Rigid Pavement Evaluation and Remaining LifePrediction based on the AASHTO-93 method.

Bambang Sugeng SUBAGIO[a], Faisal GERARDO[b], Made PAUS[c]

[a] *Civil Engineering Department, ITB, Bandung, Indonesia*
E-mail: bsugengs@si.itb.ac.id
[b]*Assistant of Highway Engineering Laboratory, ITB, Bandung, Indonesia*
E-mail: office@trans.si.itb.ac.id
[c]*Graduate School of Highway Engineering, ITB, Bandung, Indonesia*
E-mail: office@trans.si.itb.ac.id

Abstract: The purpose of this research is to evaluate the structural condition of existing rigid pavement, to determinethe maintenance needed to increase its structural value and to assess the remaining service life by using the AASHTO 1993 method. Structural evaluation method is made by using two methods to determine thethickness of additional layer, which is based on the dataof road condition survey. The overlay analysisbased on the deflection data of FWD (Falling Weight Deflectometer) measurement. Backcalculation method was performed to determine the existing value of Modulus of Elasticity of the concrete pavement. Traffic data is used to predict the value of service life and the additional overlay thickness of concrete pavement. The analysis shows that the results of overlay thickness using the two methods were slightly difference.

Keywords: Rigid Pavement, AASHTO 1993, Remaining life, Modulus of Elasticity, Overlay

1. INTRODUCTION

Road infrastructure is very important to serve the traffic flow with high mobility due to economic activities in Indonesia and especially in the North Java corridor, namely “Pantura”, which is one of main arterial road in Java Island. This arterial road serves the important logistic transportation between east sides to west side of Java Island. Rigid pavement is one type pavement that being used in that corridor. When a rigid pavement reached the end of its service life then the pavement need the treatment such as, reconstruction, replacement, or overlay on existing concrete pavement.

Due to the amount of traffic volume and also the axle load intensity on Pantura Highway, the pavement structures were frequently induced the damage both structurally and functionally. Accordingly, it is necessary to conduct regular inspections and to continue serving the traffic flow. The structural evaluation of pavement was carried out and an overlay thickness on rigid pavement was calculated using the AASHTO 1993 method.The purpose of this research is to evaluate the structural condition of existing rigid pavement, to determinethe maintenance needed to increase its structural value and to assess the remaining service life by using the AASHTO 1993 method.

In order to determine the required overlay thickness, there are two procedures in the AAASHTO 93 method; those are comparison based on conditions survey and comparison based on remaining service life. Overlay thickness resulted from each method will then be compared and selected to obtain the optimized result between two values, based on economical and efficiency criteria. Pavement evaluation in this research consist of structural and functional evaluation of the existing rigid pavement, prediction of remaining service life and the maintenance needed to increase the functional and structural condition of rigid pavement by using the AASHTO 1993 method.

2. RESEARCH METHODOLOGY

Stages of researchin the preparation of this study are presented in **Figure 1** as follows;

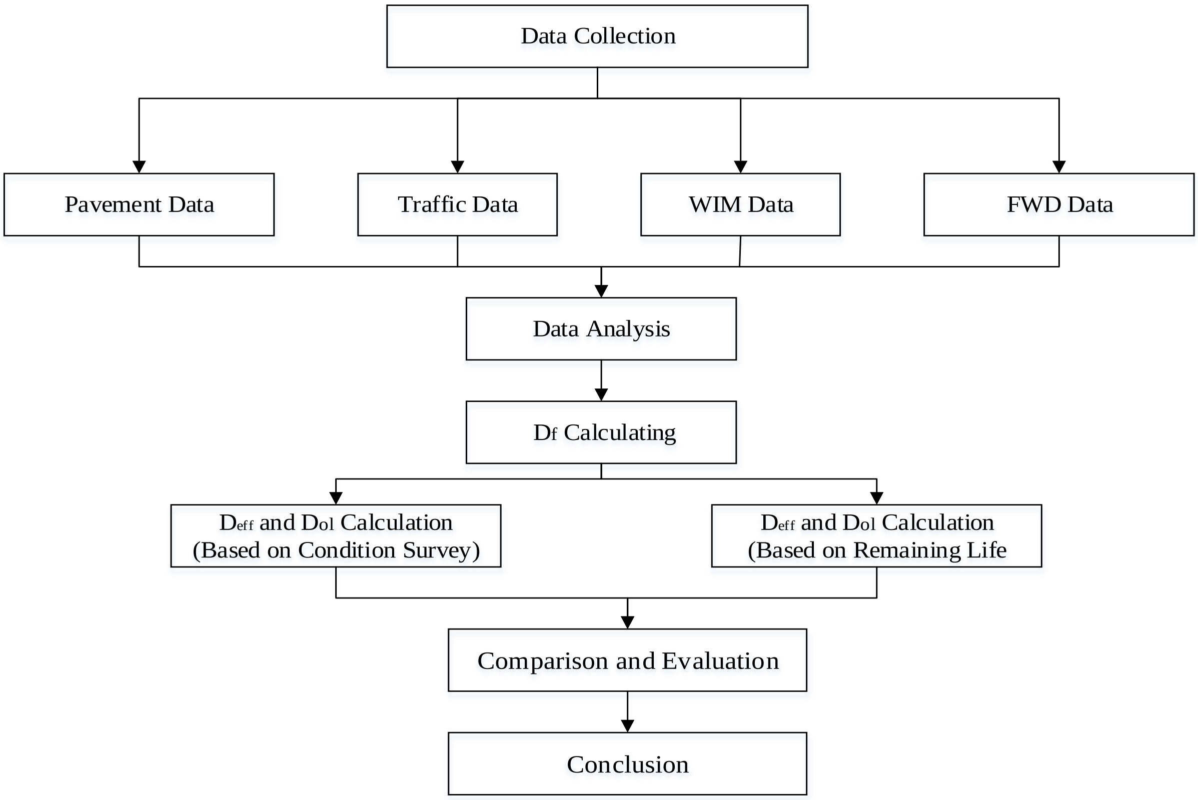
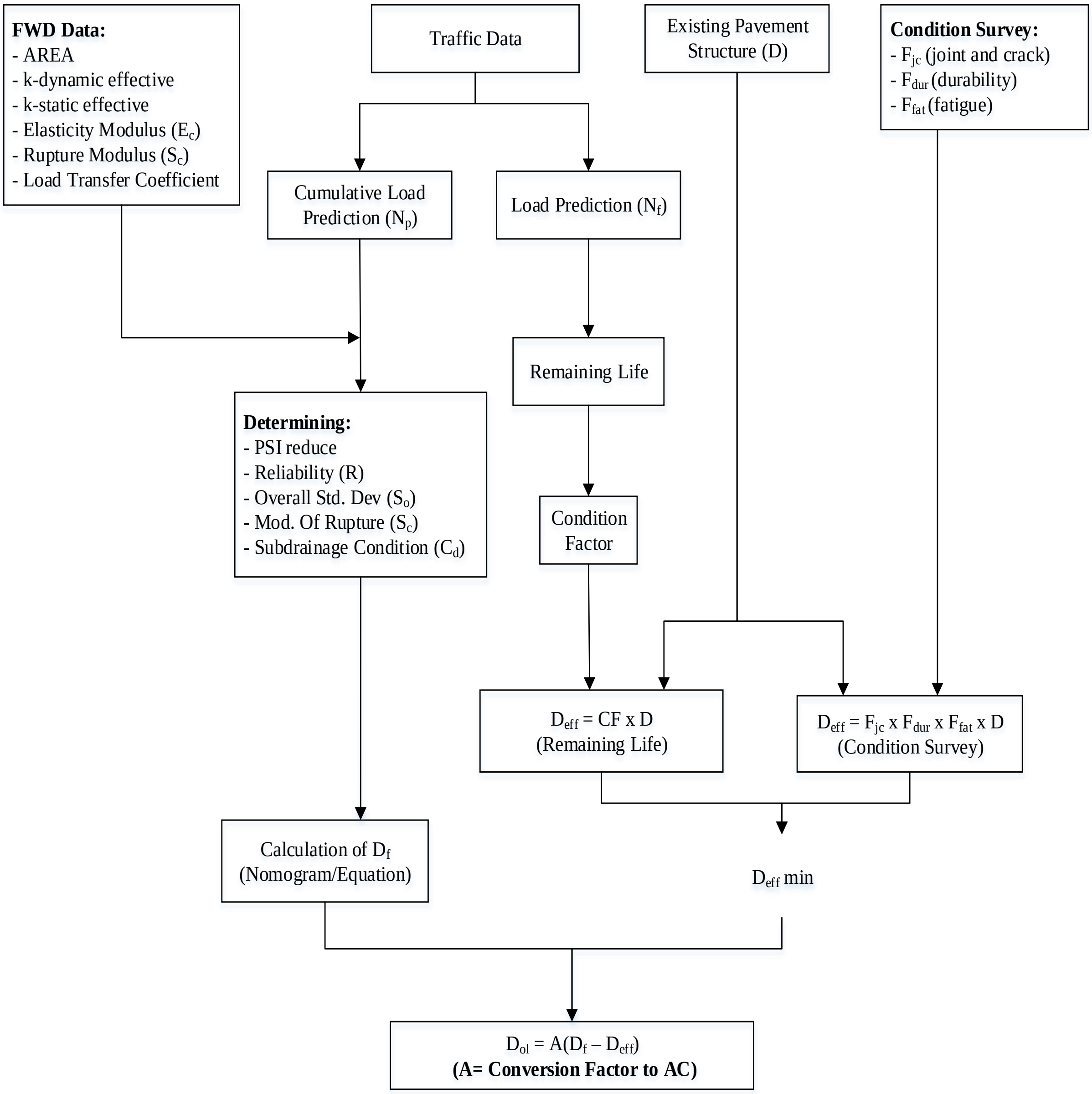


Figure 1. Flowchart of Research Program.

The stage of this research was shown above, that consists ofthe collection data: existing rigid pavement, traffic data, axle load data and the FWD deflection data, the data analysis and the calculation process, which are based on Condition Survey method and Remaining Life calculation. The case study selected was the one section of rigid pavement between Batang to Kendal, located in North Java corridor. Another data collected were the existing pavement condition, the traffic volume, the air and pavement temperature, and the FWD deflection data. All the data collected were then analyzed and calculated by using the AASHTO 1993 method.

2.1 Structural Evaluation Method ForRigid Pavement

Pavement structural data, such as: FWD deflection data, k-dynamic, k-static, elasticity modulus, rupture modulus and load transfer coefficient, were collected before the calculation process. The traffic data in term of: cumulative ESAL were used to calculate the cumulative load prediction (N_p and N_f). The existing rigid pavement thickness was used to determine D_{eff} by using two methods: remaining life and condition survey. The results of Condition survey: F_{jc}, F_{dur} and F_{fat} were used as an input. The total thickness in the future (D_f) was determined by using the formula or monogram. The overlay thickness was then determined from two alternatives: based on remaining life or based on condition survey. The optimum result was then selected, which is intended to improve both the structural and functional condition of the rigid pavement analyzed. All the procedures were shown in **Figure 2.**



Source: Badisga, S.M. 2005

Figure 2.AASHTO 1993 Method for AC Overlay on Rigid Pavement

2.2 Asphalt Concrete (AC) Overlay on Rigid Pavement

Resurfacing with an asphaltic concrete (AC) on top of concrete pavement is one alternative of rehabilitation method in rigid pavement, except when the conditions of the old pavement really need to be removed and replaced. The conditions where the asphalt concrete overlay on concrete pavement is not feasible, were the number of plate cracked and chipped (spalling) in the joint was so big and need replacement, pretty big damage on concrete pavement has occurred due to problems of durability, and the free space in the vertical direction of the bridge is not sufficient for the required overlay thickness. Implementation of the resurfacing concrete pavement above included the following activities: repair damaged areas and improve drainage beneath the surface, widening the pavement construction (if necessary), spraying tack coats, including the construction of cracked reflection controllers.

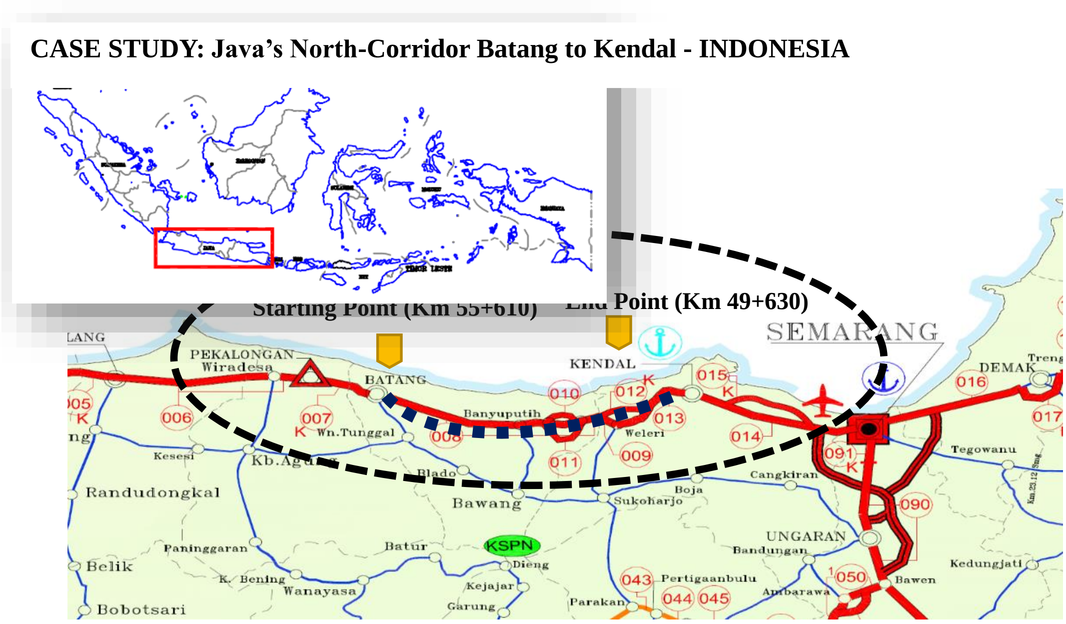


Figure 3. Location of Case Study: Batang to Kendal

The location of research studies was laid on North Java corridor, between Batang to Kendal, with 5.98 km length of roads (km 49 + 630 until 55 + 610 km), that can be seen in **Figure 3**.

3. PRESENTATION DATA

This data shows the existing rigid pavement structuresince the road sections has been opened.There are three stages of Batang-Kendal construction road, presented in Table 1, with the design life of 20 years each.

Table 1. Pavement Construction Data

Stage	Starting Km	End Km	Length (m)	Opening Year	Position	Direction
Stage 1a	49+630	55+610	5980	2002	O	Semarang
Stage 1b	49+630	50+355	725	2002	N	Jakarta
Stage 2	50+355	52+580	2245	2012	N	Jakarta
Stage 3	52+580	55+610	3030	2013	N	Jakarta

Source: Bina Marga's, 2014

The details of construction scheme can be seen in **Figure 4**.

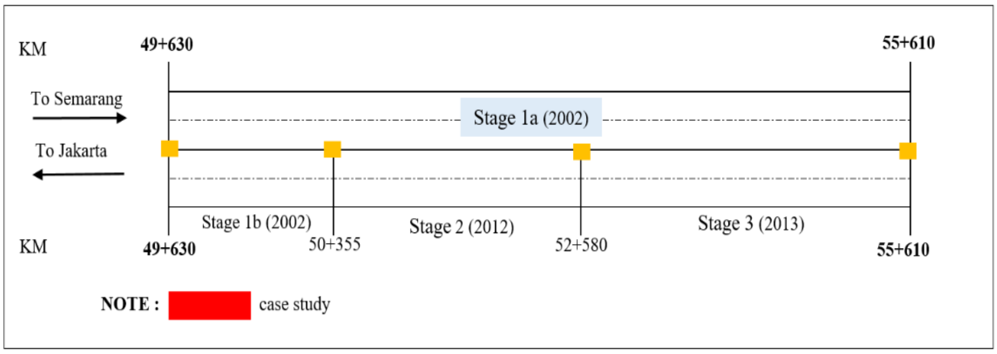


Figure 4. Stage of Road Construction at Batang-Kendal

3.1 Existing Pavement Condition Data

The existing road pavement structure consist of 4 (four) layers, that is concrete pavement surface without reinforcement or Jointed Plain Concrete Pavement (JPCP) with 30 cm thickness and f_s of 45MPa concrete quality, Subbase lean concrete layer K-125 with 10 cm thickness, Base course layer Class A with 15 cm thickness and selected fill soil foundation with 15 cm thickness.

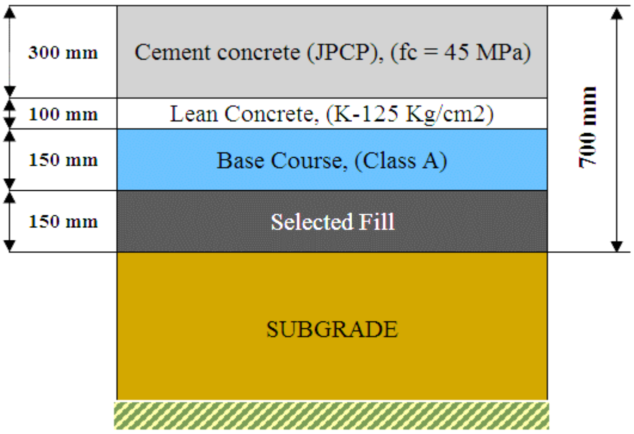


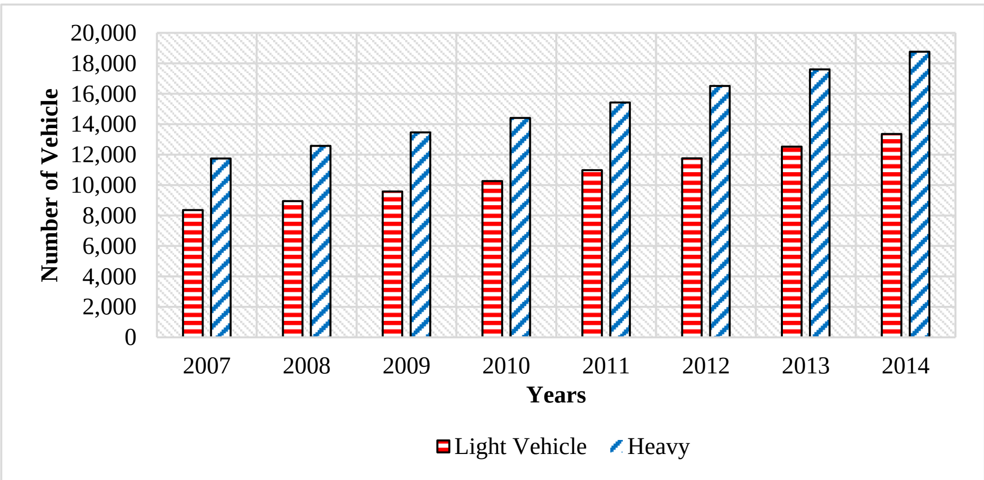
Figure 5. Typical Structure Pavement of Batang-Kendal section

3.2 Deflection Data from FWD

The Deflection data used in this research is the Falling Weight Deflectometer (FWD) data, thatwas conducted in 2014 on Batang-Kendal segment. The position of FWD Deflection was at the center of the rigid pavement plate.

3.3 Traffic Data

The historical data of traffic volume was used from IRMS (Bina Marga's) database, for road section from Batang to Kendal. The data that will be used in this study are the traffic growth rate and the cumulative ESAL calculated for each section. In the structural analysis, the vehicle types considered in this study were the vehicles class 2, 3, 4, 5a, 5b, 6a, 6b, 7a, 7b, and 7c, while vehicle type 1 and 8 is not taken into account. The average annual daily traffic volume (AADT) from 2007 to 2014 is presented in Figure 6 below.



Source: Bina Marga's, 2014

Figure 6. Traffic data for Batang-Kendal section

3.4 Design and Actual Truck Factor

The "Design" and Actual Truck Factor, defined as the total equivalent damage for each vehicle was calculated using the maximum allowable limit of axle load configuration in the vehicle classification data. This data will then be compared to the "actual" Truck Factor, based on the WIM (Weight-in-Motion) survey. The vehicle axle load data was obtained from WIM (Weight-in-Motion), It is similar to a gross weight survey for moving vehicle, and the weight proportion for each vehicle tires was determined by analyzing the dynamic pressure of each tires.

Thevehicle axle load data used in this research are resulted from WIM Survey at Cirebon-Losari section in 2012. The comparison of Design and Actual Truck Factor was shown in Table 2.

Table 2. Comparison of Design and Actual Truck Factor

	Vehicle Class				
	7A	7B	7C1	7C2	7C3
TF Design (Bina Marga's)	4,452	8,290	6,707	7,380	6,130
TF Actual (WIM)	5,385	10,490	6.707	10,881	11,215

Source: Bina Marga's, 2012

3.5Pavement Damage Data

The pavement damage was observed within a certain distance along Batang to Kendal section. Most of the damage was found at km 49 + 630 to 50 + 355 where the section was opened in 2002. Along km 50 + 355 to km 52 + 580 is shown a quite lot of damage where the pavement was opened in 2012. And the less damage was found at km 52 + 580 to km 55 + 610 which was opened in 2013. The summary of the rigid pavement damage was shown in the table below:

Table 3. Pavement Damage for Slow Lane

No.	Segment			Length (m)	Number of Slab	Area (m^2)	Slab Dimension		Damage Classification		Opening Year
							L	P	Crack		
							m	m	Total	%	
1	49+630	-	50+355	725	155	2712.5	3.5	5	155	100%	2002
2	50+355	-	52+580	2225	445	7787.5	3.5	5	280	62.92%	2012
3	52+580	-	55+610	3030	606	10605	3.5	5	1	0.17%	2013

Source: Pavement Condition Survey, 2015

Table 4. Pavement Damage for Fast Lane

No.	Segment			Length (m)	Number of Slab	Area (m^2)	Slab Dimension		Damage Classification		Opening Year
							L	P	Crack		
							m	m	Total	%	
1	49+630	-	50+355	725	155	2712.5	3.5	5	148	95.48%	2002
2	50+355	-	52+580	2225	445	7787.5	3.5	5	130	29.21%	2012
3	52+580	-	55+610	3030	606	10605	3.5	5	0	0.00%	2013

Source: Pavement Condition Survey, 2015

4. RESULT AND DISCUSSION

4.1 Cumulative ESAL Analysis

Cumulative ESAL is the cumulative number of equivalent load 18 Kips passed for one year. This value was obtained by multiplying the Average Daily Traffic Volume (ADT) with the values of Truck Factor (TF), traffic growth factors, the direction distribution, the lane distribution coefficient and the number of days in a year.

4.1.1 Prediction of Cumulative ESAL in the future (N_f)

In order to calculate the predictive number of cumulative ESAL (N_f), the design life used was 5 years starting from 2015. The result of this calculation was used to determine the required overlay thickness, which is based on average daily traffic volume (ADT) in 2014.

Table 5. The Actual Cumulative (N_f) for 5 years

Starting Period	End Periode	Duration	Actual Load	
		year(s)	Slow Lane	Fast Lane
2015	2019	5	31,232,458.95	48,074,947.97

4.1.2 Calculation of Cumulative Actual ESAL Passed (Np)

The Cumulative actual ESAL passsed on the road section (N_p) is calculated based on average daily traffic volume (ADT) starting from the road opened to the traffic, and then they converted into ESAL in order to determine the remaining life of the concrete pavement.

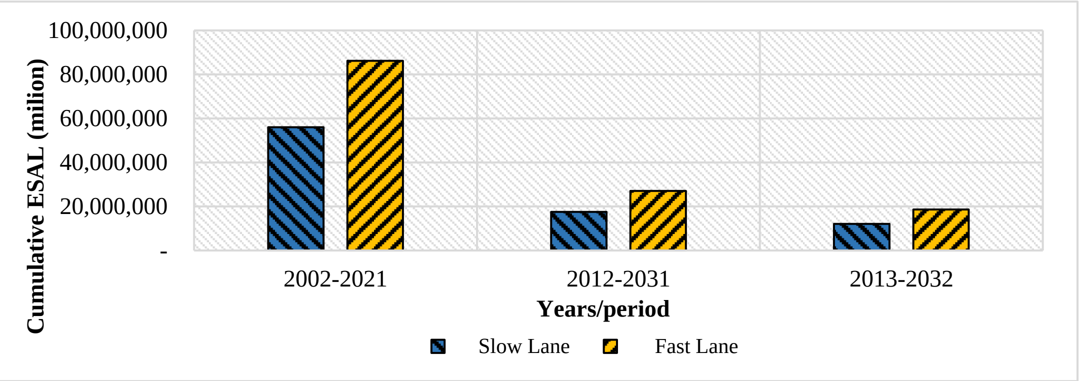


Figure 7. Actual ESAL Passed (Np) Since The Road Opened

The Cumulative ESAL to Achieve"failure" ($N_{1.5}$) is the total ESAL that passed a concrete pavement during the service life until the pavement will failure at the end. The "$N_{1.5}$" is used to determine the remaining service life of the rigid pavement. In this study, the design life of the rigid pavement is 20 years.

Table 6. Cumulative ESAL calculated until Rupture ($N_{1.5}$)

No.	Opening Year	Design Service Life (years)	End of Service Life	$N_{1,5}$
1	2002	20	2021	51,150,033.38
2	2012	20	2031	101,061,096.73

3	2013	20	2032	108,182,699.81

The comparison results between "$N_{1,5}$" and "Np" for all pavement sections showed that the pavement opened in 2002, achieved the end of pavement service life ($N_{1.5}$) that was smaller than actual design life (N_p).

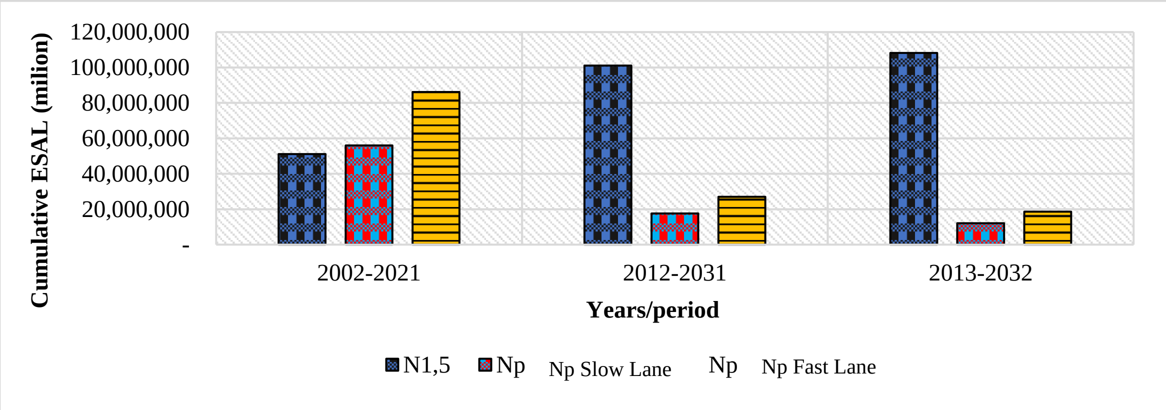


Figure 8. Comparison of Cumulative ESAL to Rupture ($N_{1.5}$) and Cumulative ESAL Passed the design Lane (Np)

4.2 OVERLAY ANALYSIS USING AASHTO 1993 METHOD

The Modulus of Elasticity and the Modulus of Subgrade Reaction of rigid pavement structure were calculated as an input of this calculation.

4.2.1 Modulus of Subgrade Reaction (k)

The results of the Modulus of Subgrade Reaction based on FWD deflection analysis in the center of the plate can be described as follows:

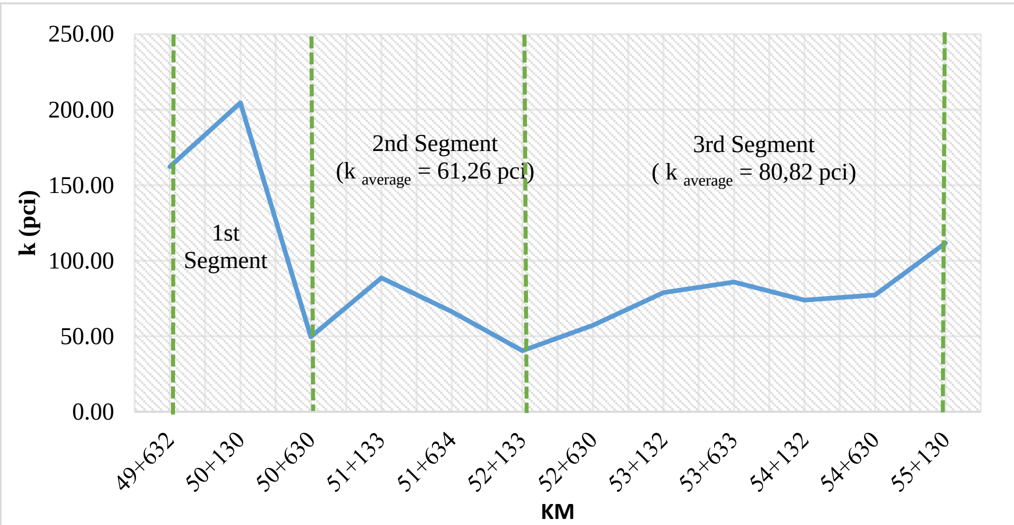


Figure 9. Modulus of Subgrade Reaction (k) in the Slow Lane

The Modulus of subgrade reaction (k) represents the soil bearing capacity of the load in the concrete slab. This analysis shows that the slow lane gave the average value of “k” at 88,61 pci for segment 2 (km 51+133), and 117,76 pci for segment 3 (km 55+130), and the minimum value at 40,41 pci for segment 2, (km 52+133) and 57,29 pci for segment 3 (km 52+630). In the fast lane, the maximum “k” was 62.14 pci for segment 2 (km 50 + 886) and 91.51 pci for segment 3 (km 54 + 381) and the minimum "k" was 29.99 pci for segment 2 (km 50 + 380) and 38.06 pci for segment 3 (km 54 + 880).

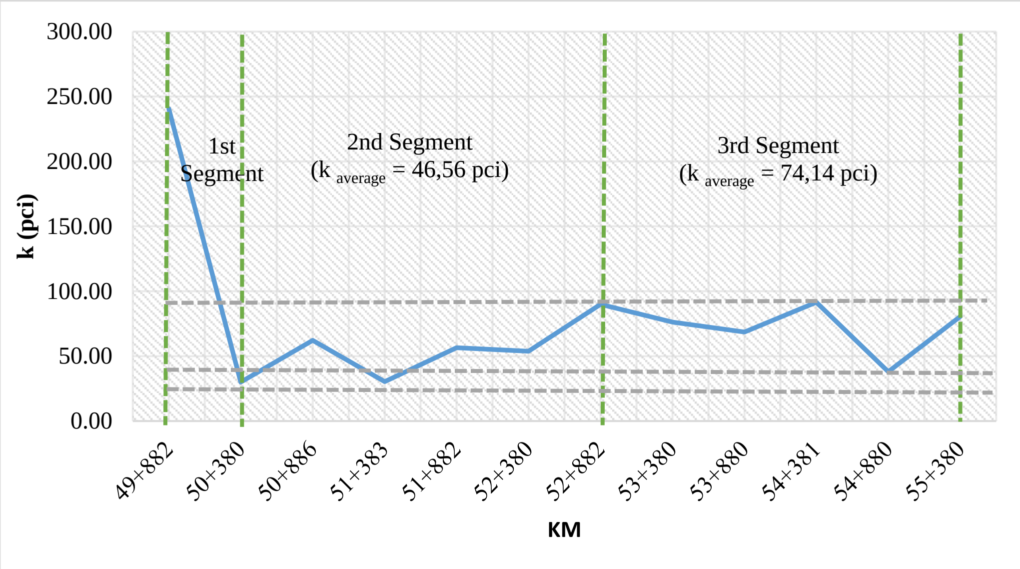


Figure10. Modulus of Subgrade Reaction (k) in the Fast Lane

4.2.2 Concrete Modulus of Elasticity (Ec)

Using the AASHTO 1993 method, the Modulus of Elasticity of concrete pavement in the slow lane, is shown as follows:

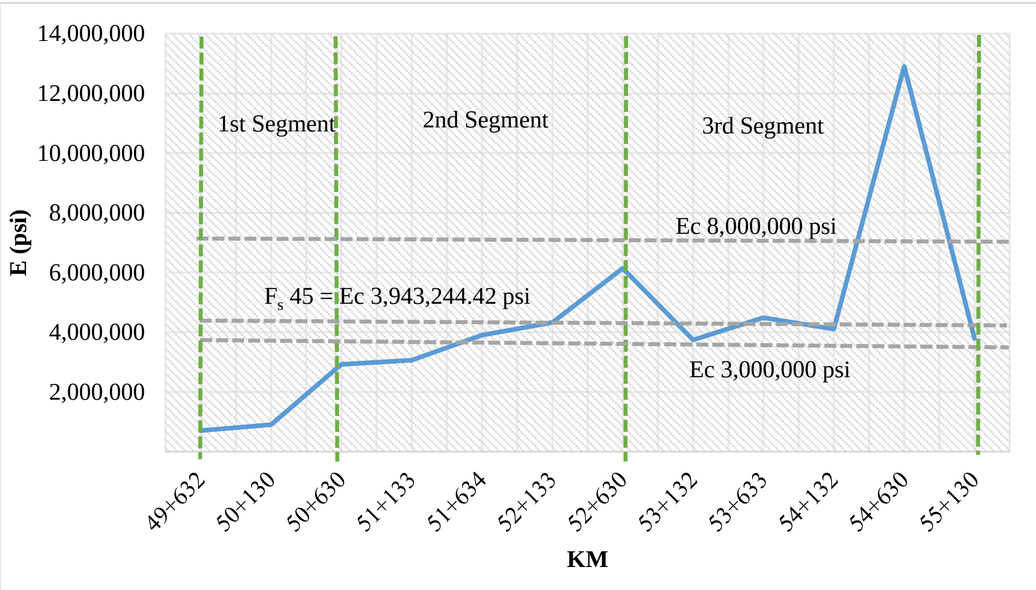


Figure11.PCC Elastic Modulus for Slow Lane

The average value of "E" was laid between 3 million psi to 8 million psi. Some "E" value that are obtained out of the border line, indicate an error that may occur from thickness measurement of the plate, concave deflection measurements through cracks, or quite severe of concrete pavement damage.

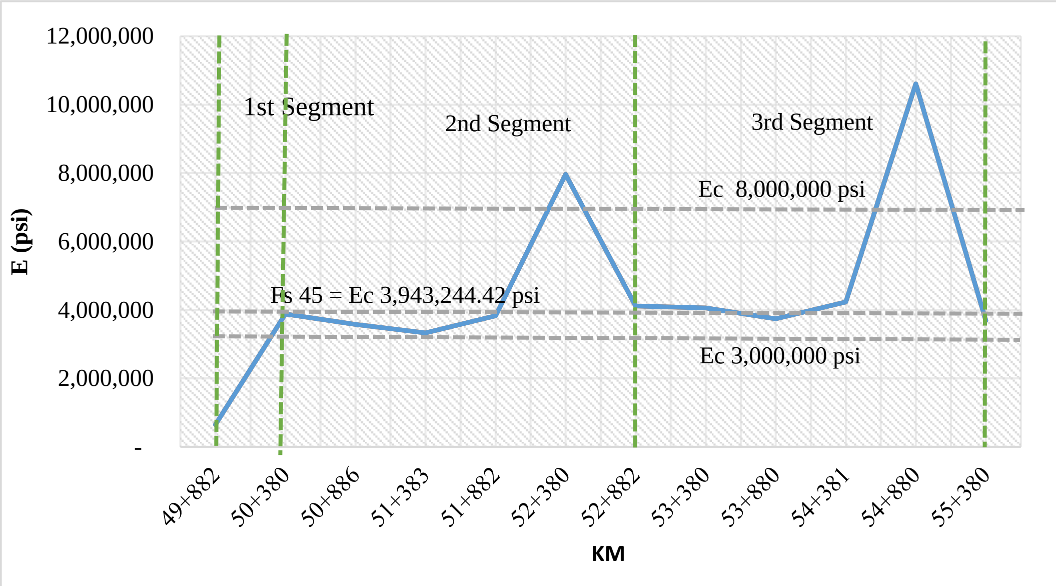


Figure12. PCC Elastic Modulus for Fast Lane

4.2.3 Analysis of D_f(Deflection in Future)

The D_f value was calculated to predict the traffic loading for the next 5-year and to increase the structure capacity of concrete pavement. The D_f value can be obtained by using the AASHTO-93 rigid pavement equations or nomogram. The overlay analysis used the greatest value of $D_f$for each segment, because the greatest value of D_f considered as the weakest point of the concrete pavement segment.

Table 7. The Maximum Value of $D_f$for Each Segment

No	KM	D_f (Slow Lane) (inch)	D_f (Slow Lane) (cm)	Segment
5	50+630	12.90	32.76	2
15	53+132	12.46	31.65	3

No	KM	D_f (Fast Lane) (inch)	D_f (Fast Lane) (cm)	Segment
8	51+383	13.75	34.93	2
18	53+880	13.35	33.90	3

4.3 Analysis of Overlay Thickness (D_{ol})

The results of the calculation of overlay thickness by using the condition and remaining service life is shown in the following table;

Table 8. Recapitulation of Overlay Thickness for 2nd and 3rd Segment

2nd Segment	Slow Lane			Fast Lane		
(Km 50+355 - 52+580)	(inch)	(cm)	Rounded	(inch)	(cm)	Rounded
Condition Survey Method	5.91	15	15	6.22	15.79	16
Remaining Life Method	2.94	7.46	8	4.81	12.22	13

3rd Segment (Km 50+355 - 52+580)	Slow Lane (inch)	Slow Lane (cm)	Slow Lane Rounded	Fast Lane (inch)	Fast Lane (cm)	Fast Lane Rounded
Condition Survey Method	1.62	4.11	5	3.09	7.84	8
Remaining Life Method	1.84	4.67	5	3.73	9.48	10

Considering the practical implementation, the overlay thickness values should be the same between the slow lane and fast lane. The value of overlay thickness recommended for each segments was shown as follows, that is 16 cm for segment 1 and 10 cm for segment 2.

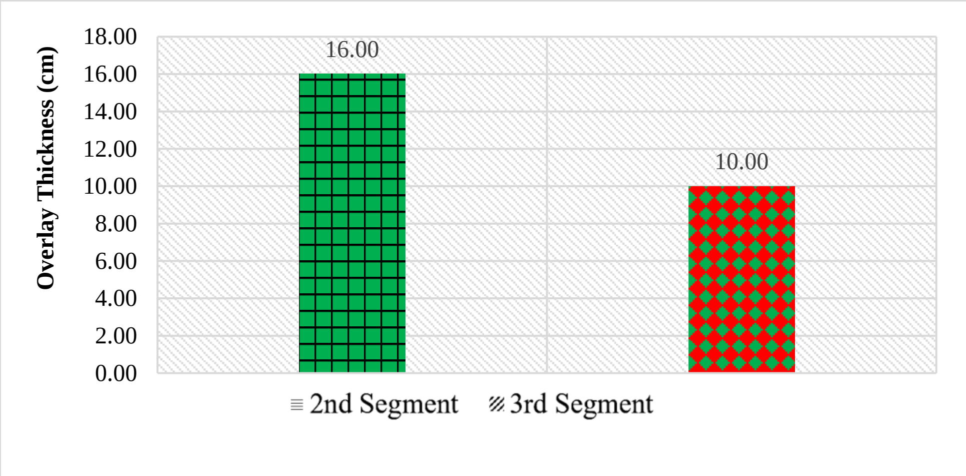


Figure. 13 Overlays Thickness of 2nd Segment and 3rd Segment

5. CONCLUSIONS

Based on the analysis of research results, it can be concluded as follows:

1. The actual Trucks factor is relatively high, especially for vehicle class 7B, 7C1, 7C2 and 7C3. This value shows the "overloading effect" in the road section considered and does not comply with the standards of Department of Public Works.
2. In overlay analysis based on AASHTO 1993 method, the value of Modulus of Subgrade Reaction (k) give little impact to overlay thickness, even though the value of "k" has increased or decreased very significantly.
3. The value of Concrete Modulus of Elasticity on segment 1 (km 49 + 630-50 + 355) is below 3 million psi for both in the slow lane or in the fast lane, meaning that the section has been suffered severe damage.
4. The Remaining life of concrete pavement on segment 1 (km 49 + 630 to km 50 + 355) has been achieved, since the results of the analysis provide Np> $N_{1.5}$, meaning that this segment needs to be totally improved.
5. The overlay thickness based on condition survey methods in the 2nd segment was 15 cm for slow lane and 16 cm for fast lane. While using the remaining life method in the 2nd segment, the overlay thickness was 8 cm for slow lane and 13 cm for fast lane. Then the result using those two methods was slightly different

REFERENCES

AASHTO. (1993),*Guide for Design of Pavement Structures 1993*, American Association of State Highways and Transportation Officials, Washington DC, USA.

Bina Marga. (2014), *Collection Data*, Ministry of Public of Works and Housing, (Direktorat Jenderal Bina Marga; In Indonesia), Jakarta, Indonesia.

Badisga, S.M. (2005), *Evaluation Structural of Rigid Pavement using Elcon Program and AASHTO 1993 Method (Case Study:Padalarang-Cileunyi-Toll Road)*, Highway Engineering Program, ITB, Bandung, Indonesia.

Huang Y.H. (1993), *Pavement Analysis and Design*, *University of Kentucky*, Prentice Hall, Englewood Cliffs, New Jersey 07632.

Nefiadi, N. (1990), *Comparison of Pavement Structural Characteristics as Determined Using Benkelman Beam and Falling Weight Deflectometer*, Highway Engineering Program, ITB, Bandung, Indonesia.

Paus, M. (2016), *Evaluation Structural Conditions and Remaining Lifeof Rigid Pavement Case Study: National Roads Batang-Kendal*, Highway Engineering Program, ITB, Bandung, Indonesia.

Sormin, S. M. (1996), *Analysis of Deflection Characteristics of Rigid Pavement Structures using Falling Weight Deflectometer*, Highway Engineering Program, ITB, Bandung, Indonesia.

Sutrisna, I. (2004), *The Analysis of Addition Layer Thickness (Overlay) on Rigid Pavement by Elcon Program and Asphalt Institute Method (Case Study: Padalarang-Cileunyi-Toll Road)*, Highway Engineering Program, ITB, Bandung, Indonesia

Ullidtz, P. And Stubstad, R.N. (1985), *Analytical-Empirical Pavement Evaluationusing The Falling Weight Deflectometer*, Transportation Research Record 1022.

Yoder E.J. and Witczak M.W. (1975), *Principles of Pavement Design*, 2nd Edition, John W. Ley & Son.