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Cost and Thickness of Rigid Pavement using MDP 2017 and AASHTO 1993 Methods

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Abstract

The planning and evaluation process of toll road pavement thickness plays an important role in sustainable toll road design. The design of the road structure needs to be adjusted to the construction needs and the pavement serves to protect the road layer from excessive pressures due to vehicle loads. The recalculation of rigid pavement thickness on the Cinere - Jagorawi toll road section III using the AASHTO and MDP methods aims to determine which method is more appropriate in determining the thickness of toll road pavement. In addition, this research also calculates the cost of rigid pavement work based on Permen PUPR No. 8 of 2023 with slip-form concrete paver and conventional methods. The results showed that based on the analysis of project data, the thickness of rigid pavement using the AASHTO method was 16 cm, while the MDP method produced a thickness of 28 cm. For rigid pavement thickness, the analysis results using the MDP method have the same thickness value as the pavement thickness in the field which is 28 cm, while the AASHTO method produces a pavement thickness 12 cm thinner than measured in the field. The cost-effective result of rigid pavement work using the manual method and concrete paver tools reached Rp11,239,271,456.32. This price applies with a working thickness of 29cm, a lane width of 3.7m, and a working length of 5,700m. The maximum working length is 3,291 m using the manual method, and the minimum working length is 2,409 m using the concrete paver method.

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Introduction

Increased population movement leads to increased traffic volume which can cause traffic congestion [1]. It also drives economic growth, making the construction of toll road facilities an efficient and fast transport solution. The optimal quality of toll roads pavement, which has long-term durability, is a crucial factor in ensuring the safety and comfort of toll road users. Consequently, the process of planning and evaluating the pavement thickness has become a very important element in the design of sustainable toll roads.

The recommended road structure design can be different depending on life cycle costs and traffic loads. [2]. Pavements have an important role in protecting the underlying road layers from excessive stresses caused by vehicle loads. [3]. In addition, pavements also have a crucial function in providing an optimal level of safety and comfort for drivers. Therefore, the pavement must have a smooth surface and a suitable texture. [4]. Typically, rigid pavements are more suitable for highways that serve high-speed traffic and have high traffic volumes. [5].

Rigid pavement is a type of pavement that uses cement as a binder, resulting in a relatively high level of rigidity described as a concrete layer that functions as a base course and surface course in highway construction. [6]. To ensure durability and service life in accordance with the plan, rigid pavements are usually equipped with an underlying foundation layer consisting of a subgrade, support layer, sub-foundation layer, top foundation layer, and lean concrete layer. [7].

Ananda Anggie has analyzed the thickness of rigid pavement using the AASHTO 1993 and MDP 2017 methods by designing using a similar foundation layer, namely lean concrete (Lean Mix Concrete) 100 mm thick and a drainage foundation layer with class A aggregate of 150 mm, although there are differences in certain parameters, the difference in the thickness results of the two methods is relatively small and has no significant impact. [8].

In the context of the life plan of the rigid pavement thickness studied by Annisa and Latif shows differences in the value of the thickness of the pavement, in the 20-year plan age the MDP 2017 method is 5.56% greater than the AASHTO 1993 method, on the other hand in the 40-year plan age the MDP 2017 method is 8.96% smaller than the AASHTO 1993 method besides that the thickness of the rigid pavement implemented in the field meets the redesign for the 20-year plan age according to both methods [9]. [9].

These studies show different pavement thickness values between the two methods, requiring a thorough analysis based on predicted traffic loads and life cycle costs to ensure the right type of pavement structure. Therefore, this research was made and aims to recalculate the thickness of rigid pavement on the Toll Road using the AASHTO 1993 and MDP 2017 methods.

By comparing the calculation results of these two methods, this research is expected to determine a more suitable and accurate method for determining the thickness of toll road pavement. In addition, this research calculates the cost of rigid pavement work which uses two methods, namely slipform concrete paver and conventional. The results of this research are expected to be useful for toll road planners and engineers in making more efficient, economical, and sustainable design decisions in developing toll roads in the future.

Theory

Pavement thickness planning has several methods including the Bina Marga and AASHTO (American Association of State Highway and Transportation Officials) methods. [10]. The 1993 AASHTO method is a guide from the United States that is often used by many countries as a reference in pavement calculations. [11]. The 2017 Pavement Design Manual Method is a guide published by Bina Marga as an update of the previous method with parameters including plan life, traffic data to determine VDF, as well as ESA and CESA calculations. [12].

A. Rigid Pavement Thickness using AASHTO 1993 Method

In calculating the thickness of rigid pavement using the AASHTO method, there are 12 parameters that must be met, which are [13]:

1. Traffic is the value of ESAL (Equivalent Single Axle Load) that occurs on a road section during the plan life is influenced by: vehicle type, average daily traffic volume or LHR, annual traffic growth factor, vehicle damage factor (VDF) which is calculated using the formula (1), plan age, direction distribution factor (DD), lane distribution factor (DL) can be seen in Table 1.

$$VDF = \left(\frac{Vehicle\ axle\ load}{Standard\ axle\ load}\right)^4 \quad (1)$$

TABLE I. DL VALUE BASED ON AASHTO 1993

Number of lanes each direction	D_L (%)
1	100
2	80 - 100
3	60 - 80
4	50 - 75

So that the ESAL value can be calculated using equation (2).

$$W_{18} = \sum_{N1}^{Nn} LHR_j \times DF_j \times D_A \times D_L \times 365 \quad (2)$$

2. Reability (R) based on the 1993 AASHTO method can be seen in Table 2.

3. Standard Normal Deviation (ZR) of normal depends on the reliability level chosen.

4. Standard Deviation (So) for rigid pavements ranges from 0.3 to 0.4

TABLE II. REABILITY (R) BASED ON THE AASHTO 1993 METHOD

Road Classification	**R (%)**	
	Urban	**Rural**
Toll Road	85 - 99.9	80 - 99.9
Arterial Road	80 - 99	75 - 95
Collector Road	80 - 95	75 - 95
Local Road	50 - 80	50 - 80

5. Terminal serviceability or (Pt) is affected by the road function and the frequency of traffic load repetitions. Terminal serviceability for main lanes has a Pt of 2.5, while terminal serviceability for low-traffic lanes has a Pt of 2.

6. Initial serviceability or Po value for the surface index is 4.5.

7. Serviceability Loss or ΔPSi can use formula (3)

$$\Delta PSi = P_o - P_t \quad (3)$$

8. Subgrade reaction modulus or k is the result of a combination of formulas and graphs that determine the subgrade reaction modulus based on subgrade CBR values using formulas (4) and (5).

$$M_R = 1500 \times CBR \quad (4)$$

$$k = \frac{M_R}{19.4} \quad (5)$$

9. The modulus of elasticity of concrete can be calculated by the formula (6).

$$E_c = 57000 \times \sqrt{f'c} \quad (6)$$

10. Flexural strength is determined based on the compressive strength of the concrete. The following Table 3 shows the relationship between concrete compressive strength and flexural strength

TABLE III. FLEXURAL STRENGTH BASED ON AASHTO 1993

Compressive Strength (K) (kg/cm)²	***Flexural strength* (S$_c$ ') (kg/cm)²**
120 - 175	25
155 - 230	30
225 - 335	40
280 - 400	45

11. Drainage coefficient can be symbolized by Cd there are 2 determining variables, namely the quality of drainage which has a quality standard from very poor to very good, adjusted to the speed of water out of the pavement foundation. The second variable is determined based on the percentage of the pavement structure exposed to water in one year until it approaches the water saturation level. The percentage of the approach pavement structure exposed to water in one year can be calculated using the following formula (7).

$$P_{heff} = \frac{T_{hour}}{24} \times \frac{T_{day}}{365} \times W_L \times 100 \quad (7)$$

12. Load Transfer Coefficient (J) can be calculated by referring to the following table which follows the guidelines of AASHTO 1993.

By considering the 12 parameters described previously, the thickness of rigid pavement can be calculated through an iteration process by replacing the parameters in the following formula (8).

$$\log W_{18} = Z_R \times S_o + 7.35 \times \log(D+1) - 0.06 + \frac{\log[\frac{\Delta PSi}{4.5-1.5}]}{1+\frac{1.624\times10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 \times P_t) \times \log \frac{S'_c \times C_d \times [D^{0.75} - 1.132]}{215.63 \times J \times [D^{0.75} - \frac{18.42}{(E_c:k)^{0.25}}]} \quad (8)$$

TABLE IV. LOAD TRANSFER COEFFICIENT VALUES BASED ON AASHTO 1993

Shoulder	Asphalt		*Tied* PCC	
Load Distribution	Yes	No.	Yes	No.
Pavement Type				
Plain Concrete Joint and Reinforce	03.02	38.8 - 4.4	2.5 - 3.1	3.6 - 4.2
CRCP	2.9 - 3.2	N/A	2.3 - 2.9	N/A

B. Thickness of Rigid Pavement with MDP Method 2017

While the thickness of rigid pavement with MDP 2017 method several parameters must be met [14]:

1. The planned life of a pavement depends on the type of pavement and its elements
2. The amount of ESAL which is influenced by the value of traffic volume, traffic data, vehicle type, traffic growth multiplier, and traffic on the plan lane measured in cumulative ESA (*Equivalent Standard Axle Load)* with consideration of directional distribution (DD) and commercial vehicle lane distribution factor (DL) can be seen in Table 5, *Vehicle Damage Factor* (VDF), vehicle group axis, cumulative axis load which can be calculated using equation (9).

TABLE V. DL VALUE BASED ON MDP 2017

Number of Lanes in Each Direction	D_L (%)
1	100
2	80
3	60
4	50

$$ESA_{TH-1} = (\sum LHR_{JK} \times beban\ kelompok\ sumbu_{jk}) \times 365 \times D_D \times D_L \times R \quad (9)$$

3. The thickness of the rigid pavement layer structure with rigid pavement design requirements with joints and *dowels* and *tied shoulders*, with or without crack distribution reinforcement is as follows Table 6.

TABLE VI. RIGID PAVEMENT LAYER STRUCTURE WITH HEAVY TRAFFIC

Pavement Structure	R1	R2	R3	R4	R5
Axis group of heavy (*overloaded*) vehicles (10E6)	<4.3	<8.6	<25.8	<43	<86
Dowels and concrete shoulders	Yes				

pavement structure (mm)					
Thickness of concrete slab	265	275	285	295	305
LMC foundation layer	100				
Drainage layer	150				

C. Dowel and Tie Bar

The most basic fixings in rigid pavement construction are *dowels* and *tie bars*. The function of these *dowels* and *tie bars* is to transfer vehicle loads from one slab to the surrounding slabs.

D. Estimated Cost of Work Unit Price

Based on PUPR Regulation No. 8 of 2023, the unit price of work can be calculated after accumulating the calculation results of the Analysis of the Unit Price of Work (AHSP) and indirect costs which are then summed up. [15].

$$Unit\ Price\ of\ Work\ = AHSP + Total\ Indirect\ Cost + Tax \quad (10)$$

Methodology

The object of this research study is the XX Toll Road project. The data required in this study are secondary data in the form of activity locations and LHR data in 2023 obtained from relevant agencies. The steps in the research will be presented through the flow chart attached in Figure 1. In this study, data analysis was carried out by collecting information, which aims to reach conclusions that can answer the problems and objectives that have been set. The analysis activities carried out begin with: analyzing the load that will be received by rigid pavement, the load that will be received is obtained based on the configuration and type of vehicle axis both by the AASHTO 1993 and MDP 2017 methods; analyzing the required rigid pavement thickness based on the AASHTO 1993 and MDP 2017 methods (finding the vehicle VDF value, finding the ESAL value, finding traffic growth, finding the cumulative ESAL value of the plant life, and calculating the thickness of rigid pavement); analyzing the comparison of the existing *pavement* thickness with the analysis results of the AASHTO 19993 and MDP 2017 methods; analyzing the productivity of casting manually and with *paver* tools. The analysis results will be formulated as one of the methods to determine the most optimal pavement thickness. [16].

The calculation of pavement thickness using the AASHTO 1993 and MDP 2017 methods is carried out with the following *flow chart* steps.

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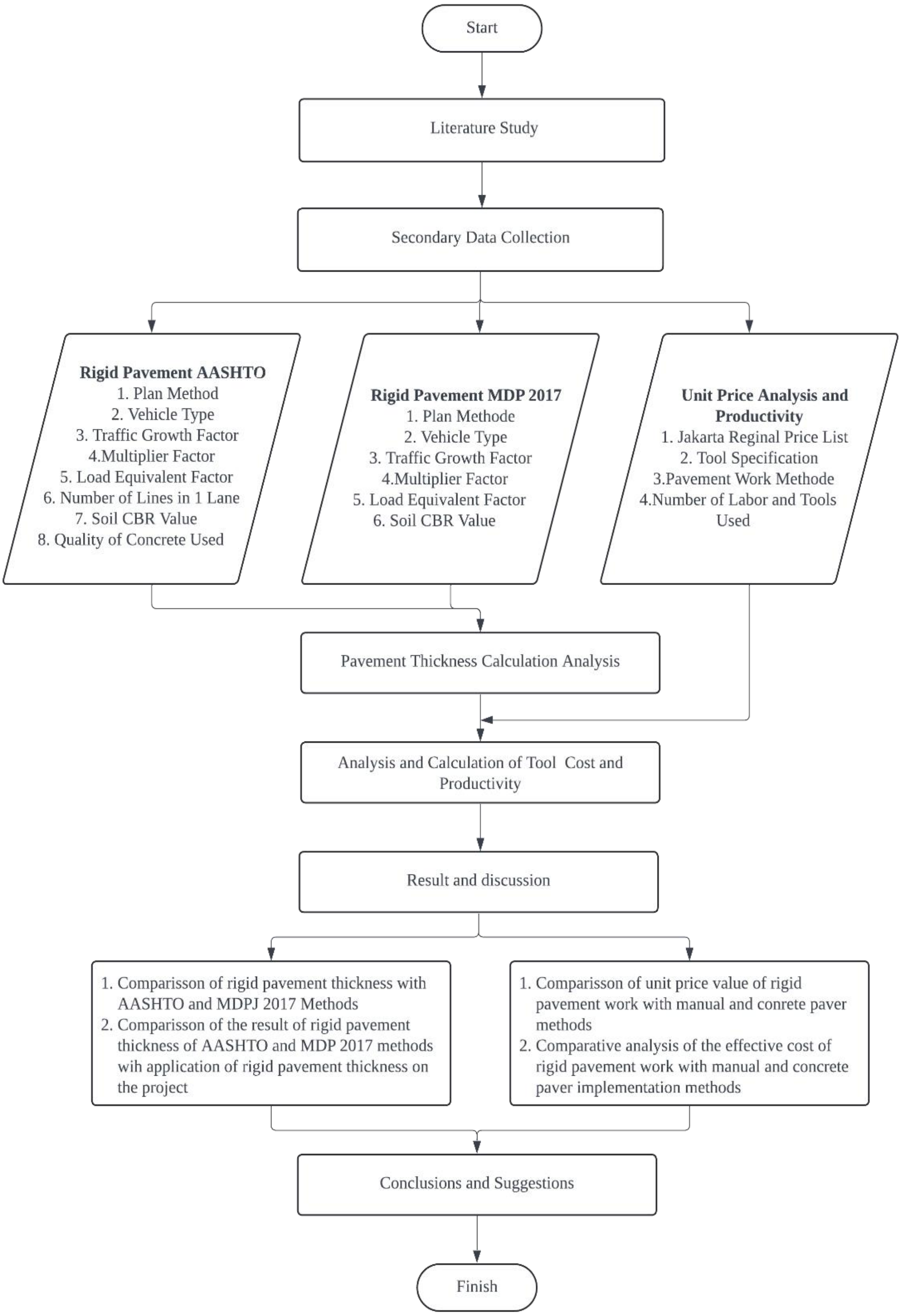

Figure 1: Research Flowchart

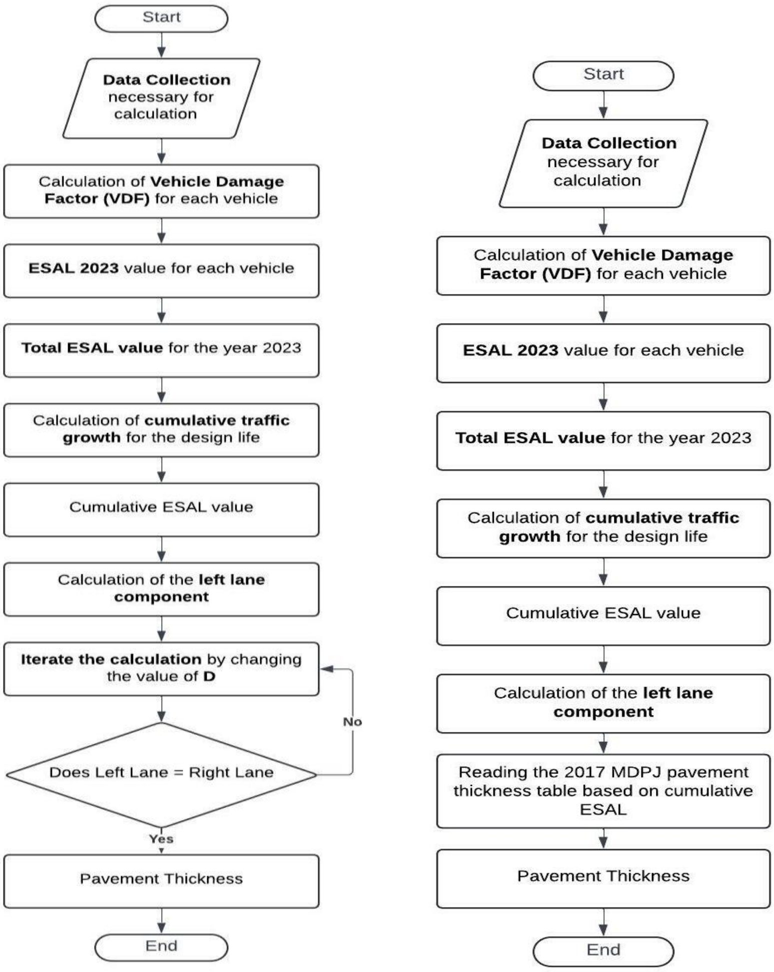

Figure 2: Flowchart of calculation of AASHTO and MDP 2017 methods

Results and Discussion

The following is the result of data collection: Daily Traffic Data (LHR) in 2023 is the amount of daily traffic expected to enter the XX Toll Road (Table 7).

TABLE VII. THE XX TOLL ROAD LHR PLAN

No.	Vehicle Type	Total	Unit	Percentage
1	Sedan, Jeep, Station Wagon	32354	vehicle/day	83.62%
2	Oplet, Sub-urban, Combi, Minibus	82	vehicle/day	0.21%
3	Pick Up, Micro Truck, Box	5103	vehicle/day	13.19%
4	Medium Bus	326	vehicle/day	0.84%
5	Large Bus	304	vehicle/day	0.79%
6	Light 2 Axis Truck	321	vehicle/day	0.83%
7	Truck 2 Axis Weight	204	vehicle/day	0.53%
TOTAL		38694	vehicle/day	100%

From Table 8, vehicle classes can be classified based on the 1993 AASHTO method and MDP 2017 as follows Table 9.

TABLE VIII. VEHICLE AXIS TYPE AASHTO METHOD

No.	Vehicle Type	Max Weight.	Axis and Wheel Type
		Tons	
1	Sedan, Jeep, Pick Up, and Public Transport	2	Single Axis Single Wheel
2	Medium Bus	6	Single Axis Double Wheel
3	Large Bus	8	Single Axis Double Wheel
4	Truck As Ringam	12	Single Axis Double Wheel
5	Heavy Truck 2 Axles	13	Single Axis Double Wheel

TABLE IX. VEHICLE AXIS TYPE MDP METHOD 2017

No.	Vehicle Type	Goals	Number of Axis Groups
1	Sedan, Jeep, Station Wagon	2, 3, 4	2
2	Oplet, Sub-urban, Combi, Minibus	2, 3, 4	2
3	Pick Up, Micro Truck, Box	2, 3, 4	2
4	Medium Bus	5b	2
5	Large Bus	5b	2
6	Lightweight 2 Axle Truck	6a	2
7	Heavy Truck 2 Axles	6b	2

Next, calculate the VDF value of the vehicle which can be determined by equation (1). The following are the results of the calculation of the VDF value of the vehicle with the 1993 AASHTO method.

TABLE X. VDF VALUE OF AASHTO METHOD VEHICLE

No.	Vehicle Type	VDF
1	Sedan, Jeep, Pick Up, and Public Transport	0.0005
2	Medium Bus	0,4257
3	Large Bus	1,1056
4	Lightweight 2 Axle *Truck*	4,7396
5	Heavy *Truck* 2 Axles	10.6480

The magnitude of the ESAL value in 2023 with the lanes that each lane has is 3 lanes where the DL value is obtained between 60%-80% by the 1993 AASHTO method according to Table 10.

Then the amount of lane distribution (DL) used is:

- The amount of DL used = 60%
- Number of days in 1 year = 365 days
- (DA) used = 0.5

The amount of ESAL for each vehicle type can be calculated using equation (2). From this equation, the ESAL value results can be seen in Table 11.

TABLE XI. ESAL VALUE OF 2023 AASHTO METHOD VEHICLE

No.	Vehicle Type	ESAL 2023
1	Sedan, Jeep, Station Wagon	1,598.13
2	Oplet, Sub-urban, Combi, Minibus	04.05
3	Pick Up, Micro Truck, Box	252.06.00
4	Medium Bus	2,189.98
5	Large Bus	5,300.68
6	Lightweight 2 Axle Truck	23,989.84
7	Heavy Truck 2 Axles	23,785.79
TOTAL		57,120.54

Meanwhile, according to Table 5, the DL value with the MDP 2017 method is obtained at 60%. Then the amount of lane distribution (DL) used is:

- The amount of DL used = 60%
- Number of days in 1 year = 365 days

The calculation of the ESAL value of the MDP 2017 method does not involve vehicles weighing ≤ 5 tonnes because they are considered not to burden the pavement, so class 2, 3, and 4 vehicles are not included in the calculation. The amount of ESAL for each vehicle type can be calculated using equation (9). From this equation, the ESAL value results can be seen in Table 12.

TABLE XII. ESAL VALUE OF 2023 VEHICLES MDP 2017 METHOD

No.	Vehicle Type	Goals	Number of Vehicles	Number of Axis Groups	Total Axis Group 2023	ESA 2023
			Kend/day			
1	Sedan, Jeep, Station Wagon	2, 3, 4	32354	2	-	-
2	Oplet, Sub-urban, Combi, Minibus	2, 3, 4	82	2	-	-
3	*Pick Up, Micro Truck, Box*	2, 3, 4	5103	2	-	-
4	Medium Bus	5b	326	2	652	71394
5	Large Bus	5b	304	2	608	66576
6	Lightweight 2 Axle *Truck*	6a	321	2	642	70299
7	Heavy *Truck* 2 Axles	6b	204	2	408	44676
TOTAL					2,31	252,945

Calculation of traffic growth percentage (i%) = 4.8%, with a plan life = 20 years, calculation of traffic growth (R) = 32.376

The cumulative ESAL value using the AASTHO method can be calculated using equation (8).

(W18) = Total ESAL in 2023 × R
= 57,120.54× 32,376
= 1,849,310.83

While the cumulative ESAL value with the MDP 2017 method is obtained by equation (9).

(W18) = Total ESAL in 2023 × R
= 252,945 × 32.376
= 8,189,241.89

The results of iteration calculation obtained D = 6.22 inch = 16 cm. Based on the calculation results, the pavement thickness of 16 cm produces the same value between the right and left segments. So the pavement thickness used based on the calculation results of the AASHTO method is 16 cm. The pavement thickness of the MDP 2017 method is calculated with a 20-year plan life, starting from 2023 to 2043. The amount of pavement thickness of the MDP 2017 method is obtained based on the amount of cumulative ESAL by reading Table () rigid pavement thickness of 28 cm, lean concrete foundation layer thickness of 10 cm, can be thick drainage layer of 15 cm. The results of the pavement thickness obtained are 6.22 inches (AASTHO) and 11 inches (MDP 2017), then the size of the dowel and tie bar used can be seen in Table 13. [17].

TABLE XIII. DOWEL BAR AND TIE BAR SIZES

	AASTHO	**MDP 2017**
Dowel Bar	**Size**	**Size**
Stem Diameter	0,75	1,25
Trunk Length	18	18
Trunk Spacing	12	12
Tie Bar		
0.5 Inch		
Trunk Length	25	25
Install Distance for 10 ft	48	35
Tidal Distance for 11 ft	48	32
Tidal Distance for 12 ft	48	29
0.625 Inch		
Trunk Length	30	20
Install Distance for 10 ft	48	48
Tidal Distance for 11 ft	48	48
Tidal Distance for 12 ft	48	48

Cost analysis is carried out to compare the cost of rigid pavement work with conventional methods and slipform concrete paver methods with cost assumptions that can be seen in the following table.

Type of Work : Rigid Pavement
Unit Price : IDR 3,296,546
Methods : Conventional

TABLE XIV. AHSP OF RIGID WORK CONVENTIONAL METHOD

No.	Description	Unit	Estimated Quantity	Unit Price (Rp)	Total Price (Rp)
A	**Labour**				
	Workers	OH	0,96	193.459	185.721
	Foreman	OH	0,08	234.012	18.721
	Truck Mixer Operator	OH	0,08	234.012	18.721
				Total Labour Price	**223.163**
B	**Material**				
	Readymix Concrete	M3	1,05	1.659.000	1.741.950
	Dowel and Tie Bar	Kg	1,15	20.000	23.000
	Cast Plastic	M2	1,15	5.000	5.750
	Joint Filler	M'	1,15	10.000	11.500
	Non Woven Geotextile	M2	1,15	4.775	5.491
	Sealant	M'	1,15	34.100	39.215
	Formwork	M2	2,06	400.000	824.000
	Formwork Oil	Litres	0,238	25.000	5.950
				Total Price of Materials	**2.656.856**
C	**Tools**				
	Truck Mixer	hours	0,118	704.934	83.182
	Electric Vibrator	hours	0,333	20.000	6.660
				Total Price of Tools	**89.842**
D	**Total Price Of Labour, Materials, And Tools (A+B+C)**				**2.969.861**
E	**Overhead & Profit (11% X D)**				**326.685**
F	**Unit Price Of Work (D + E)**				**3.296.546**

Based on the unit price analysis above, the results of the unit price value of concrete work / m3 in Table 14 are Rp. 3,296,546

Type of Work: Rigid Pavement
Unit Price: IDR 4,503,290
Methods: *Slipform Concrete Paver*

TABLE XV. AHSP OF RIGID WORK CONVENTIONAL METHOD

No.	Description	Unit	Estimated Quantity	Unit Price (Rp)	Total Price (Rp)
A	**Labour**				
	Workers	OH	0,8	193.459	154.767
	Foreman	OH	0,08	234.012	18.721
	Slipform Concrete Paver Operator	OH	0,08	234.012	18.721
	Operator Helper	OH	0,08	203.519	16.282
	Excavator Operator	OH	0,08	234.012	18.721
	Truck Mixer Operator	OH	0,08	234.012	18.721
	Total Labour Price				**245.933**
B	**Material**				
	Readymix Concrete	M3	1,15	1.659.000	1.907.850
	Iron Dowel and Tie Bar	Kg	1,15	20.000	23.000
	Cast Plastic	M2	1,15	5.000	5.750
	Bendrat wire	Kg	1,15	16.650	19.148
	Joint Filler	M'	1,15	10.000	11.500
	Non Woven Geotextile	M2	1,15	4.775	5.491
	Sealant	M'	1,15	34.100	39.215
	Rigid Tent	Ls	1,15	1.500.000	1.725.000
	Total Price of Materials				**3.736.954**
C	**Tools**				
	Slipform Concrete Paver	hours	0,007	1298123	9.087
	Dump Truck	hours	0,11	573.125	63.044
	Excavator	hours	0,004	500.194	2.001
	Total Price of Tools				**65.045**
D	**Total Price Of Labour, Materials, And Tools (A+B+C)**				**4.047.931**
E	**Overhead & Profit (11% X D)**				**445.272**
F	**Unit Price Of Work (D + E)**				**4.493.203**

Based on the unit price analysis above, the results of the unit price value of concrete work /^{3} in the Table 15 are Rp.4,503,290

The effective length of tool use can be determined using a two-variable linear equation, i.e.:
Length of road to be calculated = 5700 m
Visualisation = M = manual
= A = tool
Total length = manual length + tool length
5700 = M+A
M = 5700 - A ... (1)

After that, an equation was formulated to determine the effective length of the work. The effective length is found when the cost of using the manual method and using the paver reaches the same value. The following equation was applied:

Manual method cost = cost with paver congcrete
$\text{cost}1\text{m}^3 \times \text{volume} = \text{cost } 1\text{m}^3 \times \text{volume}$
Manual method cost x P manual = cost with paver congcrete x P paver congcrete
$\text{Rp } 3{,}296{,}545.73 \times (5{,}700 - \text{A}) = \text{Rp } 4{,}503{,}289.64 \times \text{A}$
$\text{A} = 2{,}409.07 \text{ m}$

From the above calculations obtained:
Effective length using the tool method = 2,409 m
Effective length using manual method = 5,700 - 2,409 = 3,291 m
Large effective cost:
The cost-effective calculation uses the width and thickness that have been applied to the project, so :

Work width	= 3.7 m
Thickness of work	= 0.28 m
Cost using tool method	= P×L×T×Price per 1m^3
	= 2,409×3.7×0.28× Rp4,503,289.64
	= IDR11,239,271,456.32
Cost using manual method	= P×L×T×Price per 1 m^3
	= 3,291×3.7×0.28× Rp3,296,545.73
	= IDR11,239,271,456.32

Conclusions

From the research, it can be concluded that the type of rigid pavement used is jointed rigid pavement without reinforcement, with a thickness based on the analysis results using the AASHTO method of 16 cm and the MDP 2017 method of 28 cm. There is a significant difference between the thickness produced by the AASHTO method and the thickness used in the field, which is 12 cm thinner. As for the MDP method, the pavement thickness obtained is the same as the thickness used in the field, which is 28 cm. The cost of rigid *pavement* work using the *slip-form concrete paver* method is around Rp. 4,503,290/m^3, while for the conventional method is around Rp. 3,296,546/m^3. The effective cost of rigid pavement work, with a width of 3.7 m, and length of 5,700 m, is at a value of Rp11,239,271,456.32. This price is applicable with a working thickness of 28 cm, whereas the *slipform concrete paver* method allows working at a minimum length of 2,409 m to a maximum of 3,291 m.

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