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Prediction of pavement remaining service life based on repetition of load and permanent deformation

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Abstract. One of the methods which was applied in the assessment of flexible pavement performance was mechanistic method assuming structures of road pavement to become multi-layer structure for flexible pavement, that the vehicle load working on the pavement layer under repetition with power failure worth 1 (one) unit which was assumed as evenly distributed static load, and therefore the pavement material would provide response in the form of stress, strain, and deflection.This is closely related in order to assess the structure of flexible pavement and to predict the remaining service life on the roads of Pulau Indah sta 0 + 000 to sta. 0 + 845 in Kota Kupang, Nusa Tenggara Timur. The performance appraisal indicator which was used was fatigue cracking happening bottom of the asphalt layer and permanent deformation (rutting) on the surface of subgrade.The strain estimate on the flexible pavement layer structure needs carefulness and high accuracy and therefore a software like KENPAVE which produces horizontal tensile strain of 8,802E-05 and vertical compressive strain of 2,642E-04 was used. By applying equation of The Asphalt Instituteit was obtained repetition of permit load when reaching fatigue cracking (Nf) was 16.071.516 ESAL and permanent deformation (rutting) was 14.703.867 ESAL and also it was predicted the remaining service life of pavement applied the equation of *AASTHO 1993* by considering Traffic Multiplier factor (TM 1.8, TM 1.9 and TM 2.0) obtained the remaining life service due to fatigue of 5.51% in the year of 13^{th} (TM 1.8), 7.95% in the year of^{12th} (TM 1.9) and 3.11% (TM 2.0) in the year of 12^{th}, also the remaining service life due to rutting of 4.69% in the year of 12^{th}(TM 1.8), 7.79% in the year of 11^{th} (TM 1.9), and 2.94 in the year of 11^{th} (TM 2.0).

1. Introduction

Road infrastructure performance service, from the stage of implementation to the planned service life keeps undergoing an increase of loading due to traffic volume, so that the road built must have reliable carrying capacity. Thus, it needs study and research to conduct about the behaviour of flexible pavement towards response of vehicle axle load or other factors. In flexible pavement structure, the load of vehicle under goes repitition has 1 (one) power failure which is assumed as evenly distributed static load, and therefore the material of pavement will provide response in the form of stress, strain, and deflection. [1]. This is closely related in order to predict the performance of pavement structure on the road of in the form of values of load repitition when reaching fatigue and rutting and to predict the remaining service life of the pavement.

Performance appraisal indicator which is applied often for flexible pavement is fatigue cracking occurred bottom of the asphalt layer and permanent deformation (rutting) on the surface of subgrade. The estimate of strain response in each pavement layer structure needs carefulness and high accuracy level and therefore a software named KENPAVE developed by Yang H. Huang P.E is required [2].

This research aims to study in detail in as certaining condition and remaining service life and therefore solution of handling improvement next day in particular related to behaviour of flexible pavement towards vehicle load.

2. Experimental

2.1 Flexible pavement response against traffic load.

Traffic load working on the flexible pavement is assumed as evenly distributed static load that the material of pavement will give response in the form of horizontal tensile strain (ε_t) bottom of the asphalt layer as an indicator of fatigue cracking and vertical compressive strain value (ε_c) on the surface of subgrade being the cause of permanent deformation (rutting) on the road pavement. According to the data of Pulau Indah road existing pavement, with the assistance of Kenpave software, it will ease the strain estimate applied in counting the repetition value of fatigue and rutting permit load. The Asphalt Institute recommended equation of flexible pavement fatigue cracking in order to estimate the number of load repetition as the following:

$$Nf = 0.0796(\varepsilon_t)^{-3.291}(E)^{-0.854} \quad (1)$$

with :

Nf : the number of fatigue load repetition
ε_t : horizontal tensile strain bottom of the asphalt layer
E : Asphalt layer elastic modulus

And equation to count the number of rutting load repetition as the following:

$$Nd = 1.365 \times 10^{-9}(\varepsilon_c)^{-4.477} \quad (2)$$

with:

Nd : the number of rutting load repetition
ε_c : vertical compressive strain on the surface of subgrade

2.2 Prediction of traffic volume.

The analysis of traffic volume was based on the results of factual Avarage Daily Traffic (ADT) survey which was conducted by applying road pavement design manual of Highways year 2013 and therefore cumulative standard axle load ESAL (Equivalent Single Axle Load) and CESA (Cumulative Equivalent Single Axle Load) could be estimated using the following equation:

ESA = Σvehicle type ADT x VDF x DL (3)
CESA = ESA x 365 x R (4)

with:

ESA : Equivalent Single Axle
CESA : Cumulative Equivalent Axle Load
R : Vehicle Growth Factor
ADT : Average Daily Traffic
VDF : Vehicle Damage Factor
DL : Lane Distribution

2.3 Analysis of remaining service life.

Analysis of remaining service life is a concept of pavement damage due to repetition load causing fatigue and permanent deformation (Rutting).AASTHO 1993 recommended equation to count remaining service life obtained from fatigue equation (Nf) and *rutting* (Nd).

$$RL = 100\ [\ 1 - \left(\frac{\mathrm{Np}}{\mathrm{N1.5}}\right)\ ] \quad (5)$$

with:

RL : Remaining Life (%)
NP : Total Traffic to date
$N_{1,5}$: Total Traffic to pavement failure

3. Results and Discussion

3.1 Flexible pavement response against traffic load.

In order to count flexible pavement response due to traffic load in the form of horizontal tensile strain and vertical compressive strain, it is required to have property material data from data material properties from existing pavement, will be analyzed by using KENPAVE software as presented in Table 1.

Table 1. Existing pavement, modulus typical value and poisson's ratio

Type of pavement	Thickness	Typical Modulus	Poisson's ratio
	(mm)	Mpa	
HRS-WC	30	800	0.40
HRS-Base	70	550	0.40
Base course class A	150	300	0.35
Sub base course class B	200	200	0.35
Selected embankment	300	100	0.35
Subgrade	~	40	0.35

The result of running output from Kenpave program and repetition causing fatigue and rutting damage is by in putting the value of horizontal tensile strain (ε_t) and vertical compressive strain (ε_c) in the equation 1 and 2 is presented in Table 2.

Table 2. Response of flexible pavement towards traffic load

No	Review point (cm)	Location	Response		Load repetition	
			horizontal tensile strain(ε_t)	vertical compressive strain(ε_c)	Nf	Nd
1	3,00	bottom of asphalt layer	8.802E-05		16.071.519	
2	75,00	surface of subgrade		2.642E-04		14.703.867

3.2 Traffic volume prediction.

Traffic volume data were obtained from secondary data of survey result year 2016 conducted by Department of Public Works Nusa Tenggara Timur Province on Pulau Indah roads in 2 directions as direction of Bundaran PU-Pulau Indah and reverse direction of Pulau Indah-Bundaran PU conducted for 6 days in busy-hours for 12 hours/day. From the Average Daily Traffic (ADT) data and therefore by using equation 3 and equation 4, it will be obtained ESA and CESA value as presented in Table 3 and Table 4.

Table 3. The result of ESA Value Estimation

Type of Vehicle	ADT	VDF	DL	ESA
Private Car	3164	0.0005	0.8	2
Truck 1.2, Mini Bus	105	0.8	0.8	67
Big bus, Tanker	1773	1.0	0.8	1385
Trailer, Truck 1.2.2	53	7.6	0.8	320
Total				**1774**

3.3 Analysis of

remaining service life

Analysis of remaining service life can be estimated by using equation of AASTHO 1993 when the condition reaches fatigue and rutting load repetition in standard CESA, and by assuming the condition of overloading based on TM factor times CESA for 20 years, the result of estimate presented in Table 5.

Table 4. The result of CESA Value Estimation

No	Year	R	CESA
ESA 1774			
1	2016	1.00	647,510
2	2017	2.00	1,295,149
3	2018	3.00	1,943,209
4	2019	4.00	2,591,594
5	2020	5.01	3,240,302
6	2021	6.01	3,889,335
7	2022	7.01	4,537,331
8	2023	8.01	5,186,558
9	2024	9.01	5,836,045
10	2025	10.02	6,485,793
11	2026	11.02	7,135,800
12	2027	12.03	7,786,067
13	2028	13.03	8,436,594
14	2029	14.04	9,087,381
15	2030	15.04	9,738,429
16	2031	16.05	10,389,737
17	2032	17.05	11,041,305
18	2033	18.06	11,693,134
19	2034	19.07	12,345,224
20	2035	20.08	12,997,574

Table 5. Standard Load Repetition and the effect of TM factor

No	Year	Load Repetition			
ESA	1774	Standard	TM 1.8	TM 1.9	TM 2.0
1	2016	647,510	1,165,343	1,230,084	1,294,825
2	2017	1,295,149	2,331,268	2,460,783	2,590,298
3	2018	1,943,209	3,497,777	3,692,098	3,886,419
4	2019	2,591,594	4,664,868	4,924,028	5,183,187
5	2020	3,240,302	5,832,544	6,156,574	6,480,604
6	2021	3,889,335	7,000,803	7,389,736	7,778,670
7	2022	4,537,331	8,167,195	8,620,928	9,074,661
8	2023	5,186,558	9,335,805	9,854,461	10,373,116
9	2024	5,836,045	10,504,882	11,088,486	11,672,091
10	2025	6,485,793	11,674,427	12,323,006	12,971,585
11	2026	7,135,800	12,844,439	13,558,019	14,271,599
12	2027	7,786,067	14,014,920	14,793,526	15,572,133
13	2028	8,436,594	15,185,868	16,029,528	16,873,187
14	2029	9,087,381	16,357,286	17,266,024	18,174,762
15	2030	9,738,429	17,529,171	18,503,014	19,476,857
16	2031	10,389,737	18,701,526	19,740,499	20,779,473
17	2032	11,041,305	19,874,349	20,978,480	22,082,610
18	2033	11,693,134	21,047,642	22,216,955	23,386,269
19	2034	12,345,224	22,221,404	23,455,926	24,690,448
20	2035	12,997,574	23,395,635	24,695,392	25,995,150

Analysis of the remaining service life was conducted towards the condition of fatigue and rutting which is presented in Table 6, Figure 1,and Figure 2.

Table 6. The analysis of the remaining service life of fatigue and rutting

No	Year	The remaining service life of fatigue *(%)*				The remaining service life of rutting *(%)*			
		Standard	TM 1.8	TM 1.9	TM 2.0	Standard	TM 1.8	TM 1.9	TM 2.0
1	2016	95.97	92.75	92.35	91.94	95.60	92.07	91.63	91.19
2	2017	91.94	85.49	84.69	83.88	91.19	84.15	83.26	82.38
3	2018	87.81	78.24	77.03	75.82	86.78	76.21	74.89	73.57
4	2019	83.87	70.97	69.36	67.75	82.37	68.27	66.51	64.75
5	2020	79.84	63.71	61.69	59.68	77.96	60.33	58.13	55.93
6	2021	75.80	56.44	54.02	51.60	73.55	52.39	49.74	47.10
7	2022	71.77	49.18	46.36	43.54	69.14	44.46	41.37	38.28
8	2023	67.73	41.91	38.68	35.46	64.73	36.51	32.98	29.45
9	2024	63.69	34.64	31.01	27.37	60.31	28.56	24.59	20.62
10	2025	59.63	27.36	23.32	19.29	55.89	20.60	16.19	11.78
11	2026	55.60	20.08	15.64	11.20	51.47	12.65	7.79	2.94
12	2027	51.55	12.80	7.95	3.11	47.05	4.69	*failure*	*failure*
13	2028	47.51	5.51	*failure*	*failure*	42.62	*failure*		
14	2029	43.46	*failure*			38.20			
15	2030	39.41				33.77			
16	2031	35.35				29.34			
17	2032	31.30				24.91			
18	2033	27.24				20.48			
19	2034	23.19				16.04			
20	2035	19.13				11.60			

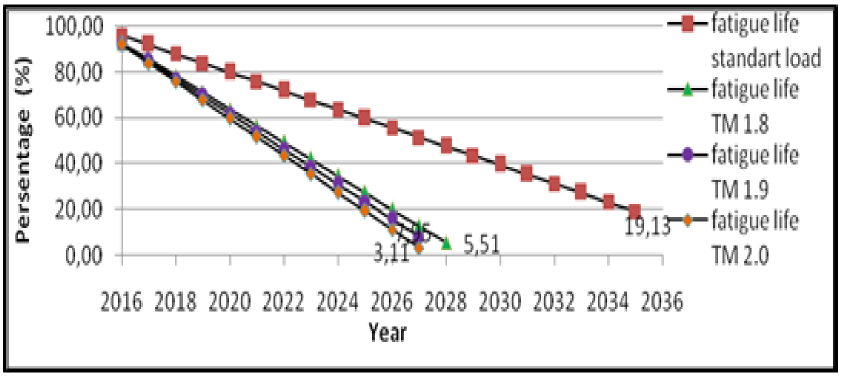

Figure 1. Analysis of the remaining service life of fatigue by TM factor

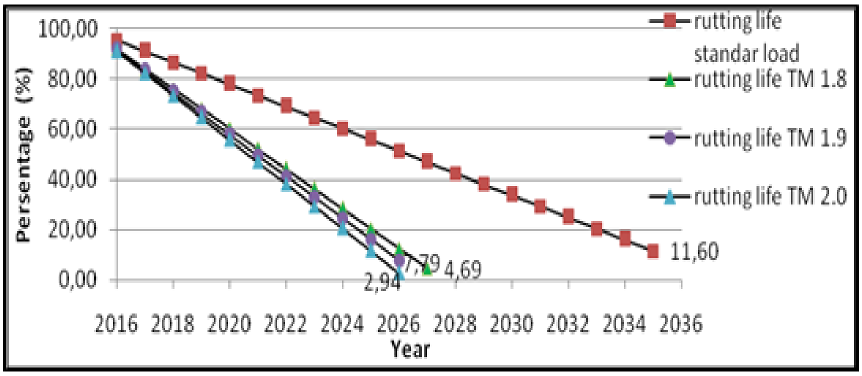

Figure 2. Analysis of the remaining service life due to rutting by TM factor

4. Conclusion

The result of running output obtained from Kenpave program in the form of horizontal tensile strain (ε_t) in the bottom of the asphalt layer was 8.802E-05 and vertical compressive strain (ε_c) on the surface of subgrade layer was 2.642E-04. Using the equation of fatigue and rutting obtained fromThe Asphalt Institute, it was obtained fatigue load repetition of 16.071.519 ESAL and *rutting* load repetition of 14.703.867 ESAL.

The result of CESA prediction estimate for 20 years with standard load of 8.16 Ton, it was obtained 12.997.574 ESAL value which was still in a safe condition under fatigue dan rutting load repetition value. If CESA prediction for 20 years times TM factor, it would result in load repetition of 23.395.635 ESAL (TM 1.8), 24.695.392 ESAL (TM 1.9) and 25.995.150 ESAL (TM 2.0) meaning that it went beyond fatigue dan rutting load repetition and therefore the pavement underwent failure condition.

The remaining fatigue service life in standard load in the end of year twentieth (2035) will remain 19.13 %, due to factor (TM 1.8) the remaining service life will remain 5.51 % in the 13th year (2028), due to factor (TM 1.9) the remaining service life will remain 7.95 % in the twelfth year (2027) and due to factor (TM 2.0) only remains 3.11 % in the twelfth year (2027). Meanwhile, the remaining rutting life service with standard load in the end of the twentieth year (2035) will remain 11.60 %, due to factor (TM 1.8) the service life only remains 4.69 % in the year twelfth (2027), due to factor (TM 1.9) the remaining service life only remains 7.79 % in the year eleventh (2026) and due to factor (TM 2.0) only remains 2.94 % in the eleventh year (2026) meaning that the damage due to rutting in the pavement will be reached first compared to the damage due to fatigue.

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