Road Design Using Deflection Method Case Study: Lolowau - Siwalawa II, Gunungsitoli City

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Abstract. Roads are a means of connecting one area to another that can be traversed by vehicles. The initial damage condition of the highway is mainly caused by the presence of overloaded cars passing through the road, poor planning of the quality of the dense traffic pavement layer that does not comply with the requirements, design errors in determining the thickness of the pavement, and inadequate road supporting facilities (road drainage system). To anticipate road damage, an overlay is needed. This research was conducted on the Lolowau-Siwalawa II road in Gunungsitoli City, along 10.7 km. The calculation of the overlay thickness was carried out using CESA analysis. The study's results indicated that the road pavement width was planned to be 4.5 meters, with two lanes and 2-way vehicle lane directions, and a design life of 10 years. Overlay with Lapen pavement of 22 cm and a cover layer of 7 cm.

Keywords: Road design, Pavement design, Deflection method

1 Introduction

Road infrastructure plays a crucial role in the development of a region. Roads provide access from one location to another, using vehicles as the means of transportation [1]. Law of the Republic of Indonesia No. 38 of 2004 concerning Roads states that road access is a land transportation infrastructure consisting of all road elements and supporting structures. As a transportation infrastructure, road planning can be done above ground, underground, or above water [2]. In designing a road, it is essential to ensure that optimal road maintenance is also supported [3]. Initial damage to roads is primarily caused by overloaded vehicles, inadequate pavement quality planning for heavy traffic, design errors in determining pavement thickness, and insufficient road support facilities (road drainage systems) [4].

To anticipate road damage, an overlay is necessary. Overlay planning is usually carried out to improve the pavement on road sections [5]. Road pavement needs to be overlaid due to poor road construction or other damage to the road. Lolowau-Siwalawa II Road in Gunungsitoli City is a main road that is generally used by large vehicles. The large number of heavy vehicles passing on this road causes the road surface to become damaged, so measures are needed to

ICIESC 2025, September 16, Medan, Indonesia

DOI 10.4108/eai.16-9-2025.2361062

anticipate more severe damage. The research on this road improvement program aims to facilitate and smooth the flow of vehicles on the Lolowau-Siwalawa II road section, a district road. The impact of this road improvement will be able to increase economic growth and the standard of living of the people living around the road.

Road problems aren't solely caused by congestion, but can also be caused by low road capacity. Low capacity isn't strictly due to road construction; it can be caused by several factors, such as numerous side obstacles, suboptimal road width, and so on. Road design research using the deflection method is conducted to develop design details that meet standards and increase road capacity. This road improvement research provides crucial information for local governments, allowing them to utilize it in implementing city infrastructure.

2 Literature Review

2.1 Geometric Planning

Elements in geometric road planning consist of cross-sections, horizontal and vertical alignments [6]. The geometric design of the road route must be guided by applicable planning guidelines, taking into account existing terrain conditions, land use, topography, spatial planning, and the development plan for the area along and around the road [7].

The 1970 Highways Agency (Bina Marga), as an extension of the government in writing the road, issued the Geometric Planning Regulations for Highways (Geometric Design Specifications for Rural Highways), which serve as guidelines (standards) for geometric planning [8]. These highway geometric planning standards contain provisions on detailed geometric planning and road components. With the advancement of technology, not all of these provisions can be used, as some are no longer in line with current technological developments.

In this study, the geometric design standards used are taken from the 2017 Highway Geometric Design Regulations, which specify several standard values that do not have to be fully met, including [9]:

a. The standard pavement type is called "lapen." This type of pavement is generally no longer suitable due to advances in road construction technology. In this study, the planned pavement surface layers are hotmix and lapen.

b. The pavement slope is specified as 3%. The 3% slope is only relevant for lapen pavement. Using hotmix, the pavement slope is 2%.

c. The maximum slope specified in the regulations is 10%. This is not a problem in this study due to the essentially flat topography of the terrain.

d. Standardization of other parameters, such as speed, superelevation, radius of curvature, and others, is a limit that must always be met. Similarly, for road gradient planning, under certain conditions, speed and radius values sometimes fail to reach the required minimum values. In this case, criteria/limits are needed to determine the extent to which standards can be violated so that the geometric conditions of the planned road section still meet the safety and comfort of road users.

2.2 Cross-Section

The road surface is an essential component of the cross-section. Generally applicable road cross-section planning includes the number of lanes and dimensions of vehicle traffic lanes, shoulders, drainage channels (closed/open), embankments, and other elements within a specific section or segment [10]. The existing pavement widths in the effective segments of the widened road are 4.0 meters and 3.0 meters, respectively. For all sections to be widened, the pavement width is planned to be 4.5 meters. The widening is carried out symmetrically on both sides of the road, at 0.5 meters and 0.75 meters, respectively. The standard shoulder width is 1.0 meter per side. The 1.0-meter-wide shoulder is paved with granular material, namely class S base aggregate [11].

2.3 Slope Direction of Ravines and Cliffs

The standard slope of embankments (towards the ravine) is 1.5:1, using standard embankment materials. The standard slope of excavation embankments (towards the hill) is 1:2. For rocky/rocky soil conditions, it can be 1:4 up to a 90° vertical position, depending on the hardness of the material [12].

2.4 Horizontal and Vertical Alignment

A road with a horizontal alignment is a road axis along which straight and curved sections are drawn. Horizontal alignment planning determines the position of the road alignment, curves, and curve element planning, among other things. Vertical alignment is a perpendicular projection of the road axis established during the horizontal alignment planning stage onto the drawing plane. An essential criterion in geometric planning is the design speed selected according to the previously determined road class. The planning process for these two geometric elements is generally carried out reciprocally, meaning the final geometric road design result is the accumulation of the requirements of each geometric component.

For this planned section, the alignment is generally, or essentially, relatively stable, especially for flat to hilly terrain. Generally, no relocation or realignment is necessary. In hilly areas, there are relatively sharp inclines and curves. Still, the existing terrain can be categorized as mountainous (transverse slope > 25%), and the curve radii and longitudinal gradients are generally or primarily within standards. The design speed applicable to hilly areas ranges from 20 to 40 km/h [13].

In horizontal alignment planning, the primary challenge is determining the applicable superelevation, given the existing pavement [14]. Each curve with a predetermined radius is first checked for the appropriate design speed and required superelevation. The expected curve radius meets the minimum standard of 30 meters [15]. However, due to limited conditions, such as curves in challenging terrain (e.g., rocky hills) and minimal terrain, the minimum curve radius is 18.0 meters, and the absolute minimum radius is 12.0 meters [14].

If the pavement treatment involves raising or grade revision, the design speed and superelevation values can be used directly. For overlays over existing pavement, the transverse slope of the existing pavement is first checked [16]. The superelevation used will generally be chosen to match or approximate the existing superelevation, and the speed will be adjusted, with a speed limit of no less than 20 km/h. With the radius and superelevation obtained, the length of superelevation that can be applied is then determined, namely by first calculating the minimum superelevation length based on geometric planning standards [18].

3 Methodology

The research implementation phase began with an initial field visit to collect data on traffic, pavement, and environmental conditions. Traffic data were collected through traffic surveys for various types of vehicles and transportation. The results will be analyzed to obtain MSA and VDF. Analysis of road conditions is conducted by surveying the pavement's condition and performing soil testing. Traffic and pavement conditions are then analyzed to obtain pavement plans such as new roads, road reconstruction, widening, or adding pavement (overlay).Figure 1 below shows the methodology used in the research and is depicted in the research flowchart

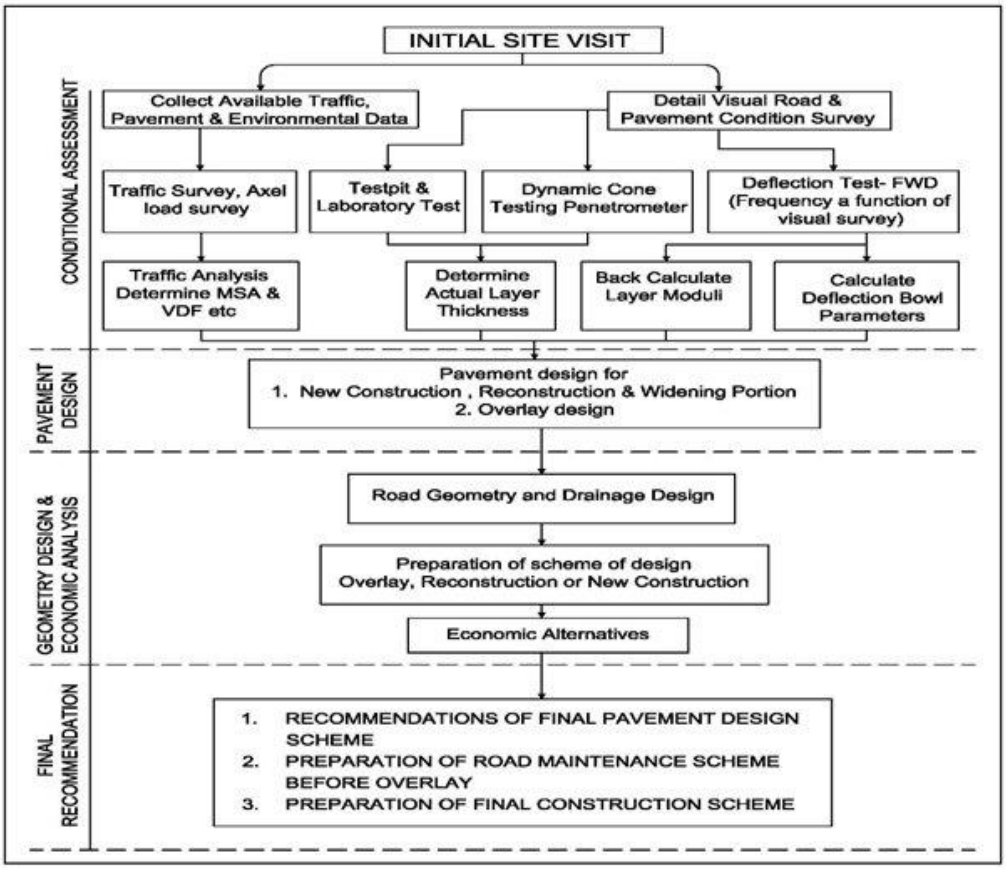

Fig. 1. Research Flowchart.

4 Result

The road design research using the deflection method was conducted on the Lolowau-Siwalawa II road in Gunungsitoli City. The road being studied is 3 km long, starting from Station 49+000 to Station 59+700. This road is relatively flat, making it suitable for designing using the deflection method.

The pavement design for this road section consists of four types of pavement layers [19]:

a. Additional pavement layer over the existing layer

b. Widening pavement layer

c. Paving over the subgrade from the cut-fill area or rising area, or over the existing dirt/gravel road surface.

For each type of treatment, the required pavement index value is calculated according to the soil bearing capacity and the planned traffic load. For additional layers above the existing pavement, the remaining value of the existing pavement layer is calculated by knowing the type of material and its condition [20]. By knowing the remaining value of the pavement, the required pavement index value can be calculated. For widening, a full pavement is planned by adjusting the thickness of the asphalt layer and the top base layer on the additional layer, for pavements where the road body is raised (with embankment) or road body excavation (cutting), the planned pavement layer is a full pavement where the bearing capacity of the subgrade is according to the results of the DCP at the relevant location [21].

4.1 Planning Criteria and Methods

The planning method used is the Pavement Flexural Design Method with Component Analysis [22]. Pavement deflection data calculations are presented in Table 1.

Table 1. Calculation of Pavement Deflection Data for Lolowau - Siwalawa II, Gunungsitoli City

	Road Function:	Collector			
No.	Km	D	D average	S	1+2.8S
	SEGMENT I				
1	49+000	1,14			
2	49+200	1,16			
3	49+400	1,18			
4	49+500	1,20			
	SEGMENT II				
1	51+000	1,18			
2	51+200	1,24	1,29	0,11	1,433
3	51+400	1,20			
4	51+500	1,22			
	SEGMENT III				
1	53+700	1,42			
2	53+900	1,42			
3	54+100	1,40			

	Road Function:	Collector			
No.	Km	D	D average	S	1+2.8S
4	54+200	1,38			
	SEGMENT IV				
1	59+200	1,40			
2	59+400	1,42			
3	59+600	1,40			
4	59+700	1,38			

Table 1 explains that four segments are the research locations. Each benchmark is 200 cm apart, with a deflection thickness varying between 1.14 and 1.42 cm, or an average thickness of 1.29 cm. The resulting slope is 0.11 cm.

Based on Table 1, a pavement planning analysis was conducted using the following criteria [23]:
a. Design Life = 10 years
b. Traffic growth = 6% per year
c. Road Class: Secondary Arterial (Rural Road)
d. Optimization of local material use

The calculation of the equivalent axle load for a 10-ton MST can be seen in Figure 2 below.

Type of vehicle and figures		Axis Load Configuration	Tonnage	ESA Equivalent Number
Motorcycle				
Passenger Car		↓ 1,00 ↓ 1,00	2	0,0024
Minibus		↓ 1,20 ↓ 1,9	3	0,0178
Micro truck, Pick up,etc		↓ 1,50 ↓ 3	4	0,1012
Small bus		↓ 2,00 ↓ 4	6,3	0,3199
Big bus		↓ 3,00 ↓ 6	9	0,3876
Light Truck 2 as		↓ 3,00 ↓ 5	8,3	0,2362
2 axle light truck		↓ 6,00 ↓ 10	15,15	3,7796
3 axle truck		↓ 6,00 ↓↓ 18	25	4,4525
Semi-Trailer Truck		↓ 6,00 ↓↓ 10 ↓↓ 18	37,04	3,4996
Truck Trailer		↓ 6,00 ↓↓ 9 ↓↓ 12 ↓↓ 18	42	3,9821

Figure 2 Calculation of Vehicle Axle Load Equivalent Figures for MST 10 Tons

Figure 2 shows that the 3-axle truck has the highest ESA value of 4.4525, even though the tonnage is 25 tons. Meanwhile, for the most considerable tonnage, namely 42 tons for a trailer truck, the equivalent ESA value is only 3.9821.

Figure 3 shows the ESA Equivalent Values obtained for various vehicle types carrying an 8-ton MST axle load.

Figure 3 shows that the 3-axle truck has the highest ESA value of 2,5958, even though the tonnage is 25 tons. Meanwhile, for the most considerable tonnage, namely 42 tons for a trailer truck, the equivalent ESA value is only 1,3630

Type of vehicle and figures		Axis Load Configuration				Tonnage	ESA Equivalent Number
Motorcycle							
Passenger Car		1,0	1,0			2	0,0024
Minibus		1,2 STRT	1,9 STRT			3	0,0178
Micro truck, Pick up,etc		1,5 STRT	3,0 STRT			4	0,3070
Small bus		2,0 STRT	4,0 STRT			6,3	0,3199
Big bus		3,0 STRT	6,0 STRT			9	0,3876
Light Truck 2 as		3,0 STRT	5,0 STRT			8,3	0,2362
2 axle light truck		6,0 STRT	10,0 SGRG			15,15	1,6589
3 axle truck		6,0 STRT	18,0 SGRG			25	2,5958
Semi-Trailer Truck		6,0 STRT	10,0 SGRG	18,0 SGRG		37,04	1,3268
Truck Trailer		6,0 STRT	9,0 SGRG	12,0 STRT	18,0 SGRG	42	1,3630

Figure 3. Calculation of Vehicle Axle Load Equivalent Figures for MST 8 Tons

4.2 Discussion

The analysis results from Figures 1 and 2 are then used to calculate the pavement thickness design plan using the following standards:

a. Pavement width = 4.5 meters
b. Number of lanes = 2

c. Lane direction = 2
d. Design life = 10 years
e. Traffic growth rate = 6%
f. Vehicle distribution coefficient
   - Light vehicles C = 0.50
   - Heavy vehicles C = 0.20

Table 2 shows the results of Average daily traffic for Lolowau - Siwalawa II, Gunungsitoli City in 2022 and 2023. Average daily traffic analysis shows that the most common vehicles on Lolowau - Siwalawa II, Gunungsitoli City road are motorcycles, followed by passenger cars. The total number of vehicles in 2022 was 199 units, and in 2023 it increased to 215 units.

Table 2. Average daily traffic for Lolowau - Siwalawa II, Gunungsitoli City

No	Vehicle Classification	Daily traffic	
		2022	2023
1	Motorcycle/Rickshaw	106	112
2	Passenger Car	88	94
3	Minibus	2	2
4	Micro Truck, Pickup dll	1	1
5	Small Bus	0	1
6	Big Bus	0	2
7	Small 2 Axle Truck	1	2
8	2 Axle medium truck	0	0
9	3 Axle Truck	0	0
10	Semi-Trailer Truck	1	1
	Jumlah	199	215

Table 3 is used to analyze the damage factors that occurred at the research location. The Damage Factor is a measuring tool for determining the effects of damage to a road caused by vehicle loads, which can affect the pavement structure, pavement materials, and the system involved. The Damage Factor is used to help assess the potential level of damage and failure caused by these loads.

Table 3. Damage Factor MST 10 Ton

No	Vehicle Classification	Damage Factor MST 10 Ton
1	Motorcycle/Rickshaw	0,00000
2	Passenger Car	0,00235
3	Minibus	0,01777
4	Micro Truck, Pickup dll	0,30702
5	Small Bus	0,31988
6	Big Bus	0,38757
7	Small 2 Axle Truck	0,23623
8	2 Axle medium truck	1,65888
9	3 Axle Truck	2,59577

No	Vehicle Classification	Damage Factor MST 10 Ton
10	Semi-Trailer Truck	1,32684
11	Trailer Truck	1,36299

Next, calculate the Accumulated Standard Load Equivalent (CESA)
Using the CESA formula = (LHR x DL x 365 x VDF x (((1 + i $)^{UR}$) -1) / i)/ 10^6

Table 4. Damage Factor MST 8 Ton

No	Vehicle Classification	Damage Factor MST 8 Ton
1	Motorcycle/Rickshaw	0,00000
2	Passenger Car	0,0005278
3	Minibus	0
4	Micro Truck, Pickup dll	0
5	Small Bus	0
6	Big Bus	0
7	Small 2 Axle Truck	0
8	2 Axle medium truck	0
9	3 Axle Truck	0
10	Semi-Trailer Truck	0
11	Trailer Truck	0
	CESA	0,001 x10^6

Traffic movement on the design lane is expressed in Cumulative Equivalent Standard Axle (cumulative standard axle load) or CESA [24]. CESA analysis is carried out by calculating the directional distribution factor (DD) and the commercial vehicle lane distribution factor (DL). For two-way roads, the directional distribution factor is generally taken as 0.50, and for the commercial vehicle lane distribution factor (DL), it is 100% [25]

Deflection Before Overlay $D_{beforeov}$ = 1,433 mm

Deflection after Overlay (plan) $D_{afterov}$ = 22.208 x CESA -0.2307 = 5,229 mm

Additional Layer Thickness Required H_o = -21,086 cm

Added Layer Thickness Correction (Fo) (F_o)

The location of the Lolowau - Siwalawa II road section obtained an average annual temperature (AAT) of 34.8

F_o = 0.532 x EXP (0.0194xTPRT) = 1,045

Corrected Added Layer Thickness (Ht) = H_o x F_o = - 22 cm

Additional layer thickness required for design life = 10 years

With a LAPEN pavement of -22.03 cm The wearing course is set at LAPEB = 7.00 cm

5 Conclusion

This study concludes: 1) The road pavement width is planned at 4.5 meters, with two lanes and two-way traffic, with a planned lifespan of 10 years. The overlay design uses a 22 cm LAPEN pavement and a 7 cm thick cover layer.

This study recommends: 1) Overlay planning must be accompanied by improvements to other infrastructure, such as road shoulders, drainage systems, and so on, to maintain the road's intended lifespan. 2) Vehicle tonnage must be limited to ensure the load on the road matches the calculated tonnage.

Acknowledgment.

The research conducted was funded by the Unimed Research and Development Institute (LPPM Unimed), sourced from Unimed's PNBP Fund for the 2025 Fiscal Year. Unimed Rector's Decree No. 0063/UN33/PPKM/PPT/2025 validated this research.

The researcher did not work alone, but coordinated with several parties who assisted in this research. The researcher would like to express her gratitude to all the involved parties, including the students (Ira Zahrianti, Yohana Hutajulu, Fristdo Setiawan Simanungkalit, Adinda Puspa Ayumi, and Berkatson Nitehe Harefa), who served as data collectors, surveyors, and data recapitulators. She also expressed her gratitude to the core team who contributed to the planning, implementation, and analysis of all aspects of the research. She also expressed her appreciation to the Dean of the Faculty of Engineering, the Head of the Soil Testing Laboratory and his team, the Head of the Material Testing Laboratory and his team, and the management for their dedicated work in completing the research.

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