and the distance between bends (combined back bend). The alignment was moved to the east because the area is still mostly vacant land and involves several permanent buildings/settlements. The dotted line in the figure indicates that the new alignment will overlap the residents' buildings south of bend 1 and south of the tangent after bend 2. The resume of existing value shows in Table 3.

Table 3. Recapitulation of existing

Parameter	Value			Description
	Existing		Bina Marga 2021	
Vehicle design	40 km/h			
Road class	Class III			
Road function	Collector			
ADT	24,596 PCU/day			
Lane width	3m			
JPH	Bend 1	43.70 m	45.12 m	Not satisfied
	Bend 2	21.94 m	45.12 m	Not satisfied
Free Space Bend Side	Bend 1	4.70 m	7.2 m	Not satisfied
	Bend 2	0.7	7.8 m	Not satisfied
Super elevation	Bend 1	11%	8%	Not satisfied
	Bend 2	18.9%	8%	Not satisfied
Horizontal alignment				
Bend 1	Rc	37 m		
C-S	Ls	40 m		
	θs	30.970°		
	θc	49.616°		
	Lc	32.041 m		
	Ltot	72.041 m		
	X	38.847		
	Y	7.058		
Bend 2	Rc	30 m		
S-C-S	Ls	10 m		
	θs	9.549°		
	θc	64.430°		
	Lc	33.74 m		
	Ltot	53.74 m		
	X	9.97 m		
	Y	0.554 m		
Vertical alignment				
Sta 0+142.54 – Sta 0+157.46	G1	-1.63%		
	Grade (Δ)	1.63%		
	K	7.91%	9%	Not satisfied
	Lv	12.91 m		

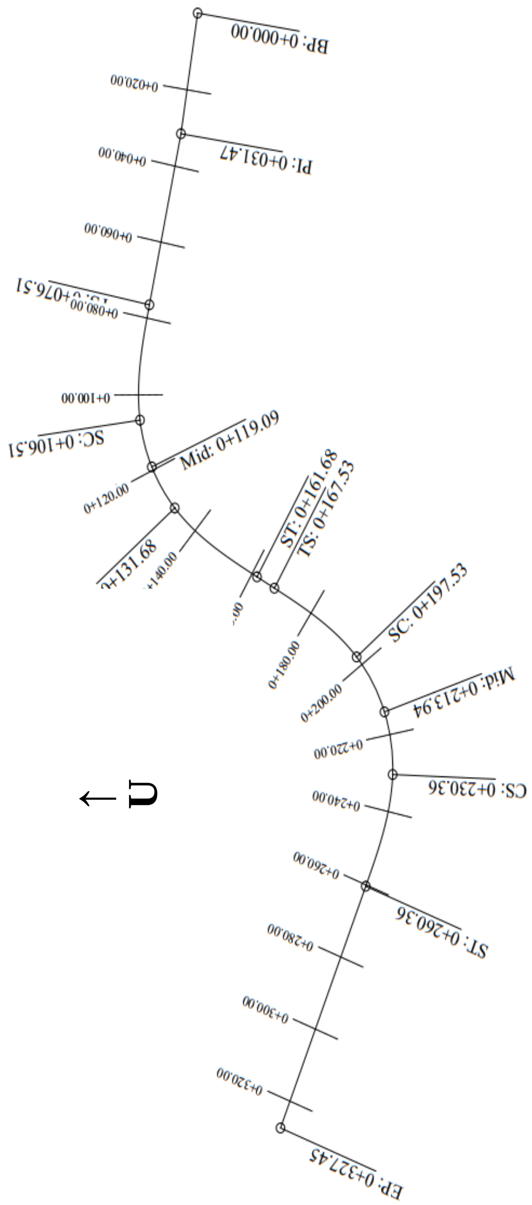

Figure 8. Alternate horizontal alignment bend

The alternative horizontal alignment bend can be seen in Figure 8. Turn 1 and turn 2 use Spiral – Circle – Spiral type bends because the transition shift is greater than the widening of the bend (p-value) and to make it easier to service large dimension vehicles. The length between bends (combined back bends) has been planned to meet the minimum length by utilizing the transition curve. The radius at both bends is larger than the existing one to meet the super-elevation criteria. The comparison of alternative and existing design parameters shows in Table 4.

Table 4. Comparison of alternative and existing design parameters

Parameter	Value	Existing	Unit
ALIGNMENT Horizontal			
Bend 1 (Spiral – Circle - Spiral)			
Radius (R)	44	37	m
Length Circle (Lc)	29.12	32.02	m
Length Spiral (Ls) in & out	26	40	m
θc	37.982	49.616	°
θs	16.928	30.958	°
X	25.774	38.831	m
Y	2.545	7.207	m
Emax	5.6	11.04	%
Side free space	8.38	7.594	m
Stopping visibility	52.419	43.7	m
Bend 2 Spiral – Circle – Spiral			
Radius (R)	44	30	m
Length Circle (Lc)	36.83	33.74	m
Length Spiral (Ls) in & out	26	10	m
θc	47.959	64.43	°
θs	16.928	9.55	°
X	25.774	9.97	m
Y	2.545	0.55	m
Emax	5.6	18.9	%
Side free space	7.557	0.7	m
Stopping visibility	50.6	21.94	m
Alignment Vertical			
A1	1.66	1.63	%
LV	29.98	12.91	m
K	18.06	7.97	

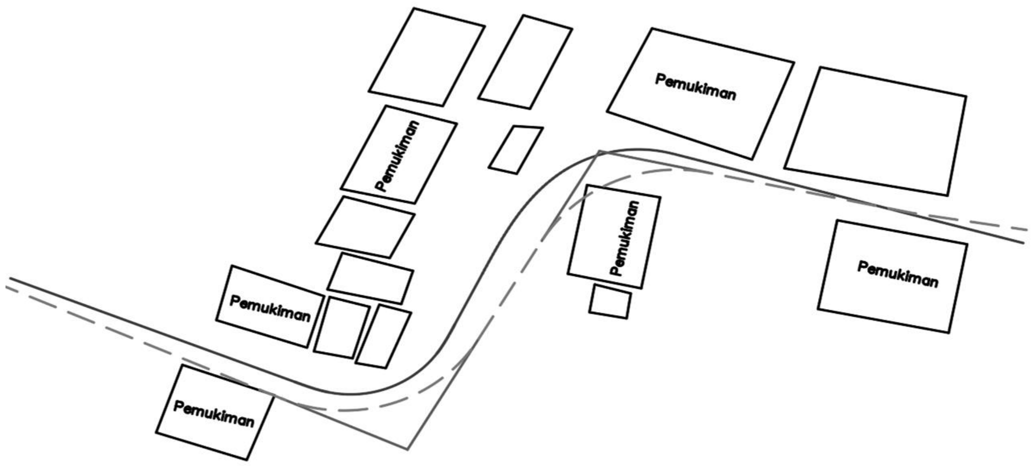

Figure 9. Changes to alternative design pathways

5. Conclusions

Based on the analysis of the geometric feasibility evaluation of the Singosaren – Sampakan road section 13.8 km, Bantul Regency, it can be concluded that.

1. The combined return curve geometry does not meet the requirements for the 2021 Bina Marga Road Geometric Design Guidelines (No. 13/P/BM/2021).
2. The bend geometry parameters evaluated on this road section are: Road class and road classification; Design speed; Vehicle dimensions; Visibility; Side free space; Horizontal alignment, in the form of bends, transition curves, and super-elevation, as well as Vertical alignment.
3. The modeling redesign was carried out to meet the requirements for the geometric design guidelines for Bina Marga roads in 2021. There were several adjustments to the redesign of the Sampakan - Singosaren road section: alignment changes, horizontal alignment changes, and vertical alignment changes. The new alignment produces a radius of 44 m at bend 1 (east) and bend 2 (west), stopping sight distance and side clearance of 52.419 m and 8.38 m at bend 1, while bend 2 is 50.6 m and 7.557 m. Bends 1 and 2 use the S – C – S type with a transition curve of 26 m, so a maximum super-elevation of 5.6% is obtained due to the large radius.
4. Comparison of the geometric design between the existing and alternative bends, namely:
    a. Road alignment, in the alternative design, is moved to the east as far as ± 9 m and to the south as far as ± 5 m.
    b. The stopping sight distance on the field is 43.7 m at turn 1 and 21.94 m at turn 2. At the same time, the alternative design meets the requirements with 52.419 m at turn 1 and 50.6 m at turn 2.
    c. The existing free space at bend 2 is too close and does not meet the requirements, whereas in the alternative design it is 7.557 m.
    d. The radius and super-elevation on the existing design of bend 1 is 37 m, emax = 11.04%, bend 2 is 30 m, and emax = 18.9%. Whereas in the alternative design of bend 1 and bend 2 it is 44 m and has a super-elevation of 5.6%.

6. Recommendations

Several suggestions can be given to the organizers of the road, in this case, the Department of Public Works, Housing, Energy and Mineral Resources of the Province of Yogyakarta.

1. The environmental situation is increasingly congested; many vehicles have large dimensions, and there are changes in road functions. To be able to produce maximum performance, it is advisable to consider road criteria based on the 2021 Bina Marga Road geometric guidelines standards
2. Making changes to the road alignment design was moved to the east as far as ± 9 m and to the south as far as ± 5 m to obtain sufficient length for the transition curve, the distance between bends, and bend radius as well as flexibility for bend radius which will affect super-elevation and side free space.

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