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Evaluation of Assessment of Flexible Pavement Damage Conditions on Urban Roads in Indonesia

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ABSTRACT

Road infrastructure plays a vital role in supporting social and economic activities. However, deterioration and damage to urban roads remain a persistent issue in Indonesia, including in West Java Province. In Cirebon City, the Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo road segment serves as a key arterial route, facilitating the mobility of people and goods. Due to its high traffic volume and strategic importance, maintaining this road section is crucial for urban functionality and development. This study aims to establish a systematic and objective priority scale for urban road maintenance by integrating the Pavement Condition Index (PCI), Surface Distress Index (SDI), and Analytical Hierarchy Process (AHP) methods. While PCI and SDI are used to assess the technical condition of the pavement, AHP allows for decision-making based on multiple criteria, including traffic volume and land use. The combination of these three methods provides a more comprehensive and balanced framework for prioritizing repair efforts, aligning technical evaluations with functional and strategic considerations. The analysis revealed varying levels of pavement damage across the study area. Based on the AHP results, the STA 2+300 to 2+400 road segment was identified as the highest priority for intervention due to its critical condition and functional importance. This integrated approach ensures that limited resources can be allocated more effectively to road sections requiring immediate attention, supporting sustainable and data-driven infrastructure management in urban environments.

1. INTRODUCTION

Roads are a critical component of transportation infrastructure, essential for regional connectivity and the movement of people and goods. In developing countries like Indonesia, smooth traffic flow depends heavily on the quality of road conditions[1] Well-maintained Road networks help accelerate regional growth, lower transportation costs, and improve access to essential services and labor markets[2], [3].

Over time, road quality naturally deteriorates, especially under frequent heavy vehicle traffic that exceeds the original design load, leading to structural damage such as cracking, deformation, and subsidence. This not only affects user safety and comfort but also raises maintenance costs if left unaddressed[4] [5]. In regions such as West Java, recurring road damage has become a major issue, impacting the economy, public safety, and transportation efficiency[2], [6]. Damaged roads featuring potholes, cracks, and surface deformation—can increase fuel consumption, vehicle wear, and the risk of accidents. Since transportation is closely tied to economic productivity, infrastructure quality is vital for development [7].

Urban road damage is particularly urgent due to the high mobility demand and economic activity in city environments. Studies show that rough surfaces can reduce average speeds by up to 25%, increase rolling resistance by 5%, and raise transportation costs by 21%, affecting both logistics and supply chain operations[2], [6]. Higher traffic on damaged roads also disrupts service delivery, lowers customer satisfaction, and harms business continuity[6], [8]. Environmentally, poor road surfaces lead to increased CO_2 and particle emissions due to higher engine load. Research indicates that potholes and uneven roads contribute to fuel inefficiency and air pollution, impacting public health[9],

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[10]. One such urban road facing these issues is Jl. Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo (STA 0+000 – 3+000), a major arterial corridor in Cirebon City and part of the northern Java transport route.

An analytical approach using PCI values can be used in data-based decision making in road management, thereby supporting the creation of a more reliable, safe, and sustainable transportation network [11]. To assess the road's condition, visual surveys were conducted using the Pavement Condition Index (PCI) and Surface Distress Index (SDI). PCI provides a numerical score (0–100) representing road condition, while SDI classifies the types of surface damage. These evaluations support effective maintenance planning based on damage severity. Referring to Permen PU No.13/PRT/M/2011, road maintenance covers three main categories, namely routine maintenance, periodic maintenance, and structural improvement[12].

The Analytical Hierarchy Process (AHP) method is a decision-making method used to systematically solve multi-criteria problems. This method helps in determining priorities systematically and logically, through a process of organizing problems into a structured hierarchy that facilitates evaluation and selection of the best alternatives[13]. There are many factors to consider, and AHP helps to compile and organize information systematically. Basically, the AHP method accommodates both qualitative and quantitative aspects in the decision-making process, enabling a more comprehensive analysis of the various criteria involved[14]. Referring to the Procedures for Preparing Road Maintenance Programs No. 018/BNKT/1990, the determination of road maintenance priorities and the types of maintenance carried out by Bina Marga[15] are based on two main criteria, namely the physical condition of the road and the average daily traffic volume. Land use is an important consideration in determining road repair priorities because these factors are interrelated. Therefore, this study uses three criteria for prioritizing road repairs, namely road damage conditions, Average Daily Traffic (ADT), and land use. AHP is a relevant method to be applied in road planning and management.

This study combines PCI, SDI, and AHP to provide a comprehensive and systematic framework for assessing road conditions, prioritizing repairs, and supporting maintenance planning, including pavement thickness design and cost estimation. This latest research applies the Pavement Condition Index (PCI) method based on the 2016 IKP Bina Marga standard and the 2024 Pavement Design Manual (MDP) to accurately evaluate road conditions in urban areas. This update enables more comprehensive identification of road damage, while the Surface Distress Index (SDI) is used to analyze specific types and patterns of damage. The Analytical Hierarchy Process (AHP) method is applied to determine the priority scale for road repairs, taking into account technical and strategic factors. This integrated approach is expected to produce more effective and sustainable road maintenance policies to support optimal urban mobility.

2. RESEARCH METHOD

Figure 1 shows the flow chart of this study. The location used as the object of this study is the 3 km stretch of Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo Street.

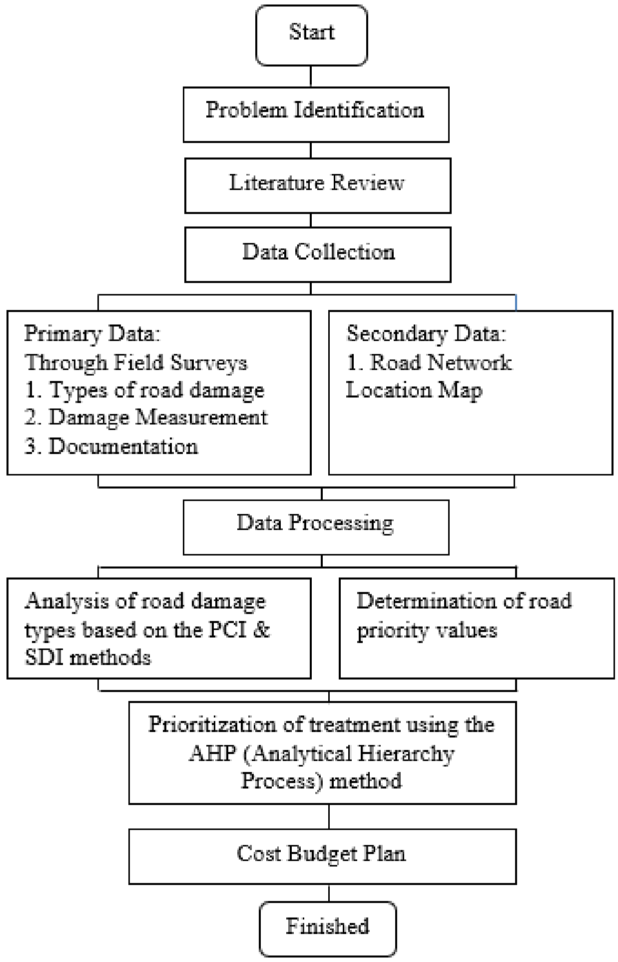

Fig. 1. Research Flow Chart

Fig. 2. Research Location

2.1 Data Collection Techniques

In this study, road damage assessment and identification were carried out using the Pavement Condition Index (PCI) and Surface Distress Index (SDI) methods. Data analysis for determining road maintenance priorities was conducted using the Analytical Hierarchy Process (AHP) method, and recommendations were made for road pavement types and budget plans.

3. RESULTS AND DISCUSSION

From the research results, survey data processing was carried out using the Pavement Condition Index method (PCI) based on the 2016 guidelines of the Ministry of Public Works and Public Housing [16], the Surface Distress Index (SDI) based on the 2011 Bina Program guidelines[17], the Analytical Hierarchy Process (AHP) method, and the design of flexible pavement thickness in this study referred to the 2024 Road Pavement Design Manual Guidelines, which were used as standard references in determining pavement structure dimensions [18].

3.1 Road Geometric Data

Geometric road data was obtained by conducting a direct survey using a roll meter from stationing 0+000 – 3+000 on Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo Street.

Table 1. Road Geometric Data

Description	
Street Name	Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo
Location	Kejaksan District & Kesambi District, Cirebon City, West Java
Observation Point	STA 0+000 s.d STA 3+000
Width Effective Pavement	± 12 – 14 m
Road Type	4 lanes 2 way split (4/2 T)
Road Status	National Road
Road Function	Collector
Road Class	I
Field	Flat
Median	Yes
Road Markings	Yes

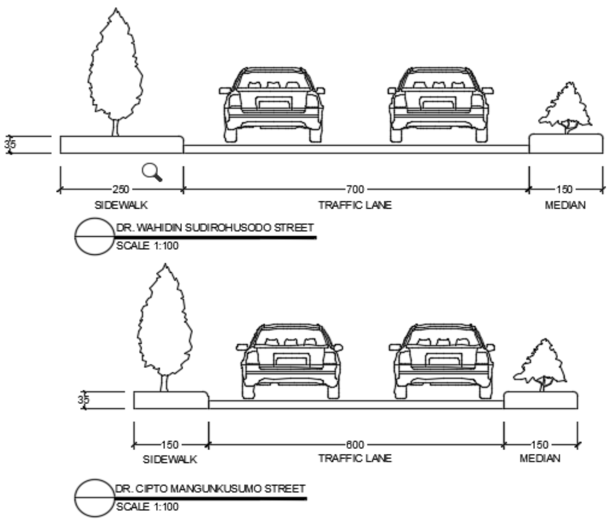

Fig. 3. Road Geometrics

3.2 Pavement Condition Index Method (PCI)

A survey to collect pavement condition data was conducted from stationing 0+000 – 3+000 on the section of Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo Street. The type, number, and severity of each damage were assessed through visual inspection and recorded in the data sheet. Survey data was processed to obtain the Deduct Value, Total Deduct Value, Corrected Deduct Value, and PCI value.

3.3 Surface Distress Index Method (SDI)

Based on observations conducted on the section of road from Dr. Wahidin Sudirohusodo to Dr. Cipto Mangunkusumo, several damages were found on the flexible pavement along a 3-kilometer stretch. The recording of road damage survey results covers several aspects as follows:

a. SDI1 based on crack area (total area of crack).
b. SDI2 based on average crack width (average crack width).
c. SDI3 based on number of potholes (total number of potholes).
d. SDI4 based on wheel rutting depth (average depth of wheel rutting).

Table 2. Total Crack Area Parameter

Parameter	Category	SDI_1 Value
Total area of Cracks	NONE	0
	<10%	5
	10-30%	20
	>30%	40

Table 3. Average Crack Width Parameters

Parameter	Category	SDI2 Value
average crack width	NONE	SDI_1
	FINE < 1 mm	SDI_1
	MED 1-3 mm	SDI_1
	WIDE > 3 mm	SDI_1 x 2

Table 4. Number of Holes Parameter

Parameter	Category	SDI_3 Value
Total number of potholes	NONE	SDI_2
	< 10/km	SDI_2 + 15
	10-50/km	SDI_2 + 75
	> 50/km	SDI_2 +225

Table 5. Average Depth of Wheel Rutting Parameter

Parameter	Category	SDI_4 Value
Average depth of wheel rutting	NONE	SDI_3
	< 1 cm	SDI_3 + 2,5
	1- 3 cm	SDI_3 + 10
	> 3 cm	SDI_3 + 20

Table 6. Recapitulation Level Damage of PCI and SDI

No	STA	Based on	
		Level Damage (PCI)	Level Damage (SDI)
1	0+000 - 0+100	Poor	Medium
2	0+100 - 0+200	Fair	Medium
3	0+200 - 0+300	Poor	Severe Damage
4	0+300 - 0+400	Poor	Severe Damage
5	0+400 - 0+500	Serious	Severe Damage
6	0+500 - 0+600	Serious	Medium
7	0+600 - 0+700	Very Poor	Medium
8	0+700 - 0+800	Poor	Medium
9	0+800 - 0+900	Very Poor	Medium
10	0+900 - 1+000	Poor	Good
11	1+000 - 1+100	Fair	Medium
12	1+100 - 1+200	Failed	Medium
13	1+200 - 1+300	Serious	Medium
14	1+300 - 1+400	Satisfactory	Good
15	1+500 - 1+600	Poor	Medium
16	1+500 - 1+600	Satisfactory	Good
17	1+600 - 1+700	Poor	Medium
18	1+700 - 1+800	Poor	Medium

19	1+800 - 1+900	Poor	Good
20	1+900 - 2+000	Satisfactory	Medium
21	2+000 - 2+100	Fair	Good
22	2+100 - 2+200	Serious	Medium
23	2+200 - 2+300	Failed	Good
24	2+300 - 2+400	Failed	Medium
25	2+400 - 2+500	Very Poor	Good
26	2+500 - 2+600	Serious	Medium
27	2+600 - 2+700	Serious	Good
28	2+700 - 2+800	Failed	Medium
29	2+800 - 2+900	Satisfactory	Good
30	2+900 - 3+000	Very Poor	Medium

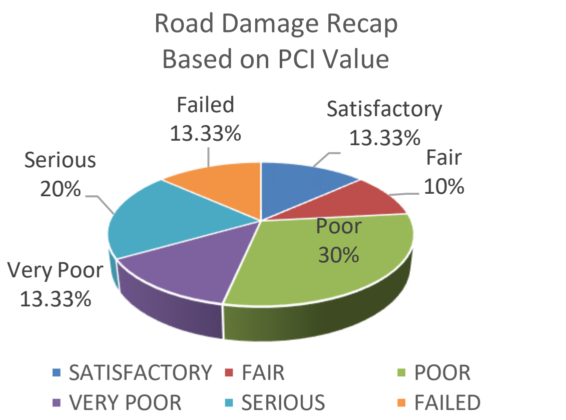

Fig. 4. Road Damage Recap Values Based on PCI

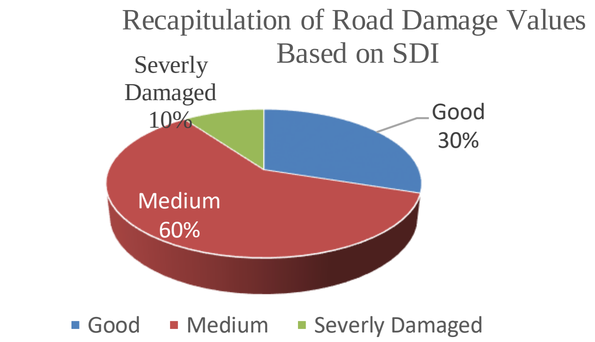

Fig. 5. Road Damage Recap Values Based on SDI

3.4 Decision Making Using the Analytical Hierarchy Process Method (AHP)

1. Intelligent Stage

In this case, the criteria for determining the priority of road maintenance were as follows:

a. There are three alternative road segments per 100 meters:
- Segment 12 = STA 1+200
- Segment 24 = STA 2+400
- Segment 28 = STA 2+800

b. The criteria for selecting road maintenance are as follows:
- Criterion 1 = Road Condition
- Criterion 2 = Daily Traffic Volume
- Criterion 3 = Land Use

2. Modelling Stage

In the Analytical Hierarchy Process Method (AHP), a hierarchical structure must be created during the modeling stage.

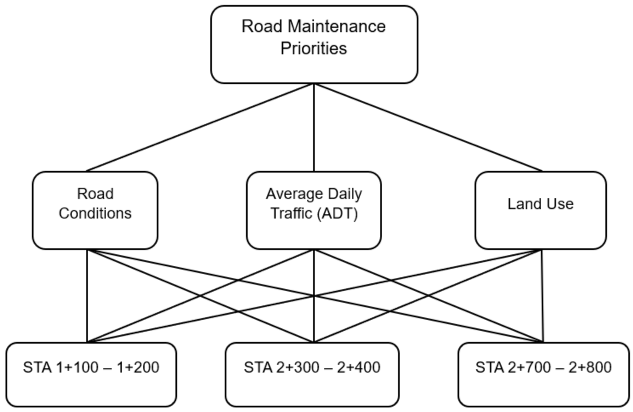

Fig. 6. Hierachy Structure

3. Choice Stage

At this stage, it is necessary to consider each criterion used based on Table 7.

Table 7. Pairwise Comparison Scale

Intensity of bag Importance	Description	Explanation
1	Both elements are equally important	Both elements have an equally significant influence on the objective
3	One element is slightly more important than the others	Experience and judgment slightly favor one element over another
5	One element is more important than the others	Very strong experiences and judgments favor one element over another
7	One element is clearly more important than the others	One strong element is supported and dominant in practice
9	One element is absolutely more important than the other elements	Evidence supporting one element over another has the highest possible level of affirmation reinforcing
2,4,6,8	Value between two values of adjacent considerations	This value is given when there are two compromises between two choices
Opposite	If activity I receives a score compared to activity j, then j has the opposite value compared to I.	

4. Use of Expert Choice Software

After comparing the predetermined goals with the reference values in Table 7, inconsistencies were checked to obtain the weighting values for the prioritized roads.

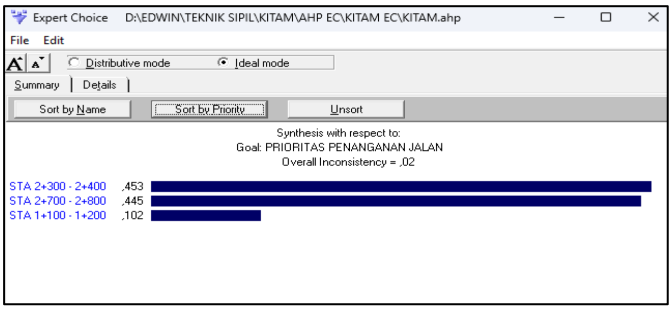

Fig. 7. Results of Data Processing Using Expert Choice Software

STA 2+300 – 2+400 was selected as the top priority due to its highest score in road condition, daily traffic volume, and land use, with a final weight of 0.453 based on the Expert Choice analysis Flexible Pavement Thickness Design

3.5 Flexible Pavement Thickness Design

Determining Traffic Growth Factors Calculating traffic growth over the plan period using cumulative growth factors using Equation:

$$R = \frac{(1 + 0{,}01\ i)^{UR} - 1}{0{,}01\ i} \tag{1}$$

Traffic on Planned Lanes

Planning Parameter Data, as follows:

- Directional Distribution Factor (DD) : 0.5 %
- Lane Distribution Factor (DL) : 80 %
- Traffic Growth Rate Factor :4.8
- Design Life (years) :10

Table 8. Traffic Growth Rate Factors

	Jawa	Sumatera	Kalimantan	Average Indonesia
Arteries and Urban	4.80	4.83	5.14	4.75
Rural collector	3.50	3.50	3.50	3.50
Village roads	1.00	1.00	1.00	1.00

Table 9. Lane Distribution Factors

Number of Columns per direction	Commercial vehicles on the design lane (% of the commercial vehicle population)
1	100
2	80
3	60
4	50

Table 10. Flexible Pavement Treatment

A. Handling of Bending Pavement with Bending Pavement		
Traffic Load Criteria (million ESA4)	ESA 4 < 10	ESA 4 ≥ 10
Lifetime of the bending pavement plan	Whole treatment: 10 years	-Reconstruction – 20 years - Structural plus-layer – 10 years - Non-structural add-on – 10 years - Temporary handling – as needed
B. Handling of Flexible Pavement with Rigid Hardening		
Traffic Load Criteria (JSKN)	JSKN < 15 Million	JSKN ≥ 15 Million
Life of the Bending Paving Plan	Whole handling: 15 years	- Reconstruction and added layers with rigid pavement – 40 years

1. Load Equivalent Factor (Vehicle Damage Factor)

In road pavement design, traffic loads are converted to standard loads (ESA) using the Load Equivalent Factor.

Table 11. VDF4 and VDF5 values in West Java

Condition	Vehicle Class	Gol 5B	Gol 6A	Gol 6B	Gol 7A1	Gol 7A2	Gol 7A3	Gol 7B1	Gol 7B2	Gol 7B3	Gol 7C1	Gol 7C2A	Gol 7C2B	Gol 7C3	Gol 7C4
VDF 4	Faktual	1.2	0.5	3.8	7.8	16.3	-	-	12.9	-	6.7	12.8	14.8	20.8	-
	Normal	1.2	0.5	0.8	2.8	4.6	-	-	5.9	-	4.5	6.6	6.4	7.0	-
VDF 5	Faktual	1.3	0.4	5.5	12.3	33.6	-	-	18.9	-	9.6	21.5	26.8	44.2	-
	Normal	1.3	0.4	0.7	3.2	6.3	-	-	6.9	-	5.7	8.6	8.9	9.6	-

2. Average Daily Traffic Data

After conducting a three-day Average Daily Transportation (ADT) survey, namely two weekdays and one weekend day, from 6:00 a.m. to 6:00 p.m. on the Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo street STA 0+000 – 3+000 road section.

Table 12. Average Daily Traffic Data

No	Vehicle type	Category	LHR 2025	VDF 4 Actual	VDF 4 Normal	VDF 5 Actual	VDF 5 Normal
1	Motorcycles	1	24514	-	-	-	-
2	Sedans, Jeep	2	13999	-	-	-	-
3	Passenger Transport	3	50	-	-	-	-
4	Pickups	4	67	-	-	-	-
5	Small Buses	5A	14	-	-	-	-
6	Large Buses	5B	3	1.2	1.2	1.3	1.3
7	Light 2-Axle Trucks	6A	4	0.5	0.5	0.4	0.4
8	2-Axle Truck - Medium	6B	2	3.8	0.8	5.5	0.7
9	3-Axle Truck - Heavy	7A1	2	7.8	2.8	12.3	3.2
10	3-Axle Truck - Heavy	7A2	3	16.2	4.6	33.6	6.3

3. Cumulative Standard Axle Load

Based on the main aspects described above, the Cumulative Equivalent Standard Axle Load (CESAL) value can be calculated using the following formula

Table 13. Cumulative Standard Axle Load

Day 1 year	DD	DL	R	Esa4 Actual	Esa4 Normal	Esa5 Actual	Esa5 Normal
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
365	0.5	0.8	12.461	7277.28	7277.281	7883.721	7883.721
365	0.5	0.8	12.461	3638.64	3638.640	2910.912	2910.912
365	0.5	0.8	12.461	11522.36	2425.760	16677.102	2122.540
365	0.5	0.8	12.461	23651.16	8490.161	37296.063	9703.041
365	0.5	0.8	12.461	98243.28	27896.243	203763.859	38205.724
			Total ESA	**137055.45**	**42450.80**	**260647.94**	**52942.22**
			CESA	**179506.26**		**313590.15**	

	CESA 4	CESA 5

3. Determination and Selection of Pavement Type

The selection of pavement type is influenced by traffic load, design life, and road foundation conditions. In CESA 5, the determination of pavement type is adjusted to be able to withstand loads during its service life, taking into account structural efficiency and field conditions.

Table 14. Selection of Pavement Type

Pavement Structure	Design Chart	ESA5 (million) in 20 years				
		0 - 1	1 – 4	4 – 10	>10 – 30	>30
AC modification	3, 3A, 3B	-	-	-		2
AC With CTB					2	-
AC modification With CTB						2
AC with an aggregate foundation layer	3, 3A, 3B	-	1.2	1.2	2	-
HRS thin over the aggregate foundation layer	4	2	2	-	-	-
Burda or Burtu with layers of aggregate foundation	5	3	3	-	-	-
AC/HRS with foundation layers Soil Cement	6	2	2	-	-	-
AC/HRS with aggregate foundation layers and subsoil repair (with cement stabilization)	7	2	2			
Rigid pavement with heavy traffic	8	-	-	-	2	2
Rigid pavement with low traffic	8A	-	-	1.2	-	-
Pavement without a cover (Japat and Gravel Road)	9	1	-	-	-	-

Note: Difficulty Level:

1. **Small – medium contractors;**
2. **Large contractors with adequate resources; and**
3. **Requires specialized expertise and experts – Burtu/Burda specialist contractors**

Since this study focuses on flexible pavement, the type of pavement selected is Hot Rolled Sheet (HRS) on top of an aggregate foundation layer.

4. Determining the Foundation Design

In determining the foundation design, CBR data is required. The CBR value of the base soil is 3.9% [19].

Table. 15. Design Chart 2 - Minimum Road Foundation Design

CBR Groundland (%)	Basic Ground Strength Class	Structural Description / Foundation	Bending Pavement		Rigid pavement
			Traffic Load & Road Plan Age (year/ESA)		
			<10	>10	
			Minimum Thickness of Ground Improvement (mm)		
5	SG2.5	Soil improvement with selected backfill material (CBR ≥ 10%)			
4	SG4		200 mm	200	200
3	SG4		300 mm	400	400
2.5	SG2.5			600	600
- Base Soil Strength < 2.5% or soft soil			For soft soil thickness > 1 m must be handled with geotechnical handling, while for ≤1 m thickness it is replaced with a minimum thickness that is the same as the provisions and applies to SG2.5 soil in this design chart		
- Expansive Soil			Handling is in accordance with geotechnical studies on the amount of expansion potential with a cover thickness of not less than 600 mm in the form of materials with an expansion potential not greater than 1.5%. On top of the cover layer, an SG2.5 repair layer must be added		

CBR pavement of 3.9% and CESA5 260647.94 resulted in a foundation design solution that required soil improvement with a minimum thickness of 300 mm.

5. Selection of Pavement Type

Determining the thickness of the pavement design with a CESA5 value of 260647.94 ESAL, the thickness of the pavement can be seen in Table 16.

Table 16. Design Chart 4 - Flexible Pavement Design with HRS

Cumulative 20-year axis load on the plan column (10^6 CESA5)	FF1 < 0.5	0.5 ≤ FF2 ≤ 4.0
Surface type	HRS or Makadam Penetration	HRS[2]
Pavement structure	Layer thickness (mm)	
HRS-WC	50	30
HRS-Base	-	35
LFA Class A	150	250
LFA Class B or natural gravel or laminated stabilized with CBR > 10%[3]	150	150

Based on Table 16. above, the thickness of the pavement structure for the road section with a value of 0.5 MILLION CESAL 5 is FF1. The pavement structure is as follows:

- HRS-WC : 50 mm
- LFA Class A (Class A Aggregate Foundation Layer) : 150 mm
- LFA Class B (Class A Aggregate Foundation Layer) : 150 mm
- Foundation Layer/Subgrade Improvement : 300 mm

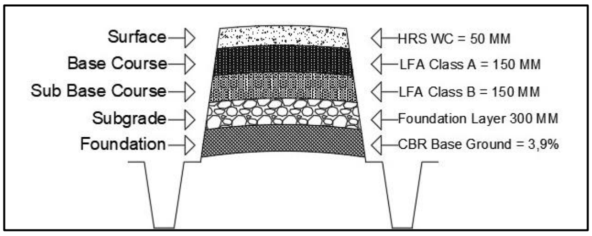

Fig. 8. Flexible Pavement Design

3.6 Cost Budget Plan

Table 17. Budget Plan for the Reconstruction of Road with Flexible Pavements

Final Recap
Cost Budget Plan
Flexible Pavement Planning HRS-WC Dr. Cipto Mangunkusumo Street Cirebon City
STA 2+300 s.d 2+400

No	Description	Total Price (IDR)
I	PREPARATORY WORK	139.834.525,22
II	EARTHWORKS AND GEOSYNTHETICS	274.414.850,92
III	GRANULAR PAVEMENT & CEMENT CONCRETE PAVEMENT WORKS	128.722.200,56
IV	ASPHALT PAVEMENT WORK	24.968.475,43
V	ROAD EQUIPMENT WORK	20.975.747,81
	Total Amount	**588.915.799,93**
	VAT 15%	**88.337.369,9**
	Total Cost	**677.253.169,92**

Rounded	**677.500.000,00**
Amount in Words :	
"Six Hundred Seventy-Seven Million Five Hundred Thousand Rupiah"	

Based on the calculations used, referring to the thickness of the flexible pavement layer and the 2024 Cirebon Regency Unit Price Analysis for the reconstruction work at STA 2+300 – 2+400 on Dr. Cipto Mangunkusumo Street in Cirebon City, a Cost Budget Plan with a nominal value of IDR 677.500.000,00 was obtained.

4. Conclusion

This study concluded that on the section of Dr. Wahidin Sudirohusodo – Dr. Cipto Mangunkusumo Street in the city of Cirebon, the Pavement Condition Index (PCI) and Surface Distress Index (SDI) methods, as well as the Analytical Hierarchy Process (AHP), were used to determine road repair priorities. The results showed that 13.33% of the road was in Satisfactory condition, 10% Fair, 30% Poor, 13.33% Very Poor, 20% Serious, and 13.33% Failed. Based on the Surface Distress Index (SDI), 60% of the road was in moderate condition, 30% in good condition, and 10% in severe condition. The Analytical Hierarchy Process (AHP) method using the Expert Choice application recommends handling the STA 2+300 to 2+400 segment, which requires road reconstruction. The paving plan uses 50 mm HRS WC, 150 mm LFA class A and B, and a 300 mm foundation layer, with a total budget of IDR 677.500.000,00. Future research should utilize emerging technologies such as automated pavement assessment and AI-based analysis to improve accuracy and efficiency in road condition evaluation and maintenance planning.

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