Prosiding Forum Studi Transportasi antar Perguruan Tinggi
Vol. 10, No. 1, Tahun 2023, p. 88-105

THE EFFECT OF A HEAVY LOAD ON RUTTING DEPTH AND FINE CRACKING ON ASPHALT PAVEMENT WITH THE HDM III METHOD

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Abstract

The goal of this research is to forecast how long it will take for the road to develop fine crack damage, as well as the rutting depth when fine cracks appear on the asphalt road surface. The research was conducted on the Pantoloan road using the HDM III technique, with changes in the construction plan's age of 5, 10, 15, and 20 years, as well as traffic growth assumptions of 2.5%, 5%, 7.5%, and 10%. The shortest time before the road reaches a fine crack (TYN) is 2.5 % traffic increase, the design life is 5 years, and the TYN value is 4.157 years, according to calculations and analyses. The design life is 20 years with a TYN value of 6.774 years, whereas the longest period before the road hits fine cracks (TYN) is at 10% traffic increase. The deepest groove on the road surface is 3,588 mm, with a design life of 5 years at a traffic growth rate of 2.5%. The lowest channel has a depth of 3,076 mm, a 10% traffic increase rate, and a 20-year design life.

Keywords : Groove Depth, Fine Cracks, HDM III, Design Life, Vehicle Weight

Abstrak

Tujuan dari penelitian ini adalah untuk memperkirakan berapa lama waktu yang dibutuhkan jalan untuk mengalami kerusakan retak halus, serta kedalaman alur ketika muncul retakan halus pada permukaan jalan aspal. Penelitian dilakukan pada jalan Pantoloan dengan teknik HDM III, dengan perubahan umur rencana pembangunan 5, 10, 15, dan 20 tahun, serta asumsi pertumbuhan lalu lintas sebesar 2,5%, 5%, 7,5%, dan 10 tahun. %. Waktu terpendek sebelum jalan mencapai retak halus (TYN) adalah kenaikan lalu lintas sebesar 2,5 %, umur rencana 5 tahun, dan nilai TYN 4,157 tahun, berdasarkan perhitungan dan analisis. Umur rencana adalah 20 tahun dengan nilai TYN sebesar 6,774 tahun, sedangkan periode terlama sebelum jalan mengalami retakan halus (TYN) adalah pada kenaikan lalu lintas sebesar 10%. Alur terdalam pada permukaan jalan adalah 3.588 mm, dengan umur rencana 5 tahun dengan laju pertumbuhan lalu lintas sebesar 2,5%. Saluran terendah memiliki kedalaman 3.076 mm, tingkat peningkatan lalu lintas 10%, dan umur desain 20 tahun.

Kata kunci: Kedalaman Alur, Retakan Halus, HDM III, Umur Desain, Berat Kendaraan

INTRODUCTION

Heavy trucks passing through frequently cause damage to flexible roads by carrying high loads that effect the axle load and are not in compliance with the Directorate General of Land Transportation's regulations. The generation III HDM (Highway Development and Management) technique may be used to examine the amount of road damage, particularly the reduction and time of road damage throughout the road's service life caused by a percentage rise in the number of excessive vehicle loads (overloading). Whereas HDM III is a road damage model developed by the World Bank to help nations plan road building and maintenance. This method allows for the prediction of road damage in the following years during the analysis period, particularly on roads with flexible pavements.

Pantoloan, being a high-traffic location served by cars entering and exiting the port, need flexible road construction planning to fulfill traffic demands and withstand the loads that travel through it. With careful planning, the flexible road should be able to serve traffic by creating a sense of security and comfort for motorists, reducing road damage.

METHOD OF RESEARCH

Site of Research

The Transportation and Highway Laboratory, Faculty of Engineering, Tadulako University, did aggregate study. The materials employed in this study are coarse and fine aggregate sourced from the Ex Watusapu-stone crusher and delivered to AMP PT. Sapta Unggul. Other resources include sand from the Labuan River Ex, as well as rock ash from the PT. Sapta Superior stone crushing plant. Meanwhile, LHR data is collected for 5 days, including 4 days of activity on weekdays and 1 holiday, Monday through Thursday, as well as Saturday. Traffic data is collected for 16 hours from this road stretch, from 6 a.m. to 10 p.m. A dynamic cone penetrometer is set above the test location in an upright posture on level and solid ground, and the CBR test is performed every 100 meters.

Figure 1. Site of Research

Techniques for Data Sampling and Processing

Sampling of aggregates in a stone crusher is located in Watusampu. As for traffic data, samples are used in traffic surveys at peak hours, and CBR data every 100 meters for 1 kilometer.

Specific Gravity of Paved Layers Information

Data on the density of the asphalt layer derived from laboratory tests, including effective specific gravity, density of solid asphalt mixture (Gmb), effective density of aggregate mixture (Gse), percentage of air voids and asphalt content (VMA), bitumen elastic modulus (Sb), and elastic modulus of the asphalt mixture (Sme).

Data from the Traffic Survey

The equivalent number of vehicle axle loads (E), daily cumulative standard axle load (w18 days), yearly cumulative standard axle load (w18 years), and standard axle load for the planned lane during design life are used to calculate traffic survey data (Wt).

Paved Mix's Volumetric Value

Aggregate, asphalt, and/or additives are mixed uniformly or homogeneously, then distributed and compacted to make solid asphalt concrete. Sukirman (2003) claims that Both laboratory and field compaction may be used to assess the volumetric parameters of solid asphalt concrete analytically. Vmb, VMA, VIM, and VFA are all regularly used parameters.

Value of Asphalt Elastic Modulus (Stiffness), Sb

For realistic situations, the following equation may be used to compute binder stiffness across a finite range, which is preferable to utilizing a nomogram.

$$\text{Sb (MPa)} = 1{,}157.10^{-7}\ t^{\ -0{,}368}\ 2{,}718^{\ -PIr}\ (SPr - T)^{5} \tag{1}$$

The above formula can only be used within a certain range:
t = 0,01 until 0,1 second
PIr = -1 until +1
(SPr-T) = 20 until 600C
For heavy traffic and high temperatures, Al-Shalout Imad et al (2007) utilized 60/70 penetration asphalt.

Elastic Modulus Value (Stiffness) Sme's Asphalt Concrete Mixture

The stiffness of asphalt as a binding agent and the density of the mixture represented in VMA are two elements that influence the stiffness value of asphalt concrete.

$$\text{Sme} = \text{Sb}\ [1 + \frac{(257{,}5 - 2{,}5.\text{VMA})}{\text{n}(\text{VMA} - 3)}]^{\text{n}} \tag{2}$$

In which:
Sme = elastic mix stiffness, MPa

Sb = bitumen stiffness, MPa
VMA = voids in mixed aggregate, (%)
n = 0.83 log (40.000/Sb)

TYN and MDR Values Using HDM III Methode

After obtaining the Elastic Modulus (Sme), the following equation must be calculated to forecast the design life of a flexible pavement using AC-WC:

$$\mathrm{TYN} = 4{,}21\ \exp\left(0{,}139\mathrm{SNC} - 17{,}1\,\frac{\mathrm{YE_4}}{\mathrm{SNC^2}}\right) \tag{3}$$

In which:
TYN = The estimated duration is until the pavement begins cracking (initation of cracking) in years.
SNC = Modified Structural Number
YE_4 = Annual traffic load (millions 80 kN ESAL, damage factor 4)

Since the construction was opened to the public, the above model may be used to estimate the initial phase of thin cracking. The presence of a small number of fine cracks is not a reason to perform repairs (maintenance) if the cracks may be easily filled.

Meanwhile, the following equation may be used to compute the groove depth on flexible pavement.:

$$\mathrm{MDR} = 1{,}0.\,\mathrm{AGER}^{0{,}166}.\,\mathrm{SNC}^{-0{,}502}.\,\mathrm{COMP}^{-2{,}30}.\,\mathrm{NE_4}^{\mathrm{ERM}} \tag{4}$$

In which:
MDR = Mean Ruth Deep (mm),
AGER = Age of the pavement since latest overlay or construction (years),
SNC = Modifikasi Structural Number (8,81)
COMP = Compaction Index (1) for good compaction, or compaction index of the pavement relative to a standart
NE_4 = Komulatif 80 kN single axle loads
ERM = Exponential Ruth Deep Mean (mm)
ERM = 0,0902 + 0,0384 DEF - 0,009 RH + 0,00158 MMP.CRX
DEF = 6,5 SNC $^{-1.4}$
MMP = Mean Monthly Precipitation (m/month), 0,0034
RH = 0
CRX = 0

CALCULATION RESULTS AND DISCUSSION

Aggregate Fraction and Specific Gravity

The results of bulk specific gravity, saturated surface dry, apparent specific gravity and absorption from coarse aggregate are presented in Table 1.

Table 1. Specific gravity of aggregate fraction

Source	Aggregate Type	Bulk Density	Absorption (%)
Stone Crusher Watusampu	Granular Material 3/4"	2.791	0.770
	Granular Material 3/8"	2.671	0.900
	Fine Aggregate	2.592	1.020
Specification		Min.2.5	Max.3%

Table 2. Gse value on aggregate composition

Aggregate Fraction	Bulk Density	Apparent Density	Mix Composition
Fraction 3/4"	2.791	2.853	10
Fraction 3/8"	2.671	2.737	35
Rock Ash	2.690	2.783	50
Sand	2.592	2.662	5
Coarse Aggregate, Fine Aggregate, and Filler Fraction Composition			
CA%	-	-	54.89
FA%	-	-	40.47
FF%	-	-	4.64
Specific Gravity of the Aggregate Mix			
Bulk Spesific Gravity (Gsb)	-	-	2.668
Aggregate Fraction	Bulk Density	Apparent Density	Mix Composition
Apparent Spesific Gravity (Gsa)	-	-	2.767
Effective Spesific Gravity (Gse)	-	-	2.728

The percentage composition of each fraction that fulfills the gradation parameters as indicated in table 3 was determined by trial and error. When evaluating mix designs, determining the proportion of each aggregate is useful since it offers values or aggregate density data that can be utilized in modulus calculations. stretchy asphalt mix (Sme).

Table 3. The aggregate fraction mix design outcomes

Number of Sieve	Opening (mm)	% pass of each fraction					Composition of Each Fraction					Total of Mixed Grad.	Spec. of Mixed Grad.
		Coarse Agg. 3/4"	Coarse Agg. 3/8"	Fine Agg.	Rock Ash	Filler	3/4" 19%	3/8" 23%	Sand 9%	Dust 47%	Filler 2%		
1	25,40	100,00	100,00	100,00	100,00	100,00	19,00	23,00	9,00	47,00	2,00	100,00	100
3/4"	19,00	100,00	100,00	100,00	100,00	100,00	19,00	23,00	9,00	47,00	2,00	100,00	100
1/2"	12,50	70,58	99,79	98,85	99,84	100,00	13,41	22,95	8,90	46,92	2,00	94,18	100-90
3/8"	9,50	33,27	99,67	97,58	99,43	100,00	6,32	22,92	8,78	46,73	2,00	86,76	90-77
No.4	4,75	8,75	54,35	96,12	94,03	100,00	1,66	12,50	8,65	44,19	2,00	69,01	69-53
No.8	2,36	3,78	13,91	91,70	65,82	100,00	0,72	3,20	8,25	30,94	2,00	45,11	53-33
No.16	1,18	3,06	7,78	88,22	44,80	100,00	0,58	1,79	7,94	21,06	2,00	33,37	40-21

Number of Sieve	Opening (mm)	% pass of each fraction					Composition of Each Fraction					Total of Mixed Grad.	Spec. of Mixed Grad.
		Coarse Agg. 3/4"	Coarse Agg. 3/8"	Fine Agg.	Rock Ash	Filler	3/4" 19%	3/8" 23%	Sand 9%	Dust 47%	Filler 2%		
No.30	0,60	2,61	5,14	78,18	26,90	100,00	0,50	1,18	7,04	12,64	2,00	23,36	30-14
No.50	0,30	2,40	4,27	48,48	18,21	100,00	0,46	0,98	4,36	8,56	2,00	16,36	22-9
No.100	0,15	1,85	2,91	7,36	9,20	99,84	0,35	0,67	0,66	4,32	2,00	8,00	15-6
No.200	0,08	1,28	1,98	1,11	4,51	85,92	0,24	0,46	0,10	2,12	1,72	4,64	9-4

The weight in air (in water), saturated surface dry weight, and weight in water (in water) acquired through Marshall testing in the laboratory utilizing AC-WC asphalt samples and specimens during an immersion method for 24 hours, as shown in Table 4.

Table 4. Specific gravity of aggregate and test object after compaction (briquettes)

Aggregate Fraction	Spesific Grafity			% of total aggregate
	Bulk	Apparent	Effective	
	A	B	C = (A-B)^2	
Coarse Agg. 3/4"	2.791	2.853	2.822	10
Coarse Agg. 3/8"	2.671	2.737	2.704	35
Rock Ash	2.690	2.783	2.737	50
Sand 9%	2.592	2.662	2.627	5
Briquette Sample (AC-WC)				
Asphalt	Weight (gram)			Gmb
	In Air (Bulk)	SSD	In Water	
5.78	1252.4	1256.9	727.9	2.367
5.78	1250.8	1255.9	722.7	2.346
5.78	1248.9	1256.1	718.3	2.322
Average				2.345

Mixed Air Cavity Paved (VMA)

The value of VMA is calculated using the asphalt content (wa) and aggregate content (wb) values. This research employed a 5.78% asphalt concentration and a 95% aggregate composition.

$$\mathrm{VMA} = 100 - \{\mathrm{wb}\ \frac{\mathrm{Gmb}}{\mathrm{Gse}}\} \tag{5}$$

$$\mathrm{VMA} = 100 - \left\{95.\frac{2{,}345}{2{,}728}\right\} = 18{,}319\ \%$$

Elastic Modulus of Asphalt (Sb)

With parameters of h = 100 mm, v = 60 kph, Pi = 67 mm, and T = 25oC, the elastic modulus of asphalt (Sb) may be calculated using the following equation.

Sb = $1{,}157 \times 10^{-7}\ t^{-0{,}368}\ 2{,}718^{-PIr}\ (SPr - T)^5$
= $1{,}157 \times 10^{-7}\ t^{-0{,}368}\ 2{,}718^{-PIr}\ (SPr - T)^5$
= 18,330 Mpa

= 272.236,775 Psi
(1 MPa = 144,93 Psi, 1 Psi = 0,0069 MPa)

Table 5. The results of the elastic modulus of asphalt (Sb)

h (mm)	5x10-4h-0,2	0,94 log V	Log t
100	-0,15	1,671	-1,8215
v (kph)	T	27 Log Pi-21,65	76,35 Log Pi-232,82
60	0,0151	27,654	-93,3992
Pi (mm, 25^{o}C, 5 sec)	Pir	Pr	SPr
67	-0,296t	43,550	55,2127
T(^{o}C)	2,718-Pir	(SPr-T)^{5}	**Sb (Mpa)**
25	1,3445	25173578,756	18,330

Elastic Modulus of Paved Mixtures (Sme)

The following formula may be used to calculate the elastic modulus of the asphalt mixture (Sme):

$$n = 0{,}83 \log \left[\frac{4\ x\ 10^{4}}{Sb}\right] \tag{6}$$

$$n = 0{,}83 \log \left[\frac{4\ x\ 10^{4}}{18{,}33}\right]$$

$$n = 2{,}771$$

$$Sme = Sb\ \left[1+ \frac{257{,}5-2{,}5(VMA)}{n(VMA-3)}\right] \tag{7}$$

So that: $Sme = 18{,}330\ \left[1+ \frac{257{,}5-2{,}5(20{,}291)}{2{,}771(20{,}291-3)}\right]$

Sme = **2.612,064 MPa** = 378.566,393 Psi

(1 MPa = 144,93 Psi, 1 Psi = 0,0069 MPa)

Table 6. The results of the Paved Mixtures (Sme)

Log (4.10^{4}) Sb	N
3,339	2,771
VMA	2,5 VMA
18,319	45,797
257,5-2,5 VMA	n (VMA-3)
211,703	42,453
257,5-2,5 VMA/n (VMA-3)	Sme (Mpa)
4,987	2612,064
	Sme (Psi)
	378566,393

Data Analysis for CBR

A Dynamic Cone Penetrometer was used to collect subgrade CBR data in the field for this investigation. The results are shown in Table 7.

Table 7**.** The results of data analysis for subgrade CBR

Number	Statiton	CBR (%)
1	0+000	12.22
2	0+100	15.37
3	0+200	7.41
4	0+300	4.47
5	0+400	5.58
6	0+500	4.02
7	0+600	4.58
8	0+700	7.44
9	0+800	13.78
10	0+900	12.43
11	1+000	10.80
12	1+100	11.90
CBR Average		9.17

The following equation may be used to calculate the segment's CBR value, which indicates the subgrade's bearing capacity and is used to estimate the segment's pavement thickness.:

$$\text{CBR segment} = \text{CBR average} - \frac{\text{CBR maks} - \text{CBR min}}{\text{R}} \tag{8}$$

$$\text{CBR segment} = 9{,}17 - \frac{15{,}37 - 4{,}02}{3{,}18} = 5{,}60\%$$

Analyzing Traffic Data

The road traffic volume (LHR) data utilized in this study is primary data gathered by a survey over 5 (five) days, with the maximum traffic volume happening on holidays (Appendix 9), with the values of MC = 16055, LV = 2655, HV = 35, HV1.2 = 711, HV1.2-2.2 = 230, and AU = 876. Because MC is not on the load list, it is treated as LV, resulting in a total LV of 18710.

Axle Load Equivalent (E)

Following a daily traffic survey (LHR), the equivalent number of each kind of vehicle is calculated, which is based on the distribution of the vehicle axle weight at the front, middle, and rear of the vehicle.

Table 8. Vehicle load distribution

Transportation Type	Total Weight (Tons)	Total Vehicle	Distribution Load (%)		
			Front	Middle	Behind
Light Vehicle	2	20118	50	-	50

Transportation Type	Total Weight (Tons)	Total Vehicle	Distribution Load (%)		
			Front	Middle	Behind
(LV)					
Heavy Vehicle (HV)	8,3	38	34	-	66
Heavy Vehicle 1.2 (HV)	18,2	765	34	-	66
Heavy Vehicle 1.2-2.2 (HV)	42	247	18	28	54
Bus 1.2	9	942	34	-	66

Cumulative Standard Axle Load (ŵ18)

Because mixed traffic (heavy and light) enters each lane of the road, daily and monthly cumulative axle load (ŵ18) is computed for both directions. On a 2-way roadway, based on a 16-hour study

Table 9. 2-way daily cumulative standard axle load (ŵ18)

Transportation Type	Total Weight (Tons)	Total Vehicle	ŵ18 (CESA)	Total ŵ18
Light Vehicle (LV)	2	20118	47,320	9169,907 CESA
Heavy Vehicle (HV)	8,3	38	10,451	
Heavy Vehicle 1.2 (HV)	18,2	765	4908,237	
Heavy Vehicle 1.202.2 (HV)	42	247	3842,286	
Bus 1.2	9	942	361,613	

Axle Load on Design Lane (W18)

The cumulative standard axle load (W18) is the total amount of traffic on the design lane over a period of one day and one year.

Table 10. Axle load calculation results (Wt)

A = $(1+g)^n$	B = A - 1	C = B/g	g	n	Wt = w18.C	Wt (Msa)
1,131	0,131	5,256	2,5%	5	8796508,331	8,797
1,280	0,280	11,203	2,5%	10	18748950,100	18,749
1,448	0,448	17,932	2,5%	15	30009224,457	30,009
1,639	0,639	25,545	2,5%	20	42749191,344	42,749
1,276	0,276	5,526	5%	5	9247188,637	9,247
1,629	0,629	12,578	5%	10	21049204,999	21,049
2,079	1,079	21,579	5%	15	36111900,883	36,112
2,653	1,653	33,066	5%	20	55336141,921	55,336
1,436	0,436	5,808	7,5%	5	9720389,394	9,720
2,061	1,061	14,147	7,5%	10	23675265,470	23,675
2,959	1,959	26,118	7,5%	15	43709294,808	43709

A = $(1+g)^n$	B = A - 1	C = B/g	g	n	Wt = w18.C	Wt (Msa)
4,248	3.248	43,305	7,5%	20	72470734,848	72,471
1,611	0,611	6,105	10%	5	10216934,282	10,217
2,594	1,594	15,937	10%	10	26671409,112	26,671
4,177	3,177	31,772	10%	15	53171505,372	53,172
6,727	5,727	57,275	10%	20	95850175,398	95,850

The results of the computation of the total cumulative standard single axle load, abbreviated as Wt, are acquired from Table 10. Using a construction service life plan (n) ranging from 5, 10, 15, and 20 years, as well as traffic growth predictions (g) of 2.5, 5, 7.5, and 10%. Wt, n, and g are the three variables that will be employed in additional calculations to determine service life until fine cracks appear.

The Link Between Axle Load (Wt) and Construction Design Life (n)

Figure 2 shows the link between axle load in the design lane throughout the design life (Wt) and construction design life (n).

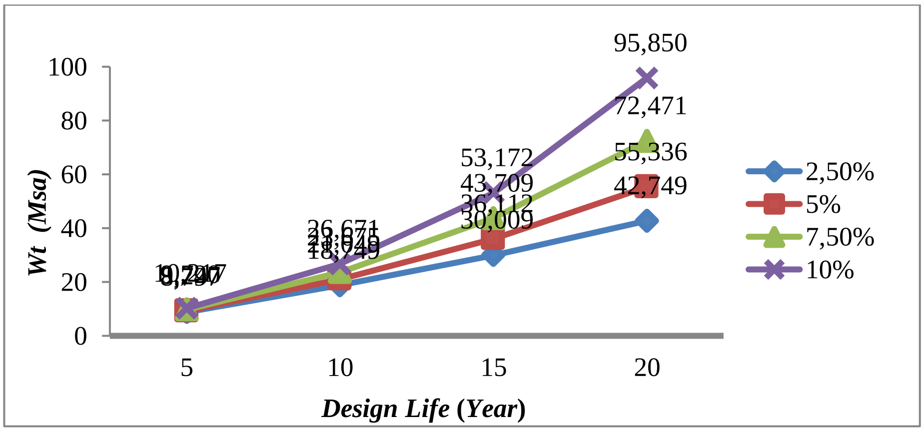

Figure 2. A graph depicting the link between axle load (Wt) and building design life (n)

Figure 2 shows that:

1) The cumulative standard single axle load (Wt) has grown as the design life of the road has increased from 5 to 20 years. The biggest rise was seen in traffic growth over 20 years, with an average increase of 28,544 Msa, while the smallest was shown in traffic growth over 5 years, with an average increase of 11.318 Msa.
2) There is a variation in Wt between the ages of the road designs for every rise in the percentage of traffic growth (g = 2.5% to 10%). The highest difference, up to 100%, was found in traffic growth g = 10%, while the smallest difference, 71.884%, was found in the service age group n = 5 years.

As a result, the average cumulative difference in standard axle load (Wt) differs between the four traffic increase percentage groups (g = 2.5% to g = 10%). The g = 10% group had the biggest variance in the Wt average difference, up to 113.56%, while the g = 2.5% category had the least variation, 11.318% or 71.88%

HDM III Method Calculation

Design Traffic (YE4) and Total Construction Thickness (HTot) : A Mathematical Model Relationship

Based on the CBR value of the subgrade and the targeted design traffict (YE4) value, the Indian Roads Congress: 37-2001 nomogram is a graph used to estimate the overall thickness of the flexible pavement layer. Several CBR alternatives are shown in this graph, ranging from 2% to 10%, with various traffic patterns ranging from 1 Msa to 10 Msa.

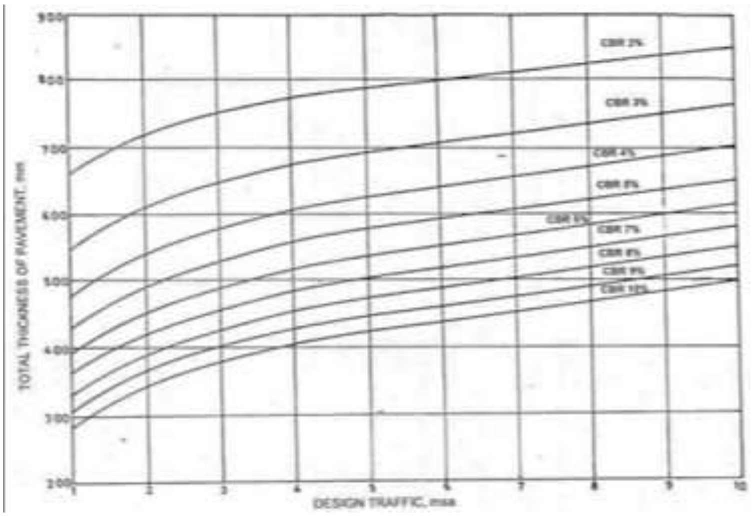

Figure 3. Pavement thickness for accumulated load of 1-10 msa (The Indian Roads Congress, 2001)

After plotting the CBR value against the cumulative design load (YE4 = 0.8 msa, for yearly traffic) in the nomogram above, the total thickness of the proposed pavement is calculated as indicated in the table. Then, as indicated in the image, interpolated for the segment CBR value of 5.6%.

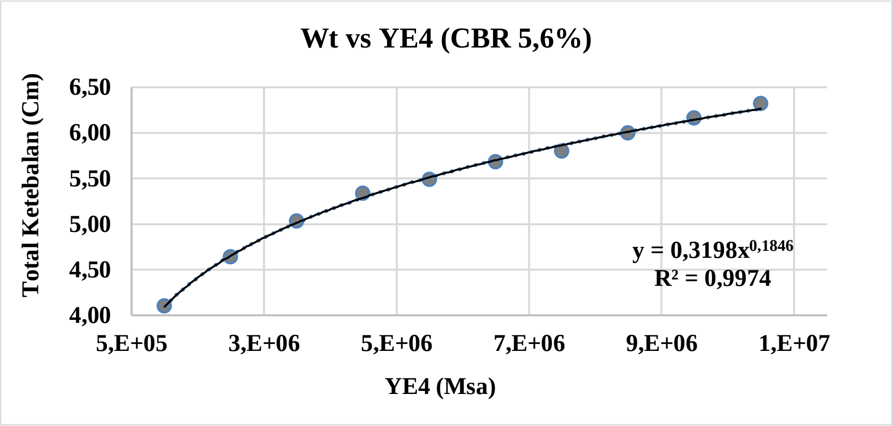

Figure 4. A graph depicting the link between total construction thickness (H Tot) and design traffic (YE4)

Table 11 shows the mathematical equation (as shown in Figure 4) will be utilized to anticipate total pavement construction thickness (HTot) based on design traffic (YE4).

Table 11. The estimated total construction thickness for a 2.5% increase in traffic

			2,50%
Service Life	5 Years	Wt = x	8.796.508,33
		H-Tot = y	612,07
		Surface	101,60
		Base	152,40
		SubBase	358,07
	10 Years	Wt	18.748.950,10
		H-Tot	703,83
		Surface	101,60
		Base	152,40
		SubBase	449,83
	15 Years	Wt	30.009.224,46
		H-Tot	767,68
		Surface	101,60
		Base	152,40
		SubBase	513,68
	20 Years	Wt	42.749.191,34
		H-Tot	819,50
		Surface	101,60
		Base	152,40
		SubBase	565,50

Meanwhile, the modulus of elasticity of the asphalt mixture is used to calculate the relative coefficient value of the surface layer (a_1). The CBR value of the layer determines the coefficient of relative strength of the base layer (a_2) and the coefficient of relative strength of the subbase layer (a_3). These values can be calculated by interpolating the data in the Table 12.

Table 12. Layer strength coefficient (a_i)

Pavement Layer	Koefisien Kekuatan Relatif, a_i
Surface Course:	
Surface treatments	0,20 - 0,40
Asphalt Mixture (cold or hot premix of low stability)	0,20
Asphalt Concrete (hot premix of high stability)	
MR = 1500 Mpa	0,30
MR = 2500 Mpa	0,40
MR = 4000 Mpa	0,45
Base Course:	
Granular Materials	
CBR = 30%	0,07
CBR = 50%	0,10
CBR = 70%	0,12
CBR = 90%	0,13
CBR = 110%	0,14
Material Bitumen	
Subbase and Selected Subgrade Layers:	
(of total pavement depth 700 mm)	
Granular Materials	
CBR = 5%	0,06
CBR = 15%	0,09
CBR = 25%	0,10
CBR = 50%	0,12
CBR = 100%	0,14

Analysis of Expected Life Until Fine Cracks Appear (TYN)

The SNC, which is influenced by the total product between the coefficient of relative strength (ai) and the thickness of each layer of pavement (hi), as well as the structural number of the subgrade (SNsg), is a parameter that must be known in advance when determining the service life until the occurrence of fine cracks (TYN). Meanwhile, the CBR value of the section on the subgrade, which was previously calculated, has an impact on SNsg. TYN is determined using the equation below.

$$\mathrm{TYN} = 4{,}21\ \exp\left(0{,}139\mathrm{SNC} - 17{,}1\,\frac{\mathrm{YE}_4}{\mathrm{SNC}^2}\right) \qquad (9)$$

$$\mathrm{TYN} = 4{,}32\ \exp\left\{(0{,}139.4{,}587) - (17{,}1.\frac{0{,}8}{4{,}587^2})\right\}$$

$$\mathrm{TYN} = 4{,}157\ \text{years}$$

Table 13. Shows the calculation results for each design age and traffic increase.

CBR 5,6%						2,5%	5%	7,5%	10%
5 Years	Wt = YE4	(sa)				8.796.508,33	9.247.188,64	9.720.389,39	10.216.934,28
		(Msa)				8,80	9,25	9,72	10,22
	TYN	(years)				4,157	4,206	4,251	4,295
	LP	a1 =	0,404	h1 =		101,600	101,60	101,60	101,60
	B	a2 =	0,107	h2 =		152,400	152,40	152,40	152,40

CBR 5,6%					2,5%	5%	7,5%	10%
	SB	a3 =	0,110	h3 =	358,066	363,74	369,45	358,07
10 Years	Wt = YE4	(sa)			18.748.950,10	21.049.205,00	23.675.265,47	26.671.409,11
		(Msa)			18,75	21,05	23,68	26,67
	TYN	(years)			4,863	4,986	5,108	5,233
	LP	a1 =	0,404	h1 =	101,600	101,60	101,60	101,60
	B	a2 =	0,107	h2 =	152,400	152,40	152,40	152,40
	SB	a3 =	0,110	h3 =	449,834	465,03	480,81	358,07
15 Years	Wt = YE4	(sa)			30.009.224,46	36.111.900,88	43.709.294,81	53.171.505,37
		(Msa)			30,01	36,11	43,71	53,17
	TYN	(years)			5,352	5,565	5,784	6,017
	LP	a1 =	0,404	h1 =	101,600	101,60	101,60	101,60
	B	a2 =	0,107	h2 =	152,400	152,40	152,40	152,40
	SB	a3 =	0,110	h3 =	513,679	540,37	568,86	358,07
20 Years	Wt = YE4	(sa)			42.749.191,34	55.336.141,92	72.470.734,85	95.850.175,40
		(Msa)			42,75	55,34	72,47	95,85
	TYN	(years)			5,750	6,065	6,403	6,774
	LP	a1 =	0,404	h1 =	101,600	101,60	101,60	101,60
	B	a2 =	0,107	h2 =	152,400	152,40	152,40	152,40
	SB	a3 =	0,110	h3 =	565,498	605,48	649,37	358,07

Predicted Age Until Fine Cracks Appear (TYN) and Construction Plan Age (n)

Figure 4 depicts the link between the expected age till the road reaches fine cracks (TYN) and the construction design age (n).

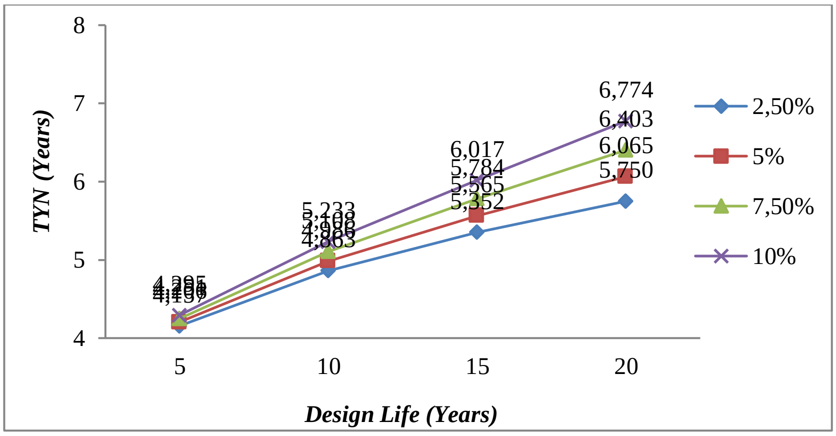

Figure 4. Relationship between estimated age till the road reaches fine cracks (TYN) and construction design age (n)

Figure 4 shows that:

1) As the road's design life grows from 5 to 20 years, fine cracks are projected to appear in the 4th to 6th year of the road's service life, with the average road life for each increase in traffic growth being 5 to 5,5 years.
2) There is a variation in TYN between the ages of the road designs for every rise in the percentage of traffic growth (g = 2.5 percent to 10%). The highest average difference (16.468%) was found in traffic growth (g = 10%), while the smallest (11.487%) was found in the service age group (n = 5 years).

As a result, the average cumulative difference for forecasting roads to have fine cracks differs between the four categories of traffic growth percentage (g = 2.5% to g = 10 %). The average TYN difference was 5.580 years or 16.4568% in the g = 10% group, while the smallest TYN difference was 5.031 years or 11.487% in the g = 2.5% category.

Using the HDM III Method, predicting the depth of the groove (Rutting) when fine cracks occur (MDR, mm)

The equation is used to forecast the Mean Deep Rut value, or the depth of the groove on the road section:

$$\mathrm{MDR} = 1{,}0\mathrm{AGER}^{0{,}166}\mathrm{SNC}^{-0{,}502}\mathrm{COMP}^{-2{,}30}\mathrm{NE_4}^{\mathrm{ERM}} \tag{10}$$

$$\mathrm{MDR} = (1{,}0.\,4{,}157^{0{,}166}).(4{,}587^{-0{,}502}).(1^{-2{,}30}3325755{,}536^{0{,}122})$$
$$\mathrm{MDR} = 3{,}588\ \mathrm{mm}$$

Table 16 shows the computation results for each design age and traffic growth.

Table 16. Groove (rutting) depth when fine cracks occur

	CBR 5,6%	2,5%	5%	7,5%	10%
5 Years	TYN = AGER	4,157	4,206	4,251	4,295
	SNC	4,587	4,615	4,640	4,665
	NE4	3.325.755,536	3.365.084,650	3.400.409,354	3.435.985,464
	MDR (mm)	3,588	3,575	3,564	3,553
10 Years	TYN = AGER	4,863	4,986	5,108	5,233
	SNC	4,990	5,061	5,130	5,202
	NE4	3.890.445,952	3.989.097,884	4.086.020,334	4.186.389,644
	MDR (mm)	3,420	3,393	3,367	3,341
15 Years	TYN = AGER	5,352	5,565	5,784	6,017
	SNC	5,270	5,392	5,517	5,651
	NE4	4.281.971,819	4.451.750,602	4.626.824,044	4.813.244,537
	MDR (mm)	3,317	3,276	3,236	3,195
20 Years	TYN = AGER	5,750	6,065	6,403	6,774
	SNC	5,498	5,679	5,872	6,082

CBR 5,6%	2,5%	5%	7,5%	10%
NE4	4.599.660,440	4.852.077,111	5.122.736,002	5.419.212,013
MDR (mm)	3,242	3,187	3,132	3,076

Figure 5 shows the link between groove depth (MDR) and building design life (n).

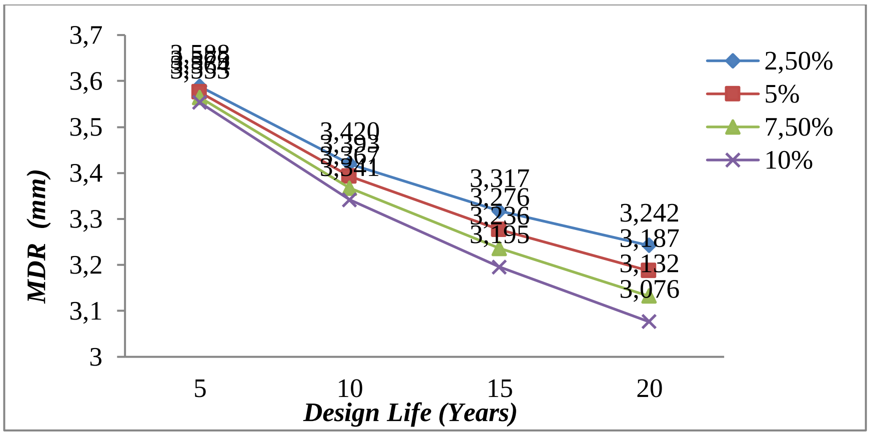

Figure 5. A graph depicting the association between groove depth (MDR) and building plan age (n)

Figure 5 shows that:

1) As the road's design life is extended from 5 to 20 years, the road is expected to develop varied grooves, with the maximum average depth of 3.392 mm at 2.5% traffic growth and the smallest average depth of 3.291 mm at 10% traffic growth.
2) As the design age grows, the trend on the graph tends to diminish, or the groove depth gets narrower. This is due to the road construction thickness factor, which varies with the plan's age (the total pavement layer gets thicker), as well as the traffic load, which is expected to increase (from 2.5% to 20%).

As a result, the average cumulative difference for groove depth varies among the four categories of traffic growth percentage (g = 2.5% to g = 10%). The g = 2.5% group had the biggest MDR difference variance of 3.392 mm (3.318%), whereas the g = 10% category had the least MDR difference variation of 3.291 mm (4.685%).

CONCLUSION

Based on the results of research and data analysis, some conclusions can be drawn as follows:

1. Traffic growth (g) and road design life (n) affect the cumulative standard single axle load (Wt). Where the value of Wt will be greater when traffic growth and the life of the plan also increases. The greater the Wt value, the greater the total thickness of the pavement, especially in the subbase layer.

2. Traffic growth (g) and road design life (n) are directly proportional to the predicted time required for the road to reach fine cracks (TYN). With the shortest time until the road reaches a fine crack (TYN), namely at 2.5% traffic growth, the design life is 5 years with a TYN value of 4,157 years. While the longest time until the road reaches fine cracks (TYN) is at 10% traffic growth, the design life is 20 years with a TYN value of 6.774 years.
3. For the depth of the groove on the road surface, the deepest groove is 3,588 mm at a traffic growth of 2.5%, the design life is 5 years. Meanwhile, the lowest channel has a depth of 3,076 mm at a traffic growth of 10% and a design life of 20 years. This is due to the thickness factor of road construction that adjusts to the age of the plan (the total pavement layer is getting thicker), along with the predicted traffic load to also increase (from 2.5% to 20%).

REFERENCES

Fahrurrozi, (2008), Pengaruh Nilai CBR Tanah Dasar Terhadap Tebal Perkerasan Lentur Jalan Kaliurang dengan Metode Bina Marga 1987 dan AASHTO 1986. Tugas Akhir. Fakultas Teknik Sipil dan Perencanaan.

Hardiani, N.P., (2008), Kajian Perkerasan Jalan Lentur Akibat Beban Lalu Lintas dengan Menggunakan Program HDM-III. Skripsi. Departemen Teknik Sipil. Fakultas Teknik Universitas Indonesia, Jakarta.

Hutauruk, A.G., (2015), Analisis Prediksi Kondisi Perkerasan Jalan Menggunakan Pendekatan HDM-4 Untuk Penanganan Jalan (Studi Kasus: Ruas Jalan Nasional BTS. Kota Gresik-Sadang). Tesis. Fakultas Teknik Sipil dan Perencanaan. Institut Teknologi Sepuluh Nopember, Surabaya.

Kementerian Pekerjaan Umum dan Perumahan Rakyat, (1997), Manual Kapasitas Jalan Indonesia. Direktorat Jenderal Bina Marga, Jakarta.

Lampiran Surat Edaran Direktur Jenderal Perhubungan Darat, Nomor SE.02/AJ.108/DRJD/2008, Jakarta.

Morisca, W., (2014). Evaluasi Beban Kendaraan Terhadap Derajat Kerusakan dan Umur Sisa Jalan (Studi Kasus: PPT. Simpang Nibung dan PPT. Merapi Sumatera Selatan). Jurnal Teknik Sipil dan Lingkungan, Vol. 2, No. 4, Desember 2014, ISSN: 2355 – 374X, Sumatera Selatan.

Ramadhan, S.W., Arifin, S., dan Oka, M., (2017), Prediksi Umur Rencana Flexible Pavement Menggunakan Metode HDM III. Prosiding Seminar Hasil Penelitian (SNP2M) 2017 (pp.7-12), Palu.

Republik Indonesia, (1990), Peraturan Menteri No.74 Tahun 1990 tentang Angkutan Peti Kemas di Jalan, Jakarta.

Republik Indonesia, (1993), Peraturan Pemerintah No.43 Tahun 1993 tentang Prasarana dan Lalu Lintas Jalan, Jakarta.

Republik Indonesia, (1993), Peraturan Pemerintah No.44 Tahun 1993 tentang Kendaraan dan Pengemudi, Jakarta.

Republik Indonesia, (2004), Undang-Undang Dasar No.38 Tahun 2004 tentang Jalan, Departemen Pekerjaan Umum, Jakarta.

Republik Indonesia, (2006), Peraturan Pemerintah No.34 Tahun 2006 tentang Jalan, Departemen Pekerjaan Umum, Jakarta.

Sentosa, L. dan Roza, A.A., (2012), Analisis Dampak Beban Overloading Kendaraan pada Struktur Rigid Pavement Terhadap Umur Rencana Perkerasan (Studi Kasus Ruas Jalan Simp Lago – Sorek Km 77 S/D 78). Jurnal Teoretis dan Terapan Bidang Rekayasa Sipil, Vol.19 N0.2 Agustus 2012 (161-168) ISSN 0853-2982, Pekanbaru.

Sukirman, S., (1999), Perkerasan Lentur Jalan Raya, Penerbit Nova, Bandung.

Sukirman, S., (2003), Beton Aspal Campuran Panas, Penerbit Granit, Jakarta.

Sukirman, S., (2010), Perencanaan Tebal Struktur Perkerasan Lentur, Penerbit Nova, Bandung.

Tranggono, M., (2013), Kajian Penggunaan HDM-4 untuk Sistem Pengelolaan Perkerasan Jalan di Indonesia. Jurnal Transportasi, Vol.13 No.2 Agustus 2013: 135-144., Bandung.