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Geometric Analysis of the Gronggong – Beber Cirebon Highway STA 0+000 – STA 2+000

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Abstract

Road infrastructure is a vital component in regional development, serving as a means of transportation, economic driver, and connectivity enhancer. Inadequate design can cause problems such as traffic congestion and accidents. Therefore, this study aims to analyze road geometry, determine pavement thickness, and estimate project costs for the Gronggong–Beber road section in Cirebon Regency. The study location is the main road connecting Bukit Gronggong and Beber District, which has a gentle to moderate hilly topography. The data used includes the 2025 Average Daily Traffic (ADT) and design parameters with a design speed (Vr) of 70 km/h and a design life of 15 years. Based on calculations, the total Annual Average Daily Traffic (AADT) value is 8109.29 SMP/day, and the road type applied is 2/2-TT. The geometric analysis results show that of the five curves reviewed (C1, C2, C3, C4, C5), all require transition curves (Pcek > 0.25). The recommended curve type is Spiral–Circle–Spiral (S-C-S). For example, at Curve 1, the radius value used is R = 180 m (exceeding Rmin = 167.75 m), with a superelevation (ed) of 6.43% and a spiral curve length (Ls) of 74.10 m. Furthermore, the vertical alignment analysis at five PV points shows that the vertical curve length (Lv) taken is 42 m, based on the flexibility requirements. Overall, the geometric redesign of the road on the Gronggong–Beber section is necessary to ensure that the road meets safety and comfort standards in accordance with technical specifications.

Keywords: Road Design, Road Geometry, Horizontal Alignment, Vertical Alignment, Gronggong-Beber Section.

1. Introduction

1.1. Background

Road infrastructure is one of the vital components in the development of a region. Roads not only serve as a means of transportation to facilitate the mobility of people and goods, but also as a major driver of economic growth, equitable development, and improved connectivity between regions [1,2]. Therefore, good and sustainable road infrastructure design is essential to support the ever-increasing mobility needs of the community [3,4]. Along with the growth in population and socio-economic activities, the need for an adequate road network has become increasingly urgent. Poorly designed roads can cause various problems, such as traffic congestion, traffic accidents, increased vehicle emissions, and premature damage to road structures. This shows that technical, environmental, and social aspects must be comprehensively considered in the road planning and design process [5–8].

Road infrastructure design involves a number of important stages, ranging from feasibility studies, traffic analysis, geometric planning, material selection, to pavement structure calculations. Each stage requires the right technical approach so that the final result of the road construction can provide maximum benefits in the long term.Intercity road geometric planning, in order to produce road geometry that provides smoothness, safety, and comfort for road users (Road Geometric Design Guidelines No. 20/SE/Db/2021) [9–11]. Several parts of road geometric planning in accordance with intercity road geometric planning procedures are road classification according to function, class, terrain, and road development authority. Planning criteria form the basis for inter-city road planning. Road sections are in accordance with Law No. 38 of 2004 on roads, road cross-sections, sight distance, horizontal alignment, and vertical alignment. All planning processes must be carried out within a road network planning process [12–15].

Some roads in Indonesia, especially regional roads such as district roads, have irregular geometric conditions and were not planned in advance before construction, but only followed the existing road conditions, resulting in irregular geometric models for the road sections [16–20]. Therefore, it is necessary to rearrange the geometric design of the road section in the Gronggong-Beber area, Cirebon Regency, West Java, which borders Kuningan Regency and functions as a primary collector road [21–23]. This road section connects the city of Gronggong-Beber with a fairly high traffic volume. Based on the researcher's observations, the geometric condition of the road section is considered inadequate. In terms of horizontal alignment, most of the curves do not meet the standards set out in the design guidelines for inter-city roads. Meanwhile, in terms of vertical alignment, there are still inclines that exceed the maximum permitted gradient [24–28].

The irregular geometric conditions cause road users to feel uncomfortable when passing through this road. Therefore, a geometric evaluation needs to be carried out on the Gronggong–Beber road section in Cirebon Regency, West Java, which borders Kuningan Regency. The road is approximately 2 km long in accordance with Road Geometric Design Guidelines No. 20/SE/Db/2021.

1.2. Research Objectives

The purpose of this research is as follows:

1. Evaluate the geometric condition of the Gronggong – Beber road section STA 0+000 – STA 2+000.
2. Designing the geometry of the Gronggong – Beber road section STA 0+000 – STA 2+000.
3. Designing drainage for the Gronggong – Beber road section STA 0+000 – STA 2+000.
4. Calculating the volume of excavation and fill for the geometric design of the new road.

2. Research Methodology

The research was conducted according to the flowchart shown in Figure 1. This research was conducted in the Gronggong–Beber area, Cirebon Regency, West Java, which borders Kuningan Regency. The starting point (STA 0+000) was located on Gronggong Hill and the end point (STA 2+000) was in Beber District.

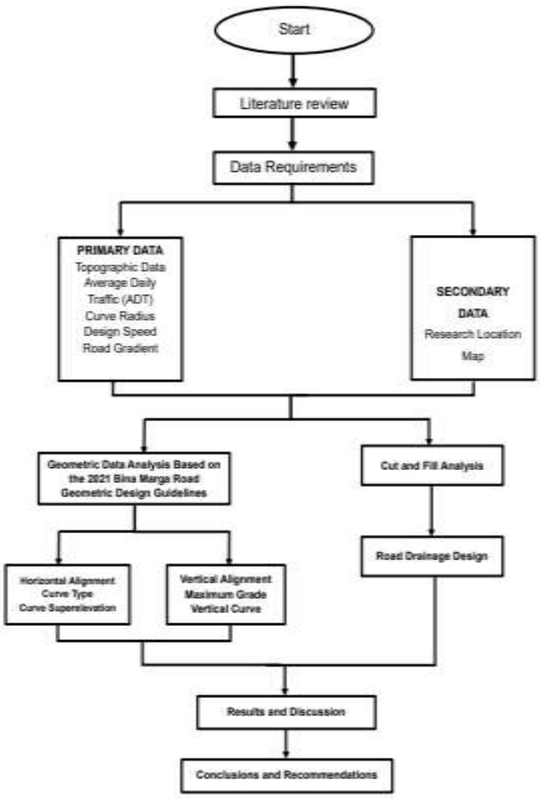

Figure 1. Research Flow Chart

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Figure 2. Research Location

3. Results and Discussion

3.1. Research Location

This research was conducted in Gronggong – Beber, covering an area of approximately 2 km. The research location started from the starting point with coordinates N 40227.982 and E -42301.315 and ended at a point with coordinates N 40483.635 and E - 41246.891. Administratively, the research location is in Cirebon Regency, West Java, which borders Kuningan Regency. The land use conditions around the location are mostly agricultural land. The starting point (STA 0+000) is located on Gronggong Hill and the end point (STA 2+000) is in Beber District. Field data collection was carried out through topographic measurement surveys using a total station. The measurement data was then processed and illustrated using AutoCAD Civil 3D 2022 software. Based on the analysis of existing conditions, it was found that the road geometry at the research location did not fully comply with the provisions of the Road Geometric Design Guidelines Number 20/SE/Db/2021.

Table 1. Road Planning Criteria Standards

Road Function	Primary Local Road (Ikk – Ikk)
Road Status	Provincial Road
Pavement Type	Flexible Pavement
Length of Road Studied	2,0 Km
Road Width	8,4 m
Traffic Lane Width	4,2 m
Road Shoulder Width	2,0 m
Road Type	2/2-Tt
LL Lane Width	4,2 m
Outer Shoulder Width	2,0 m
Roadside Channel	1,5 m
Safety Threshold	1,0 m
Median Width	No Median
Cross Slope	8%
Road Utilization Area	10,2 m
Road Right of Way (ROW)	15 m
Road Surveillance Area	3 m

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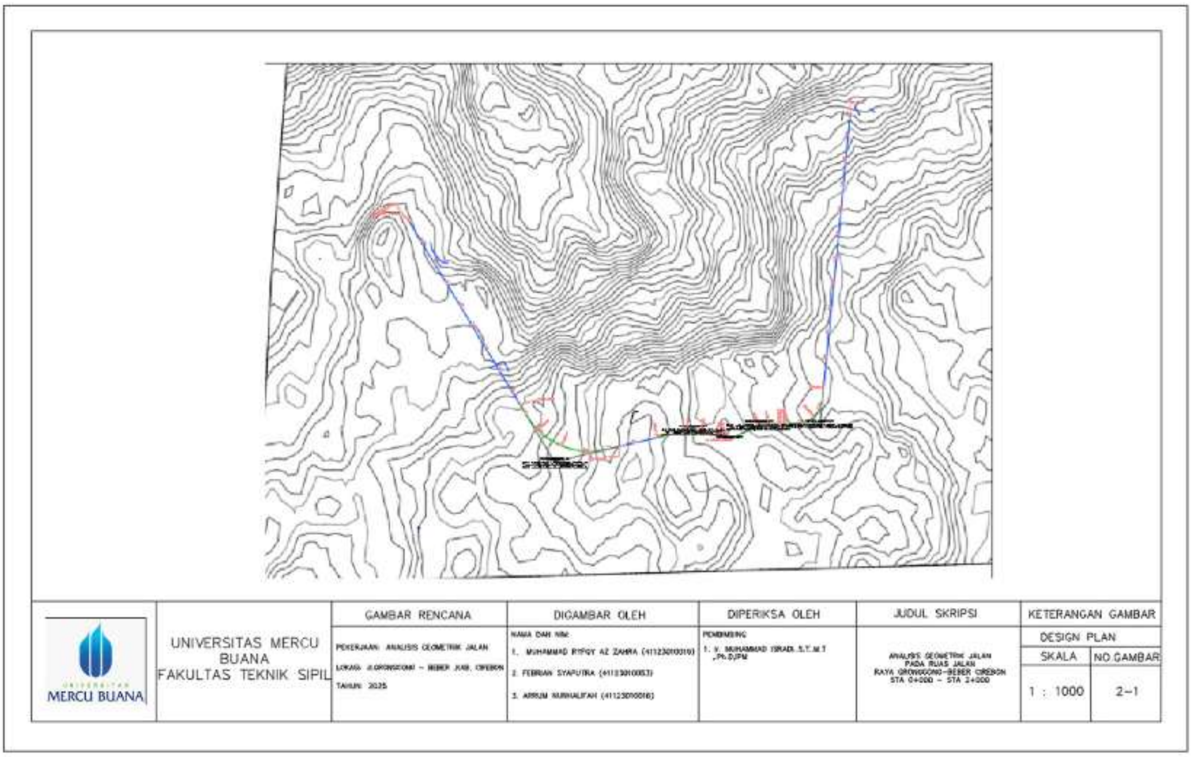

Figure 3. Research Location Layout

3.2. Horizontal Alignment Planning.

Based on the results of the horizontal alignment analysis on the Tondano–Suluan road section, several curves were evaluated for their compliance with Road Geometric Design Guidelines No. 20/SE/Db/2021. In general, most of the curves on this road section meet the applicable design requirements. However, the analysis results show that the third curve does not meet the geometric requirements set out in the guidelines.

The discrepancy at the third curve is caused by geometric parameters that do not meet the minimum required values, such as the curve radius being too small for the planned speed. This condition has the potential to reduce the level of safety and comfort for road users, especially when vehicles are traveling at relatively high speeds. In addition, geometric conditions that do not meet standards can also increase the risk of accidents, especially in poor weather conditions.

Therefore, improvements to the horizontal alignment design of the third curve are required to comply with the provisions of Road Geometric Design Guidelines No. 20/SE/Db/2021. The improvements are made by adjusting the geometric parameters of the curve to meet the applicable technical requirements. With these improvements, it is hoped that the planned road alignment will provide a higher level of safety and comfort for road users and support the optimal function of the road. Based on the results of the Horizontal Alignment Planning analysis, the results are shown in Table 2 as follows:

Table 2 Horizontal Alignment Planning.

NO	Description	BM 21	T1	T2	T3	T4	T5	UNIT
1	Δ(°)	-	72,04	30,53	46,03	28,64	84,24	Degree
2	V (km/h)	70	70,00	70,00	70,00	70,00	70,00	KM/ HOUR
3	f maks	0,15	0,15	0,15	0,15	0,15	0,15	
4	R MIN	175	167,75	167,75	167,75	167,75	167,75	M
5	R		180,00	200,00	178,00	210,00	170,00	M
6	D MAKS		8,54	8,54	8,54	8,54	8,54	DRJAT
7	FC Method 1	FC						

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NO	Description	BM 21	T1	T2	T3	T4	T5	UNIT
8	FC Method 2							
	a. dd		7,96	7,16	8,05	6,82	8,43	Degree
	b. ed	8%	6,43%	4,29%	6,68%	3,37%	7,70%	%
9	FC Method 3							
	a. Ls1 T=3	3	58,33	58,33	58,33	58,33	58,33	m
	b. LS 2		74,10	73,85	74,13	73,74	74,24	M
	c. LS 3	re = 0.035 if Vr<=70 km/h	33,33	33,33	33,33	33,33	33,33	m
	d. Used LS		74,10	73,85	74,13	73,74	74,24	m
10	P check		1,27	1,14	1,29	1,08	1,35	requires a transition curve P CHECK>0.25
11	If not F- C							
	a. θs		11,79	10,58	11,93	10,06	12,51	drjat
	b. θc		48,45	9,37	22,17	8,52	59,22	drajat
	c. Lc		152,22	32,71	68,86	31,22	175,70	m
12	CHECK THE TYPE OF TURN		S-C-S	S-C-S	S-C-S	S-C-S	S-C-S	REQUIREMENTS FOR S-C-S TYPE CURVES If θc > 0°, and Lc> 25 meters, if one of these is not met, then the curve is an S-S type curve.
	a. Xs		73,78	73,59	73,80	73,51	73,89	m
	b. Ys		5,08	4,54	5,14	4,32	5,40	m
	c. P		1,28	1,15	1,30	1,09	1,37	m
	d. K		37,00	36,88	37,01	36,83	37,06	m
	e. Tt		168,80	91,77	113,16	90,71	192,01	m
	f. Et		44,14	8,50	16,80	7,85	61,03	m
	g. Total L		300,42	180,40	217,11	178,70	324,18	m
	CONTROL		S - C - S	S - C - S	S - C - S	S - C - S	S - C - S	IF 2.Tt>= L then Turn S - C - S
13	curve widening							
	a. b''		0,0045	0,0032	0,0046	0,0028	0,0054	m
	b.b'	2,6	2,6045	2,6032	2,6046	2,6028	2,6054	m
	c. Td	1,2	0,0125	0,0001	0,0000	0,0000	0,0000	m
	d. z		0,5478	0,5197	0,5509	0,5072	0,5637	m
	e. Wc		7,5942	7,5264	7,5602	7,5127	7,5745	M
	WIDTH ON A STRAIGHT ROAD	6	1,5942	1,5264	1,5602	1,5127	1,5745	
14.	Stopping Sight Distance (SSD)		106,5095	106,5095	106,5095	106,5095	106,5095	m
15	Overtaking Sight Distance (OSD)							
	a		2,30	2,30	2,30	2,30	2,30	m/s^2
	t1		3,94	3,94	3,94	3,94	3,94	m/s
	t2		9,92	9,92	9,92	9,92	9,92	m/s
	d1		65,21	65,21	65,21	65,21	65,21	m
	d2		193,04	193,04	193,04	193,04	193,04	m
	d3		55,00	55,00	55,00	55,00	55,00	m
	d4		128,70	128,70	128,70	128,70	128,70	m
	jd		441,95	441,95	441,95	441,95	441,95	m

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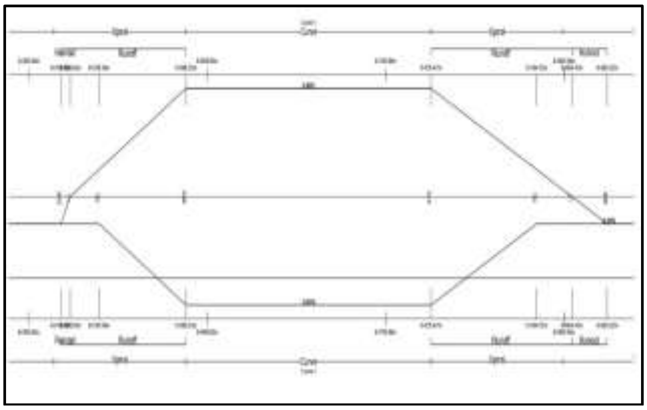

Figure 4. Design of Curve Superelevation 1

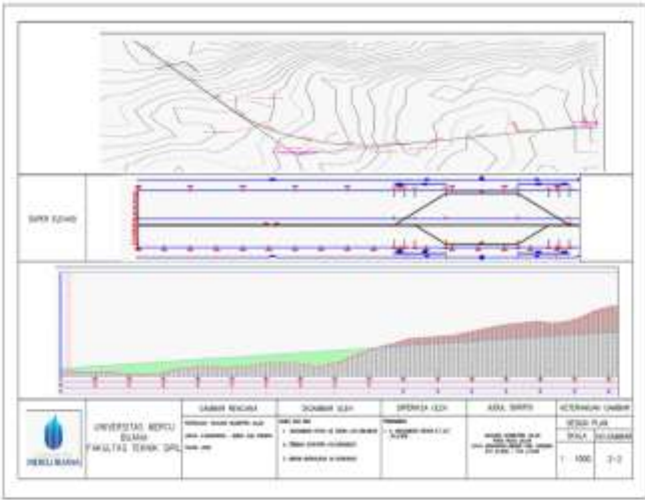

Figure 5. Example of the results of the design coordination for Turn 1

3.3. Vertical Alignment Design

In geometric road planning, vertical alignment plays a role in connecting elevation differences through a combination of inclines, declines, and vertical curves so that they meet technical and operational road requirements. Vertical alignment planning must consider safety aspects, road user comfort, and vehicle performance, especially in relation to stopping sight distance and approach sight distance. In addition, suitability with topographical conditions, drainage systems, and construction cost efficiency are also important factors in determining the longitudinal profile of a road. Therefore, vertical alignment planning is carried out with reference to applicable standards and regulations so that the planned road can function optimally and sustainably.

Vertical Alignment Planning Vertical alignment needs to be replanned in accordance with planning standards so that it meets the standards used. Therefore, it is necessary to replan the vertical alignment. Based on the results of the analysis of the original ground elevation of the longitudinal section of the road, the planned elevation for the vertical curve is taken as described in Table 3 below:

Table 3. Vertical Alignment Calculation

NO	Calculation	T1	T2	T3	T4	T5	UNIT
1	Gradien (g)						%
	Initial g	1,39949	1,38825	1,47900	1,38089	1,71473	
	Final g	1,388249	1,479001	1,380894	1,714732	1,371559	
2	PV Stationing	0+674	1+014	1+104	1+184	1+330	m

NO	Calculation	T1	T2	T3	T4	T5	UNIT
3	PV Elevation	146,303	151,01	152,21	153,31	155,32	m
4	Design Speed (Vr)	70	70	70	70	70	km/hour
5	A	0,011244	0,0908	-0,09811	0,3338	-0,3432	%
6	Visibility Distance	97,5	97,5	97,5	97,5	97,5	m
7	* based on form flexibility requirements (Lv)	42	42	42	42	42	
8	*based on drainage requirements (Lv)	0,449751	3,630084	-3,92428	13,35351	-13,7269	
9	*based on road construction requirements (Lv)	0,237525	1,917138	-2,07251	7,05232	-7,24953	
10	*based on comfort requirements (Lv)	0,141268	1,140219	-1,23263	4,19437	-4,31166	
11	take the largest Lv	42	42	42	42	42	
12	Ev	0,00059	0,004764	-0,00515	0,017526	-0,01802	
13	x	10,5	10,5	10,5	10,5	10,5	
14	Y	0,002361	0,019058	-0,0206	0,070106	-0,07207	
15	Sta PLV	0+653	0+993	1+083	1+163	1+309	m
16	Sta A	0+663,5	1+003,5	1+093,5	1+173,5	1+319,5	
17	Sta PPV	0+674	1+014	1+104	1+184	1+330	
18	Sta B	0+684,5	1+024,5	1+114,5	1+194,5	1+340,5	
19	Sta PTV	0+695	1+035	1+125	1+205	1+351	
20	Elevation PLV	146,0091	150,72	151,9004	153,02	154,96	
21	Elevation A	146,1537	150,8472	152,0763	153,0909	155,212	
22	Elevation PPV	146,3024	151,0072	152,2162	153,2885	155,338	
23	Elevation B	146,4464	151,1482	152,3766	153,4159	155,5361	
24	Elevation PTV	146,5945	151,3226	152,501	153,6661	155,608	

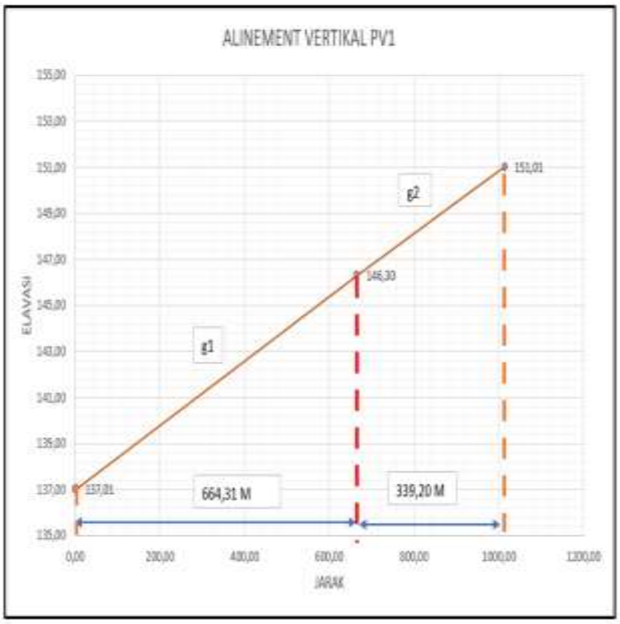

Figure 6. Vertical Alignment Design for Curve 1

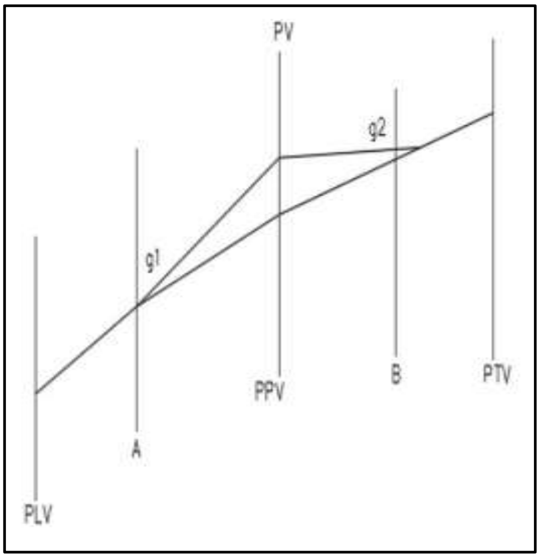

Figure 7. Design Results of Vertical Alignment Calculation for Point PV1

The result of the planning is three vertical alignments as follows:

- PPV1 is a convex vertical curve/alignment.
- PPV2 is a convex vertical curve/alignment.
- PPV3 is a convex vertical curve/alignment.
- PPV4 is a convex vertical curve/alignment.
- PPV5 is a convex vertical curve/alignment.

The three vertical curves/alignments meet the standard gradient value of $g \leq 8\%$.

3.4. Excavation and Fill Analysis

An analysis of excavation and embankment calculations was conducted to determine the volume of soil that needed to be worked on site during road construction in accordance with the planned alignment design. The calculation of excavation and embankment volumes was carried out using the average cross-sectional area method at both ends of the segment. Based on the analysis results, the excavation volume was 239.02 m^3 and the fill volume was 43.53 m^3. The difference between the excavation and fill volumes was 195.49 m^3, which, when expressed as a percentage, shows that the difference in excavation and fill volumes was 81.79%.

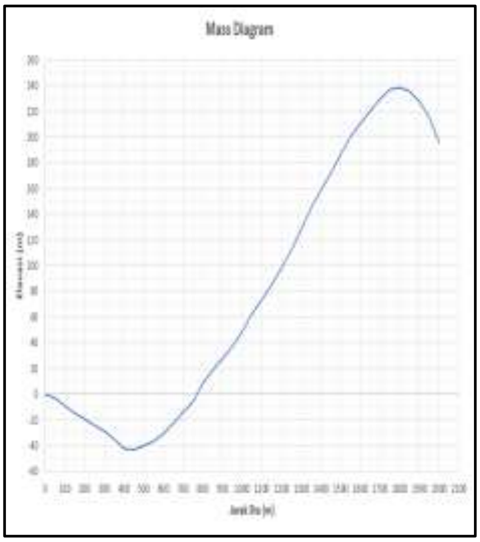

Figure 8. Mass Diagram

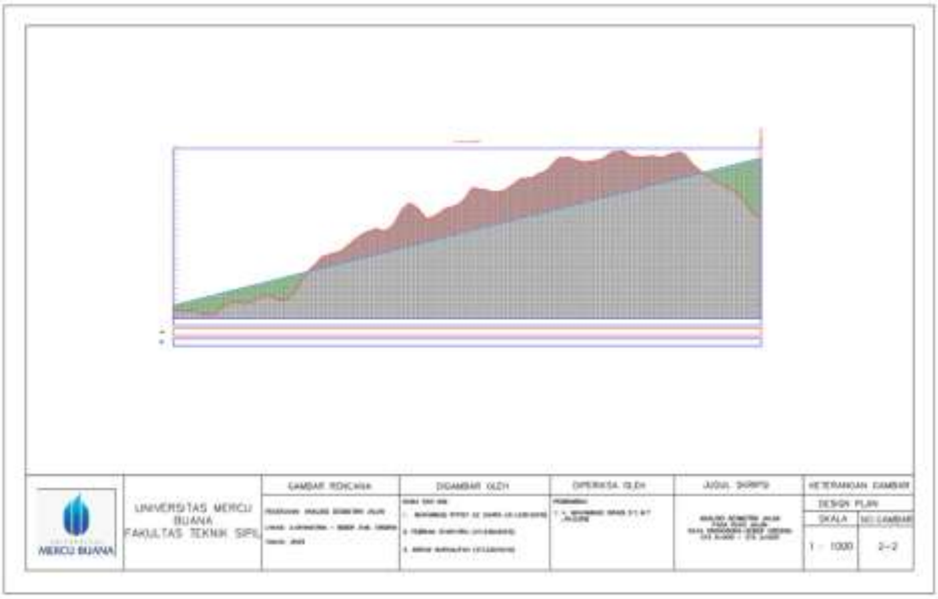

Figure 9. Vertical Long Section

I. Drainage Design

According to Laoh et al. (2013), drainage can generally be defined as a technical measure to reduce excess water, whether from rainwater, seepage, or excess irrigation water in an area/land, so that the function of an area/land is not disrupted. The following are drainage design calculations:

a. Rainfall data conversion (I)

I = 1900 – 2500 mm/year → Convert to mm/hour. (take the largest value, which is 2500 mm/year)

I $= \frac{2500}{24 \times 365}$

I $= 0,29$ mm/hour

b. Calculate the Cross-sectional Area of the Drainage Trapezoid (A):

For the initial drainage cross-section design, the following assumptions were used:

- B (Channel Width) = 1 m
- H (channel height) = 1,25 m
- Z (Channel Slope) = 1,5

Calculate the area of the channel (A):

$A = (B + ZH).H$

$A = (1 + (1{,}5 \times 1{,}25) \times 1{,}25$

$A = 3{,}59\ m^2$

c. Calculate Debit Q:

Q $= \frac{1}{3{,}6} \times C \times I \times A$

$= \frac{1}{3{,}6} \times 0{,}5 \times 0{,}29 \times 3{,}59$

= 0,14 m^3/second

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d. Calculate the velocity (V):

V $= \frac{Q}{A}$
$= \frac{0,14}{3,59}$
$= 0,040\ \frac{m}{s}$ (because the velocity is less than 0.6 > 0.14, it is sedimentary soil).

Therefore, it is necessary to redesign the cross-section.

e. Redesign the drainage system:

For the next drainage cross-section design, the following assumptions were used:

- B (Channel Width) = 0,5 m
- H (Channel Height) = 0,25 m
- Z (Channel Slope) = 1

Calculate the area of the channel (A):
$A = (B + ZH).H$
$A = (0,5 + (1 \times 0,25) \times 0,25$
$A = 0,18\ m^2$

f. Calculate the velocity (V):

V $= \frac{Q}{A}$
$= \frac{0,14}{0,18}$
$= 0,76\ \frac{m}{s}$ (because the velocity is greater than 0.6 < 0.76, the soil is not sedimented).

Therefore, the trapezoidal drainage design is sufficient.

g. Calculate the free board height:

$W = \sqrt{0,5 \times h}$
$W = \sqrt{0,5 \times 0,25}$
$W = 0,35\ m$
Because the threshold height is greater than 15 cm (15 cm < 35 cm).

So, the total depth of the channel h + w (0.25 m + 0.35 m) is 0.6 m.

h. Illustration of drainage cross-section

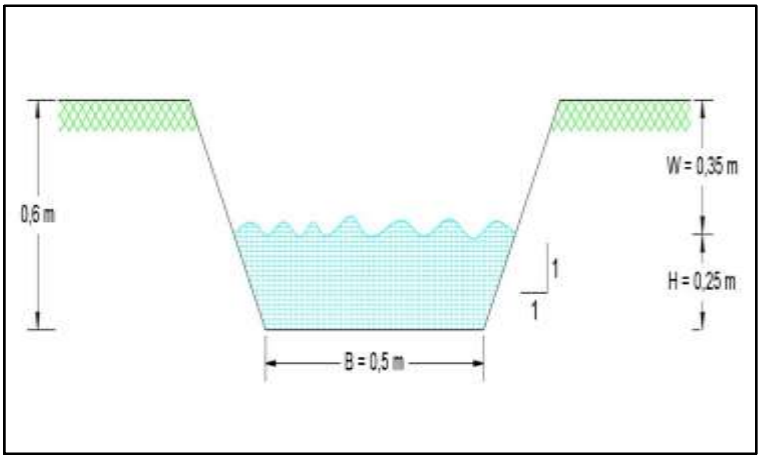

Figure 10. Drainage Design Results

4. Conclusions

Based on the results of the analysis and geometric planning of the road on the Gronggong–Beber section STA 0+000 – STA 2+000, several conclusions can be drawn as follows: 1). The results of the evaluation of existing conditions show that the road geometry on the Gronggong–Beber section does not fully comply with the provisions of Road Geometric Design Guidelines No. 20/SE/Db/2021, both in terms of horizontal alignment and vertical alignment. 2). In horizontal alignment planning, of the five curves analyzed (T1 to T5), all curves require transition curves with a Pcek value > 0.25, so the recommended curve type is Spiral–Circle–Spiral (S-C-S). The planned curve radii meet the minimum radius requirements for a design speed of 70 km/h, thereby improving road user safety and comfort. 3). The results of the vertical alignment planning show that all planned vertical curves have a curve length of Lv = 42 m, which is determined based on the flexibility requirements and meets the drainage, comfort, and road construction requirements. All planned vertical curves are convex curves with a gradient value of $g \leq 8\%$, thus complying with planning standards. 4). Based on the analysis of excavation and fill, the excavation volume was 239.02 m³ and the fill volume was 43.53 m³. The difference in volume between excavation and fill was 195.49 m³ or 81.79%, indicating that excavation work was more dominant than fill work on that road section. Based on the results of the research that has been conducted, several suggestions can be given as follows: 1). The planned geometric road design must be implemented so that road conditions on the Gronggong–Beber section comply with safety and comfort standards based on Road Geometric Design Guidelines No. 20/SE/Db/2021. 2). Given that the volume of excavated material is greater than that of fill material, it is advisable to plan for excavated material management so that excavated material can be optimally utilized or allocated to other locations where it is needed. 3). Further research is expected to continue planning to the stage of pavement, drainage, and cost estimation planning, so that a more comprehensive road plan can be obtained.

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