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

R S Usman¹, A Setyawan², M Suprapto²
¹Master Program of Civil Engineering, Universitas Sebelas Maret, Surakarta
²Civil Engineering Department, Universitas Sebelas Maret, Surakarta, Indonesia

E-mail: ramausman14@gmail.com

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 Institute it 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 13th (TM 1.8), 7.95% in the year of 12th (TM 1.9) and 3.11% (TM 2.0) in the year of 12th, also the remaining service life due to rutting of 4.69% in the year of 12th(TM 1.8), 7.79% in the year of 11th (TM 1.9), and 2.94 in the year of 11th (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 repetition 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 ($\varepsilon_t$) bottom of the asphalt layer as an indicator of fatigue cracking and vertical compressive strain value ($\varepsilon_c$) 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:

$$N_f = 0.0796(\varepsilon_t)^{-3.291}(E)^{-0.854}$$

with:

- $N_f$: the number of fatigue load repetition
- $\varepsilon_t$: 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:

$$N_d = 1.365 \times 10^{-9}(\varepsilon_c)^{-4.477}$$

with:

- $N_d$: the number of rutting load repetition
- $\varepsilon_c$: 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 Average 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:

$$ESAL = \Sigma\text{vehicle type ADT } x \text{ VDF } x \text{ DL}$$

$$CESA = ESA \times 365 \times R$$

with:

- $ESAL$: Equivalent Single Axle
- $CESA$: Cumulative Equivalent Single 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 ($N_f$) and rutting ($N_d$).

$$RL = 100 \left[1 - \left(\frac{N_p}{N_{1.5}}\right)\right]$$
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 (mm) | Typical Modulus (Mpa) | Poisson’s ratio |
|---------------------------|---------------|-----------------------|-----------------|
| 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 (\( \varepsilon_t \)) and vertical compressive strain (\( \varepsilon_c \)) 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                  | horizontal tensile strain(\( \varepsilon_t \)) | vertical compressive strain(\( \varepsilon_c \)) | 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 Trailer,| 1773 | 1.0  | 0.8 | 1385 |
| 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 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 7,008,803 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 |

4
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 | failure |
| 14 | 2029 | 43.46 | failure | failure | 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**
4. Conclusion

The result of running output obtained from Kenpave program in the form of horizontal tensile strain \( (\varepsilon_h) \) in the bottom of the asphalt layer was 8.802E-05 and vertical compressive strain \( (\varepsilon_v) \) on the surface of subgrade layer was 2.642E-04. Using the equation of fatigue and rutting obtained from the 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 year eleventh (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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