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The Effect of Traffic Volume on Remaining Service Life Based on Empirical Mechanistic Method

Dahlia, Arief Setiawan, Novita Pradani Tadulako
University, Indonesia
Email: lias.kaleleng@gmail.com, ariefsetiawan@untad.ac.id, novita@untad.ac.id

ABSTRACT

Hangtua Road in *Palu* City serves as a vital connector between the *Talise* and *Tondo* sub-districts, providing access to educational institutions, commercial areas, and residential zones. The road segment has shown visible structural damage at several points, raising concerns about its serviceability under increasing traffic demand. The problem addressed in this study is the decline in pavement performance, which threatens road safety and accessibility. The objective is to evaluate the stress and strain levels of the pavement, estimate its remaining service life, and propose appropriate maintenance solutions. A descriptive research method was employed, supported by field investigations. Primary data were collected from the Benkelman Beam (BB) deflection test and the Dynamic Cone Penetrometer (DCP) test for CBR values. The maximum deflection recorded was 0.325 mm at STA 0+500, while the minimum was 0.168 mm at STA 0+700. The analysis indicates that the existing pavement structure can continue to serve adequately if supported by routine maintenance. The recommended solution is the application of a non-structural overlay, which is expected to extend the pavement's service life by approximately 10 years while accommodating projected traffic growth. These findings provide practical guidance for local road authorities in planning cost-effective and sustainable maintenance strategies.

Keywords: *Benkelmem Beam, Kenpave-Kenlayer, Remaining Service Life, Pavement Maintenance*

INTRODUCTION

Road pavement, as a component of transportation infrastructure, functions, among other things, as a recipient of traffic loads transferred through vehicle wheels (Bozhi et al., 2023). Therefore, the pavement structure must have a high level of stability, be sturdy, and be resistant to environmental and weather influences throughout the road's design life (Sukirman, 2010). Road damage can be caused by four factors: construction materials, traffic, water, and climate. One factor influencing road damage is the increasing volume of traffic, which increases the load on the road (Department of Public Works, 1987). Recent studies confirm these causes: for example, an analysis in rural West Java found that roads are damaged largely due to poor drainage (water control) and heavy traffic loads, especially in mountainous terrain (Rachman, Rifai, Rijaluddin, & Prasetijo, 2025). Likewise, a systematic literature review shows that excessive axle loads and high vehicular traffic significantly accelerate pavement deterioration and reduce structural lifespan (IJTD International, 2023). Moreover, an assessment of pavement performance in flexible pavements shows that environmental factors alone (climate, subgrade moisture) contribute to a sizeable proportion of damage even under normal traffic (FHWA study, 2019). In another case, road sections in West Java using Pavement Condition Index (PCI) had most segments categorized as "poor to failed" due to persistent heavy vehicle loads and environmental stressors (Taufik, Suparman, Kosasih, Farhan, & Hariani, 2025). Finally, research on pavement durability under combined effects of heavy traffic and aggressive weather (e.g., heat, moisture) confirms that both load-related fatigue and environmental exposure jointly drive distress mechanisms like cracking, rutting, and deformation (Vikram & Harish Kumar, 2025).

The increasing population will result in an increase in traffic volume (LHR), which will affect the remaining life of the road (Arbani, 2018). The increase in traffic volume of two-wheeled, four-wheeled, or more vehicles can affect the condition of the road pavement, causing damage at several points, making the movement of goods, services, and people uncomfortable and reducing the road's design life. Recent empirical studies in Indonesia show that vehicle overloading and increasing average daily traffic accelerate pavement deterioration, leading to remaining life reduction by up to 30 % in sections exposed to constant heavy load traffic (Nurhidayat & Kamarudin, 2024; Rachman, Rifai, Rijaluddin, & Prasetijo, 2025). Also, thin flexible pavements under frequent heavy vehicle passages show premature cracking and rutting, especially in tropical climates where moisture interacts with load stress (Saliko et al., 2021). Research using mechanistic–empirical pavement design in Indonesia indicates that traffic growth factors above 4-5 % annually can significantly shorten pavement service life if not matched by thickness/design improvements (Implementation of Mechanistic-Empirical Pavement Design, 2022). Moreover, a simple pavement life model considering traffic wander demonstrates that uneven distribution of traffic loads also compounds damage, further reducing life expectancy especially in roads with thinner base or subgrade strength (Gajewska et al 2025).

MDP 2024 uses an empirical mechanistic approach to flexible pavement design, producing a structural catalog as its output. Rigid pavement design in MDP 2024 uses the empirical mechanistic method developed by the Portland Cement Association. In rigid pavement design, structural analysis of the pavement using software such as SDPJ (Road Pavement Design Software) is recommended, with the addition of rehabilitation design. MDP 2024 aims to define pavement design and implementation parameters and establish procedures for designing new and rehabilitated pavement structures for both flexible and rigid pavements to ensure they meet their specified service lives. Recent studies applying mechanistic-empirical design (e.g. MEPDG / AASHTO Pavement ME Design) in Indonesia have shown that local calibration (traffic, climate, material) significantly alters required overlay thickness for flexible pavements and improves prediction of IRI and cracking distress (Subagio, Dwi, & Wijaya, 2022). In rigid pavement, research on enhanced concrete models (slab-base interaction, faulting, slab curling) in the Pavement ME Design software highlights that empirical/mechanistic rigid design methods like PCA models benefit from updated transfer functions calibrated from long term performance data (Saha, Gu, Luo, & Lytton, 2021). Further, fatigue-life modelling of concrete rigid pavements under combined vehicular and environmental loading (as in RCC pavements) using M-E approach presents more accurate structural thickness designs than older purely empirical approaches (Wu, Mahdi, & Louisiana Transportation Research Center, 2022). Studies in Saudi Arabia using MEPDG showed that for regions with extreme heat and rainfall, rigid pavement designs needed modification to meet service life under both cracking and joint faulting criteria (Fuhaid, Alnaqbi, et al., 2022). Also, flexible pavement studies demonstrate that parameters such as aggregate gradation, asphalt dynamic modulus, and climatic inputs are critical to achieving required performance in rutting, fatigue, and roughness (Shakhan,. et al 2022). Finally, sensitivity analyses of the latest Pavement ME software indicate that base/subbase stiffness, traffic spectral loading (truck distributions), and slab bond/separation conditions heavily influence outputs of rigid pavement design and rehabilitation needs (AASHTO Task Force, 2022).

Hangtua Street in *Palu* City is one of the roads connecting *Talise* and *Tondo* Villages, linking East *Palu* and North *Palu*. Vehicles passing through this section vary in size and land use, including the *UNISMUH* campus, food stalls, shops, and access to the *Sutan Raja Villa*. Several areas of damage, such as potholes, can affect the remaining service life of the road. Therefore, this study aims to determine the extent of the remaining service life of the road due to increased traffic volume using empirical mechanical methods.

Previous studies on pavement performance have highlighted the importance of evaluating structural capacity and service life, yet most are limited in scope and methodology. Arbani (2018) examined the relationship between increasing traffic volume and road service life, finding that higher traffic load significantly accelerates pavement deterioration; however, the study relied primarily on traffic count data and did not incorporate mechanistic analysis to predict remaining service life. Similarly, Juwono and Subagiyo (2018) analyzed the performance of irrigation-related road infrastructure and emphasized the role of environmental and material factors in pavement damage, but their focus was not on urban arterial roads experiencing high mixed traffic such as *Hangtua* Street in *Palu* City.

The objective is to provide an accurate assessment of pavement condition under increased traffic loads, while the benefits lie in enriching civil engineering literature on pavement design and offering practical recommendations for road maintenance planning and budget allocation in *Palu* City.

RESEARCH METHOD

A descriptive research method was employed, supported by field investigations. The research location was *Hangtua* Street in *Palu* City, a road connecting *Talise* and *Tondo* sub-districts and linking East *Palu* and North *Palu*. The research period was approximately one month. The population in this study was the *Hangtua* Road section, which has fairly heavy traffic volume. The samples to be studied were the flexible pavement deflection values, measured using a BB tool for the *Hangtua* Road section, STA 0+400 to STA 0+900. Subgrade CBR data were collected in the field using a Dynamic Cone Penetrometer (DCP) on the *Hangtua* Road section, using three test samples.

Data collection techniques, namely primary data and secondary data, are presented in the following table.

Table 1. data collection techniques

No.	Data Type	Data Collection Sources
1.	Road Segment Data	Secondary data in the form of road section data and existing pavement layer thickness comes from the Palu City Public Works Department.
2.	LHR data	LHR primary data was obtained by means of a field survey on June 13, 2025
3.	Elastic Modulus Value	
	1. *Surface*	Primary data comes from BB testing
	2. Top Foundation Layer	Secondary data in the form of existing pavement layer thickness data comes from the Palu City Public Works Department.
	3. Sub-base Layer	Secondary data in the form of existing pavement layer thickness data comes from the Palu City Public Works Department.
	4. *Subgrade*	Primary data comes from direct DCP testing in the field.

RESULT AND DISCUSSION

Data Analysis of Empirical Mechanistic Method with Kenpave-Kenlayer

Deflection Data Analysis

The research location is on Jalan Hangtuah, where deflection results were analyzed. The deflection used in this calculation is the back deflection obtained from testing using a Benkelman Beam. This deflection value must be corrected for the groundwater level (seasonal factor), temperature correction, and load correction (if the test load is incorrect, it is 8.16 tons). The back deflection value is calculated according to the formula in equation 2.1.

The recapitulation of the calculation of the back deflection value on the Hangtuah Road pavement using the Benkelmen Beam (BB) tool can be seen in Table 1, so it needs to be presented in the form of graphical information which can be seen in Figure 1.

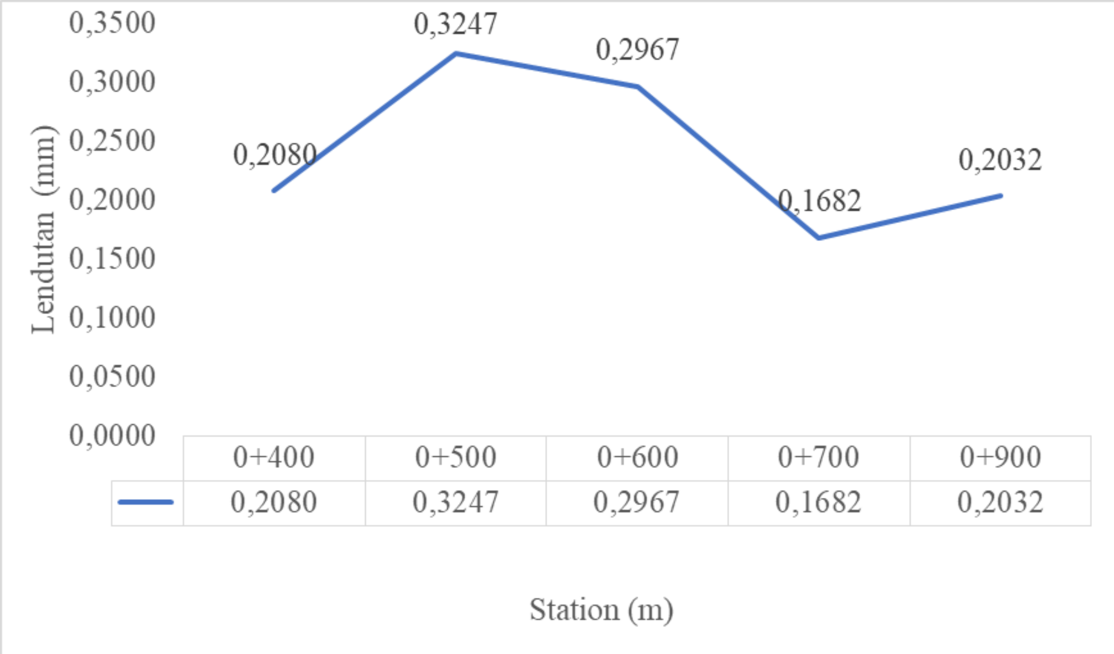

Figure 1. Variation in deflection values on Hangtuah Road

Traffic Data Analysis

Vehicle distribution and average daily traffic volume (ADR) on Hangtuah Road are presented in Table 2.

Table 2. Projection of average traffic volume (LHR) on Jalan Hangtuah

Vehicle Type	Vehicle Class	LHR 2025	LHR in 2035
Motor	1	23218	36929
private vehicles, public transportation	2	8830	14044
Small Bus	5A	63	32100
Big Bus	5B	20	32
2 Axle Truck (4 Wheels)	6A	880	1400
2 Axle Truck (6 Wheels)	6B	436	693
3 axle truck	7A	4	6

In Table 2 above, the traffic volume projection for the next 10 years, based on the pavement's design life, is calculated using equation 2.2, based on field survey results. Therefore, the traffic growth rate over a 10-year service life is 10.02%. The calculated traffic growth factor (R) over the 10-year design life is presented in Table 3.

Table 3. R-Value over the Design Life

No.	Year	R
1	2025	1
2	2035	10.02

Analysis of Subgrade Test Results

Subgrade testing using a Dynamic Cone Penetrometer (DCP) was conducted to determine the CBR (%) value on the Hangtuah Road section. The DCP testing process, conducted in the field during the rainy season, involved three test points. The three DCP test points were based on existing conditions, which were reviewed for cracking and grain separation. During the DCP testing, a 50 cm depth of soil was excavated to obtain the subgrade CBR value. As the test was conducted during the rainy season, the minimum adjustment factor for the CBR value based on the DCP test was 0.9. To obtain the seasonally corrected CBR value, the CBR value was multiplied by the adjustment factor.

Analysis of Existing Pavement Thickness Using the Empirical Mechanistic Method (Kenpave-Kenlayer) Calculation of Modulus Value of Elasticity

Calculation of the modulus of elasticity (E) of road pavement, the basic assumption used is that the pavement is considered as a homogeneous layer, has elastic properties (Boussinesq, 1885) and the E value obtained is the composite E value of a road pavement. It has been explained in the previous chapter that the value of E can be found using Equation 2.4. It should be explained here that the elastic formula (Equation 2.4) assumes the E value is constant, while in reality in the field the relationship between stress vs strain (σ vs ε) is not linear and the E value changes with the value of σ, time and also the condition of the soil under the road pavement structure layer.

Assuming that the vehicle wheel load received by the pavement is almost the same as the load that occurs on an elastic plate with a radius a and a uniform load pressure q (Huang, 2004), then the magnitude of the vertical strain that occurs due to the vehicle load received by the pavement can be calculated using Equation 2.6.

Based on the equation above, the data needed to calculate the Modulus of Elasticity (E) value includes the deflection value (d), tire pressure (q), and vehicle axle load (p). An example calculation to obtain the E value based on the FWD tool at point 1 in the normal direction of Tawaeli-Pantoloan is as follows:
Vehicle axle type: Single Axle Dual Wheels (SADW)
SADW axle load: 8.16 tons or 8160 kg
Tire pressure (q): 82.12 psi (5.77 kg/cm2)
Deflection value (d): 0.2375 mm or 0.02375 cmPoisson ratio (μ) : 0,40 (bending road pavement)

Load per wheel (p) : $\frac{Beban\ as\ kendaraan}{Jumlah\ roda\ as\ SAWD} = \frac{8160}{4} = 2040$ kg

Tire contact patch radius (a) : $\sqrt{\frac{p}{\pi q}} = \sqrt{\frac{2040}{3,14*5,77}}$ =10,62 cm

So that;

$$E_1 = \frac{(1+\mu)qa}{d}\left\{\frac{a}{(a^2+z^2)^{\ 0,5}} + \frac{1+2\mu}{a}\ [(a^2+z^2)^{\ 0,5} - z]\right\}$$

$$= \frac{(1+0,4)\ 5,77*10,62}{0.2080}\left\{\frac{10,62}{(10,62^2+4^2)^{\ 0,5}} + \frac{1+2*0,4}{10,62}\ [(10,62^2+4^2)^{\ 0,5} - 4]\right\}$$

$$= \frac{85,70758}{0,2080}\left\{\frac{10,62}{11,34832} + \frac{1,8}{10,62}\ [11,34832 - 4]\right\}$$

$$= 412.444 * \{(0,936 + 0,170) * [7,349]\}$$

$$= 412.44 * \{1,106 * 7,349\}$$

$$= 412.444 * \{8,128\}$$

$$= 3352.345\ kg/cm^2$$

The results of the calculation of the modulus of elasticity at depths of Z1, Z2, Z3, and Z4 are 6, 6, 15, and 20 cm respectively according to Table 4.12. The data of the calculation results of the modulus of elasticity (E) can be seen in Appendix A page I. The smallest deflection value on the Hangtuah Road section is in the STA 0+700 segment and the largest in the STA 0+500 segment. From Table 4.12, the value of the modulus of elasticity of the pavement is obtained. The value of the modulus of elasticity for the maximum deflection and minimum deflection of the Hangtuah Road section with each into Z1, Z2, Z3, and Z4 can be seen in Table 4.13. The maximum and minimum modulus of elasticity (E) values on the thickness of the pavement layer are input data in the kenpave – kenlayer program.

Determining the Critical Point of the Pavement Layer

The existing pavement thickness data obtained from the Palu City Public Works Agency will then be evaluated using the Kenpave-Kenlayer program to identify the critical point of the pavement layer, which will then be used to analyze the remaining service life of the Hangtuah Road pavement.

Analysis Data

Single Axle Dual Wheel (SADW) Axle Load

In this analysis, the axle load value is taken based on load conditions used in Indonesia according to Silvia Sukirman (1999), as follows:

1) The standard axle load for a vehicle is 18,000 pounds or 8.16 tons.
2) The tire pressure for one tire is 0.55 kg/cm2 = 0.55 MPa.
3) The contact radius is 11 cm.
4) The distance between each axle of the dual wheel is 33 cm.

Parameters for each pavement layer

In this analysis, the surface layer of the pavement uses a viscoelastic material. However, the calculations are based on a linear elastic layered system. The foundation and subgrade layers are assumed to still use linear elastic materials. Therefore, the calculations only use the elastic modulus parameters obtained from deflection testing.

Analysis results with standard tire pressure values

Table 4. Results of analysis of existing pavement with Kenlayer δMax STA 0+500 with standard load on Jalan Hangtuah

Point No	*Vertical Coordinate*	*Vertical Strain $\mathcal{E}_C$*	*Minor Stress Strain $\mathcal{E}_t$*
1	0	-3,68E-05	-3,68E-05
	0,001	-3,68E-05	-3,68E-05
	11,999	2,36E-04	-1,45E-04
	12	2,36E-04	-1,45E-04
	47	1,49E-04	-1,09E-04
	47,001	2,14E-04	-1,09E-04
2	0	-1,87E-05	-1,87E-05
	0,001	-1,86E-05	-1,86E-05
	11,999	1,41E-04	-1,34E-04
	12	1,41E-04	-1,34E-04
	47	1,62E-04	-1,15E-04
	47,001	2,32E-04	-1,15E-04
3	0	-1,02E-04	-1,02E-04
	0,001	-1,02E-04	-1,02E-04
	11,999	7,97E-05	-1,23E-04
	12	7,97E-05	-1,23E-04
	47	1,64E-04	-1,17E-04
	47,001	2,35E-04	-1,17E-04

Table 5. Results of existing pavement with kenlayer dmin at STA 0+700 with standard load on Jalan Hangtuah

Point No	*Vertical Coordinate*	*Vertical Strain $\mathcal{E}_C$*	*Minor Stress Strain $\mathcal{E}_t$*
1	0	-3,02E-05	-3,02E-05
	0,001	-3,02E-05	-3,02E-05
	11,999	1,20E-04	-7,39E-05
	12	1,20E-04	-7,39E-05
	47	9,02E-05	-7,67E-05
	47,001	1,53E-04	-7,67E-05
2	0	-2,14E-05	-2,14E-05
	0,001	-2,13E-05	-2,13E-05
	11,999	7,09E-05	-6,84E-05
	12	7,09E-05	-6,84E-05
	47	9,73E-05	-8,08E-05
	47,001	1,65E-04	-8,08E-05
3	0	-6,44E-05	-6,44E-05
	0,001	-6,44E-05	-6,44E-05
	11,999	3,93E-05	-6,27E-05
	12	3,93E-05	-6,27E-05
	47	9,85E-05	-8,16E-05
	47,001	1,67E-04	-8,16E-05

Table 6. Results of calculating the remaining service life of the pavement

Year to	NP (CESA5)(ESAL)	N1.5			Remaining Service Life		
		Repetitive load fatigue (ESAL)	***Load repetition of Rutting (ESAL)***	***Reduced Load Deformation (ESAL)***	***Fatigue* (%)**	***Rutting* (%)**	***Warp* (%)**
1	219438,00	250.298.730,21	23.727.613,27	24.045.545,32	99,91	99,08	99,09
2	457272,00	250.298.730,21	23.727.613,27	24.045.545,32	99,82	98,07	98,09
3	733034,48	250.298.730,21	23.727.613,27	24.045.545,32	99,71	96,91	96,95
4	1042131,02	250.298.730,21	23.727.613,27	24.045.545,32	99,58	95,61	95,66
5	1326740,54	250.298.730,21	23.727.613,27	24.045.545,32	99,47	94,41	94,48
6	1659536,81	250.298.730,21	23.727.613,27	24.045.545,32	99,34	93	93,09
7	2061657,82	250.298.730,21	23.727.613,27	24.045.545,32	99,18	91,31	91,43
8	2453760,97	250.298.730,21	23.727.613,27	24.045.545,32	99,02	89,66	89,79
9	2877206,82	250.298.730,21	23.727.613,27	24.045.545,32	98,85	87,87	88,03
10	3333116,93	250.298.730,21	23.727.613,27	24.045.545,32	98,67	85,95	86,14

Based on the analysis of existing layer data on the Hangtuah Road section using the empirical mechanistic method with the Kenpave-Kenlayer program, it is seen that the pavement is able to accept repetitive loads of 24,045,545.32 ESAL until permanent deformation occurs, 23,727,613.27 ESAL until repetitive routine loads occur and 250,298,730.21 ESAL until repetitive fatigue loads occur. on the existing pavement, it is known that the pavement layer is able to accommodate loads up to the 10th year with a remaining service life for permanent deformation of 86.14%, routine of 85.95% and fatigue cracking of 98.67%.

Based on the analysis data of the increase in traffic volume of 100%, 150% and 200%, the remaining service life due to deformation at the standard load in the 1st year of 98.17%, 98.16% and 98.15% is still able to accept the traffic load and in the 10th year the repetition due to deformation with the addition of traffic volume of 100%, 150% and 200% is 70.89%, 70.68%, 70.48% which means that the road pavement is still able to accommodate the repetition of the load against permanent deformation until the 7th year.

Determination of the thickness of the pavement layer

Traffic Conditions

Traffic data on Hangtuah Street is secondary data obtained from the Palu City Public Works Department. The traffic data for Hangtuah Street is shown in Table 4.29.

Table 7. Traffic Data for Hangtuah Street

No.	Data	Information
1.	Road Type	Secondary Collector
2.	Planned Age	10 years (2025 – 2035)
3.	Traffic growth (i) %	4,75 %
4.	Vehicle distribution	1 lane 2 directions

Traffic Analysis

Vehicle distribution and average daily traffic volume (LHR) on Hangtua Road are presented in Table 8.

Table 8. Projected average traffic volume (LHR) of Hangtua Road

Vehicle Type	LHR 2025	LHR 2026	LHR 2027	LHR 2028	LHR 2029	LHR 2035
(1)	*(2)*	*(3)*	*(4)*	*5*	*6*	*7*
1	23.218	24321	25476	26686	27954	36929
2,3,4	8.830	9249	9689	10149	10631	14044
5A	63	66	69	72	76	100
5B	20	21	22	23	24	32
6A	880	922	966	1011	1059	1400
6B	436	457	478	501	525	693
7A2	4	4	4	5	5	6
Amount	33.451	35040	36704	38448	40274	53205

So the calculation of the planned prediction of the number of vehicles each year in a 10 (ten) year period can be seen in Table 9 as follows:

Table 9. Annual LHR Number

No	Year	Number of vehicles
1	2026	35040
2	2027	36704
3	2028	38448
4	2029	40274
5	2030	42187
6	2031	44191
7	2032	46290
8	2033	48489
9	2034	50792
10	2035	53205

Handling Trigger Analysis

In analyzing the handling triggers, the Dwakil BB deflection at STA 0+400 and up to STA 0+900 on Jalan Hangtuah was used. The calculation steps are as follows:

1. Calculate the characteristic deflection curve based on testing with a Benkelmen Beam on Jalan Hangtua. This can be seen in Table 4.1.
2. Calculate the standard deviation (s).

$$s = \sqrt{\frac{(5*0.5446)-(1.6012)^2}{5(5-1)}}$$

$$= 0.0891$$

3. Calculate the average BB deflection (dr)
   The dr calculation uses the following equation:

$$d_r = \frac{1.6012}{5}$$

$$= 320\ \mu m$$

4. Calculating the representative deflection (DWakil)
   The calculation of the representative deflection (DWakil) uses the following equation:

$$D_{Wakil} = d_r + (1.28*s)$$
$$= 320.2 + (1.28 * 0.089)$$
$$= 320.31\ \mu m$$
$$= 0.320\ mm$$

The results of the Dwakil deflection calculation analysis can be compared with the trigger deflection table for selecting the type of treatment (Appendix K page XI) on the overlay and reconstruction layers with the calculated CESA value of 3,354,798.45 ESAL. The results of the analysis show that the deflection on the Benkelmen Beam pavement layer is able to accommodate a permanent deformation repetition load of 24,045,545.32 ESAL up to the design life of 10 years of 86.05%. And the selection of the type of non-structural overlay treatment. For the thickness of the non-structural added layer based on the Director General of Highways in 2024.

CONCLUSION

Analysis of the Benkelman Beam test data yielded a maximum deflection value of 0.325 mm at STA 0+500 and a minimum deflection value of 0.168 mm at STA 0+700. The remaining service life analysis of the *Hangtua* Road pavement, based on the standard load repetition analysis at maximum deflection, indicates 98.66% fatigue cracking and 85.86% rutting in the 10th year, indicating that the pavement is still capable of handling fatigue cracking and rutting loads. With increased traffic volumes of 100%, 150%, and 200%, permanent deformation loads are 70.89%, 70.68%, and 70.48%, respectively. This analysis indicates that the *Hangtua* Road pavement is still capable of serving traffic loads until the 7th year of its 10-year design life. After analyzing the standard load on *Jalan Hangtua*, based on the results of the deflection test using the Benkelman Beam tool, the recommended pavement layer treatment is a non-structural overlay with a thickness of 40-50 mm based on the Director General of Highways, 2024.

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