RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES

Social Science Journal

Strength Comparison of Flexible Pavement Structures by Road Pavement 2017 Manual Design at Trans-South Road LOT 7

By

Machsus*
Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

Zidan Maulidani Kurniawan
Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

Amalia Firdaus Mawardi
Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

Achmad Faiz Hadi Prajitno
Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

Rachmad Basuki
Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

Mohamad Khoiri
Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

Abstract

The pavement structure plays a crucial role in road construction. Road pavement structure planning consists of various methods. Even one planning method can provide more than one design. Further analysis is needed to obtain the optimal design. This study comparation between the strength of the road pavement design results based on the Road Pavement 2017 Manual Design. By carrying out a case study on Trans-South Road LOT 7 in Indonesia, seven pavement designs were obtained, consisting of five designs using a cement treated base course and two designs using A Class aggregate type of base course. The strength between designs was calculated by using KENPAVE to obtain stress and strain at the critical point, which will be converted into the ESAL unit to determine the pavement design's ability to withstand vehicle loads against three types of damage: fatigue cracking, rutting, and permanent deformation. The results of the analysis show that the pavement design using A class aggregate type base has a higher thickness and strength than the cement treated base. The pavement design-2 exceeds the design load for the three types of damage during the service life with a pavement thickness of 4 cm AC-WC, 6 cm AC-BC, 17 cm AC base, and 40 cm A class aggregate type base. Meanwhile, other pavement designs are expected to fail due to rutting and/or permanent deformation before the end of the service period. For fatigue cracking resistance, all designs give satisfactory results.

Keywords: road pavement 2017 manual design, strength, kenpave.

Introduction

The number of motorized vehicles in Indonesia continues to increase every year. As reported by the latest data from the Central Bureau of Statistics Indonesia, the average increase in the number of motorized vehicles from 2015 to 2019 was 5.77% [1]. This is not balanced by the fact that road segments grew by only 0.71% in the same year period [2]. As a result, there is a potential for congestion on certain road sections due to road capacity that continues to decrease [3]. To overcome this, the government, through the Ministry of Public Works and Public Housing of the Republic of Indonesia, is committed to continuing to build infrastructure to support community mobility. One manifestation of the government's commitment is the construction of a new national access road in the form of the Trans-South Road, namely the JLS Project along the southern coast of Java to reduce road congestion while increasing the economy of the southern region of Java. One of the series of JLS projects is the construction of JLS LOT 7, which is located in Kabupaten Blitar. For the first stage, this road will connect Desa Tambakrejo, Kecamatan Wonotirto, with Desa Serang, Kecamatan Panggungrejo.

Along with the development of science and technology, the stages of planning, implementation, and road maintenance are expected to be designed to produce a road that is durable and long-lasting. In road construction, the durability of the road structure is highly dependent on the design of the pavement structure. The type of pavement and the planning method greatly influence the design of the pavement structure. The JLS LOT 7 project uses flexible pavement types, which are more prone to damage than rigid pavements. Therefore, it is necessary to design a mature road pavement structure in accordance with applicable rules and requirements with strict control over implementation in the field.

In designing road pavement structures, there are two general methods developed, namely empirical and mechanistic-empirical. The empirical method is a method that uses an empirical approach obtained from previous experience and research and is designed using equations, tables, graphs, and images to assess the performance of flexible pavements [4]. The mechanistic-empirical method is the development of an empirical method that adds and/or replaces road pavement design procedures in accordance with the concept of material mechanics that affect road pavement performance such as wheel loads, pavement response to loads, namely stresses and strains that occur in each layer because it has a different material [5]. The advantages of the mechanistic-empirical design method, such as:

1) It can be used to design new roads as well as evaluate and repair existing ones.
2) Used analytically to evaluate the effects of changes or variations in vehicle load on pavement performance.
3) Pavement performance with new materials can be evaluated based on its mechanical properties.
4) Used to analyze the effects of changes in material properties due to the environment and climate on pavement performance.
5) Evaluate pavement response related to specific pavement damage modes, namely fatigue cracking and permanent deformation.
6) It can analyze the influence of changes in design data input, such as changes in materials and traffic loads, quickly and rationally.

In the design procedure of the empirical mechanistic method, calculations are carried out based on the analysis of multilayer elastic systems. This concept was first proposed by Yodder and Witczak in 1975 [6]. A multilayer elastic system will model a pavement structure by dividing it based on the constituent material. The calculation is carried out by taking into account the following points:

1) The material properties of each layer will be considered to be isotropic, homogeneous, and linearly elastic.
2) Each layer has a certain thickness but an unlimited horizontal length, except for the subgrade layer, which has no thickness limit.
3) Mutual friction between layers of pavement.
4) The repetition of loading can be assumed to be the sum of individual loads or can use standard axle loads.

This analysis was developed by Kerkhoven and Dormon in the book Pavement Analysis Design [6], which suggested the use of the vertical compressive strain value (ε_C) at the subgrade or subgrade as one of the failure criteria for control for the occurrence of permanent deformation and rutting in the base layer. Saal and Pell in the same book recommend the use of horizontal tensile strain values (ε_t) under the asphalt layer for control of fatigue cracking.

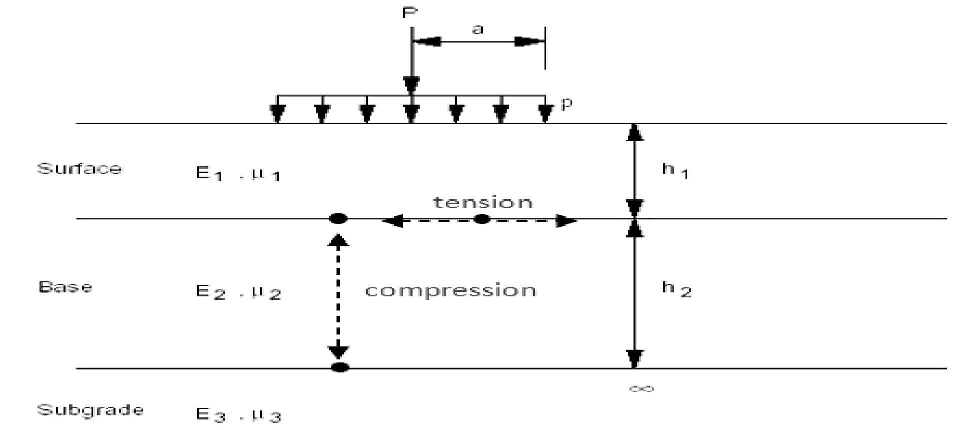

Figure Error! No text of specified style in document.**.1** *Multilayer Elastic System Concept*

The strain value at the critical point of each pavement layer point review is converted into esal load units using The Asphalt Institute's equation. Equation (1) is used to calculate fatigue cracking damage, namely damage in the form of cracks that connect randomly to form small pieces on the road structure due to vehicle loading [7]. Equation (2) for calculating rutting damage and permanent deformation in the form of deformation damage to the road pavement structure caused by the passing wheels' repetitive action [8].

$$Nf = 0{,}0796(\varepsilon_t)^{-3{,}921}|E|^{-0{,}854} \quad (1)$$

with Nf = the maximum number of load repetitions before fatigue cracking
ε_t = tensile strength at the critical point (below surface course)
$|E|$ = surface course modulus of elasticity

$$Nd = f_4(\varepsilon_c)^{-f_5}$$

(Error! No text of specified style in document.)

with Nd = the maximum number of load repetitions before rutting
ε_c = vertical compressive strain above the base course
f_5 = coefficient of permanent deformation criteria is 4.477
f_4 = coefficient of permanent deformation criteria is $1{,}365 \times 10^{-9}$

This study redesigned the pavement structure using the Road Pavement 2017 Manual Design (MDPJ 2017) [9] and the Road Pavement 2020 Supplement Manual Design [10] and then compared the alternative designs in terms of strength using the KENPAVE software through mechanistic-empirical principles. KENPAVE is an auxiliary software for designing road pavement plans, designed by Dr. Yang H. Huang, P.E., a professor of civil engineering at the University of Kentucky. This software uses the mechanical-empirical method to design pavement structures and can create flexible and rigid pavements while also estimating the pavement's design strength. Users only need to input the required data, in the form of pavement material characteristics such as Poisson ratio, modulus, wheel load, wheel pressure, and depth coordinates for stress and strain calculations at the desired position [11]. The reason for using the 2017 MDPJ as a design reference for alternative pavement designs is because, based on the results of several comparative studies of several pavement design methods, the 2017 MDPJ was chosen as the optimal design [12]–[14]. Meanwhile, the reason for choosing Kenpave software is that it is a finite element tool for easy, popular, and credible pavement design [15]. According to Mishra & Patel, this software is materialistic-based and capable of calculating various models with various material characteristics. There is a detailed traffic load characterization in terms of amount and speed, able to check up to 19 layers, and users can define 235 criteria parameters [16].

The problems that need to be raised in this study include knowing alternative pavement designs based on pavement design references that apply in Indonesia and knowing the strength of each available pavement design alternative. The limitation of this study is that this study does not discuss earthworks and uses standard non-over-dimensional over-loading traffic load calculations and strength calculations based on the results of kenpave software analysis.

Method

1.1 Literature Study

The literature study is taken from the opinions of experts adapted from books, journals, notes, and other credible literature sources and recognized for their validity and applicable regulations. This study conducted a literature study related to flexible pavement design using the MDPJ 2017 method and kenpave software.

1.2 Collecting Data

This study uses secondary data obtained from the contractor implementing the JLS LOT 7 project, namely PT. Pembangunan Perumahan (PP) Tbk for the DCP test result document [17]. Balai Besar Pelaksanaan Jalan Nasional Jawa Timur – Bali for vehicle traffic survey documents [18]. Because new road construction projects do not yet have average daily traffic statistics, data processing is necessary in order to obtain the actual average daily traffic approach. This is performed by carrying out a trip assignment [19]. The value of the material characteristics is obtained from the Road Pavement 2017 Manual Design [9]. Meanwhile, for vehicle load modeling data such as weight, pressure, tire contact area and type of vehicle axle, the standard Indonesian load is used in the form of a single-wheel double-axle vehicle with the heaviest axle load of 8 tons [20].

1.3 Modeling

The Bina Marga 2017 Road Pavement Design Manual and its 2020 supplement are followed during the calculation stages of constructing alternative pavement systems. The results of the overall design calculations will be modeled in order to determine each design's pavement strength.

The kenpave software and the kenlayer subprogram for analysis of flexible pavement design strength are used in the modeling of each alternative pavement design to obtain the output in the form of critical stress and strain values for fatigue cracking, rutting, and permanent deformation. When modeling, design parameters are entered in accordance with secondary data collected from various sources.

1.4 Analysis

Analysis of pavement design strength calculations refers to the output of kenpave software in the form of stress and strain values at critical points for the three types of road damage. The stress and strain values in kPa units will be converted into resistance loads with the original units for comparison with the design load. The conversion was carried out using equations from The Asphalt Institute. Analysis and comparison of each pavement design are carried out for the three types of damage.

1.5 Conclusion

Conclusions and suggestions are the final output of the research which contains answers to the problems. Conclusions are scientific in nature, so they can be used as a reference for readers according to the purpose of this research. Suggestions can be used as input to readers or related parties to continue or continue the review aspect in similar research.

Result and Discussion

1.6 Alternative Pavement Design

The alternative pavement design is obtained based on the MDPJ 2017 Manual Book with the following calculation steps:

1) Determine the flexible pavement's lifetime at 20 years.
2) Determine the average daily traffic design for the life of the road pavement plan based on the nearest and most recent average daily traffic data for similar roads. This data must be processed by taking into account the vehicle growth factor for primary arterial roads in Java of 4.8%, the traffic growth multiplier factor for 20 years is 20.091 and trip assignment based on the smock method is 62%.

Figure Error! No text of specified style in document.**.2** *Correlation of Project Road Section (Blue) with Data Collection Road Section Location (Yellow)*

Table Error! No text of specified style in document.**.1** *Average Daily Traffic Vehicle (vehicle/day)*

Vehicle Class	Average Daily Traffic Data	Average Daily Traffic Design
1	18879	12856
2	4475	3047
3	199	135
4	1310	892
5a	0	0
5b	27	18
6a	12	8
6b	1583	1078
7a	238	94
7b	292	199
7c	33	22

3) Set the value of influencing factors for planning structural pavement design, such as the direction distribution factor of 0.5 for 2/2 UD roads, the condition of balanced commercial vehicles in each direction, and the distribution factor of commercial vehicle lanes of 1 for one lane per lane. As for the VDF value of each vehicle class, it is shown in Table Error! No text of specified style in document.**.2**.

4) Calculating CESA (Cumulative Equivalent Standard Axles) according to design life and design traffic as pavement load.

Table Error! No text of specified style in document.**.2** *Calculation CESA Loads*

Vehicle Class	Average Daily Traffic (Vehicle/Day)	VDF_4	VDF_5	ESA_4 (10^6 esal)	ESA_5 (10^6 esal)
1	12856	0	0	0	0
2	3047	0	0	0	0
3	135	0	0	0	0
4	892	0	0	0	0
5a	0	0,3	0,2	0	0
5b	18	1,0	1,0	0,06	0,06

6a	8	0,55	0,5	0,02	0,02
6b	1078	4,0	5,1	15,81	15,81
7a	94	4,7	6,4	1,61	2,20
7b	199	12,6	17,8	9,17	12,96
7c	22	7,6	10,2	0,61	0,82
	Cumulative			27,28	36,20

5) Set the type of structure and pavement layer material based on the ability of the construction service provider. For the calculation results of $CESA_4$ 20 years interval >10–30 million esal, pavement types are used in the form of: rigid pavement for heavy traffic, modified AC-WC, AC with CTB, and thick AC > 100 mm with a grained foundation layer.

6) Obtain the pavement design after determining the thickness of each layer of pavement according to the design chart for the $CESA_5$ value in 20 years (Nr), which is shown in Table Error! No text of specified style in document.**.3**. For the CESA5 range of >30–50 million esal, the Road Pavement 2017 Manual Design provides 7 alternative pavement designs with various thicknesses for each layer of the structure.

Table Error! No text of specified style in document.**.3** *Layer Thickness Pavement Design*

Lapisan	A	B	C	D	E	1	2
AC WC	4	4	4	4	4	4	4
AC BC	6	6	12	10	9	6	6
AC Base	10	8,5	-	-	-	17,5	17
CTB	15	15	20	25	30	-	-
LPA Kelas A	15	15	15	15	15	30	40
Total	50	48,5	51	54	58	57,5	67

A visualization of the pavement structure with alternative design-A is given based on the results of the calculation of the pavement design based on the MDPJ 2017.

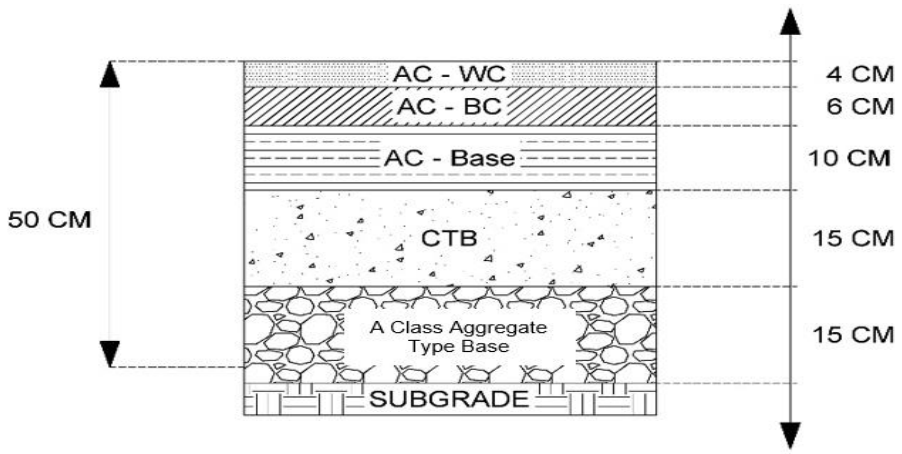

Figure Error! No text of specified style in document.**.3** *Alternative-A Pavement Design*

1.7 Strength Pavement Analysis

The calculation of the strength between alternative pavement designs is carried out using the KENPAVE software to obtain the output stress and strain values at the critical point of each pavement layer. To get it, it is necessary to prepare input data consisting of modulus of elasticity, poisson ratio, and thickness of each type of pavement material available in the Road

Pavement 2017 Manual Design. Indonesian standard axle data is required for vehicle load modeling. For this research, the standard axle load is single axle, double wheel, with the heaviest axle load of 8 tons.

Table Error! No text of specified style in document.**.4** *Characteristic Material Parameter Input*

Course Type	Thickness (cm)	Poisson Ratio	Modulus of Elasticity (MPa)
AC WC	4	0,40	1015,3
AC BC	6-12	0,40	1107,6
AC Base	8,5-17,5	0,40	1476,8
CTB	15-30	0,35	461,5
LPA Kelas A	15	0,35	230,75
	≥ 25	0,35	138,45
Subgrade	∞	0,45	55,38

Tire Pressure

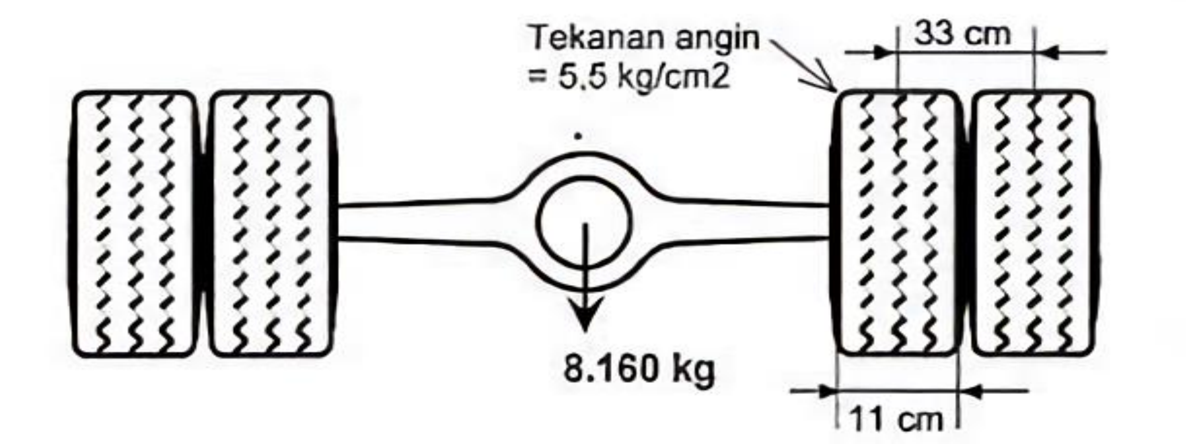

Figure Error! No text of specified style in document.**.4** *Standard Axle Configuration in Indonesia*

For each planned pavement design, modeling is conducted. The kenpave program, through the kenlayer sub-program, calculates the stress and strain values at the critical points of the pavement structure in units of kPa after the calculation parameters are entered in accordance with the pavement design conditions. Furthermore, the data is recapitulated to obtain the maximum stress and strain values for each critical point in the form of horizontal strain values for the subsurface layer, vertical strain values for the surface of the foundation layer, and subgrade layer for each design as the strain value to be used for damage control calculations.

Table Error! No text of specified style in document.**.5** *Maximum Strain Values at Critical Point*

Alternative Design	Vertical Strain Max. at Base (kPa)	Vertical Strain Max. at Subgrade (kPa)	Horizontal P. Strain Max. at Bottom Surface (kPa)
A	0,0002116	0,0002392	0,0000451
B	0,0002109	0,0002553	0,0000479
C	0,0002642	0,0002469	0,0001675
D	0,0002925	0,0002292	0,0001765
E	0,0003084	0,0002054	0,0001810
1	0,0002080	0,0002334	0,0000368
2	0,0002095	0,0001988	0,0000382

The stress and strain values at each critical point of the pavement design are converted to damage-resistant loads (Nf and Nd) using equation 1 and equation 2. The resistance load is compared with the design load (Nr) of 36.2 million esal to analyze the pavement design strength during service life.

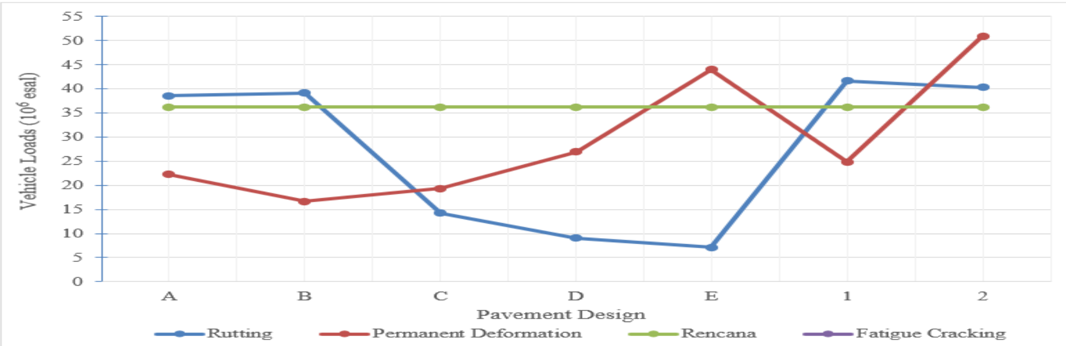

Figure Error! No text of specified style in document.**.5** *Pavement Design Strength Graphic*

Based on vehicle load analysis, it is found that most pavement designs cannot provide a resisting load as large as the design load for rutting damage and permanent deformation because the resisting load is below the expected design load. However, the design can exceed the load resistance requirements against fatigue cracking. So that it can be interpreted that a pavement design with a withstand load less than the design load will experience damage based on the type of damage reviewed before the road's service life is completed.

Alternative-2 design, on the other hand, has a high load resistance to three types of damage that exceeds the design load. As a result, only Alternative 2 of the seven existing alternative pavement designs is expected to withstand the design loads without experiencing permanent deformation, rutting, or fatigue cracking during the service life.

Table Error! No text of specified style in document.**.6** *Pavement Design Strength (10^6 esal)*

Type of Damage	**Pavement Design**						
	A	B	C	D	E	1	2
Fatigue Crack	64.752	51.341	377,5	307,5	278,6	143.439	123.660
Rutting	38,5	39,1	14,2	9,0	7,1	41,6	40,3
Permanent Deform.	22,3	16,6	19,3	26,9	44,0	24,8	50,9

Conclusion

Based on the results of the analysis and calculation stages in this study, it can be concluded several points, including:

1) The resistance load strength of 36,200,896 esal which was designed based on the Road Pavement 2017 Manual Design and its 2020 supplement resulted in seven alternative flexible pavement designs with various types and varying thicknesses of materials. The seven designs consist of five designs using a cement treated base (CTB) foundation layer and two designs using a class A aggregate foundation layer. The road pavement using class A aggregate foundation has a higher thickness than the road pavement using CTB.

2) Pavement strength is based on the output of kenpave software in the form of strain and stress at critical points for the three types of road damage, namely: fatigue cracking, rutting, and permanent deformation. The value of strain is converted to load in initial units to

be compared with the design load. From the calculation results, only one design that has a resistance load for the three types of damage exceeds the design load as well as being the strongest pavement design, namely Alternative-2 Design. Meanwhile, other alternative designs have experienced varying results in experiencing structural failure.

References

Badan Pusat Statistik, "Perkembangan Jumlah Kendaraan Bermotor Menurut Jenis (Unit) 2018-2020," 2020. https://www.bps.go.id/indicator/17/57/1/perkembangan-jumlah-kendaraan-bermotor-menurut-jenis.html.

Badan Pusat Statistik, "Panjang Jalan Menurut Tingkat Kewenangan," 2020. https://www.bps.go.id/indicator/17/50/2/length-of-road-by-level-of-government-responsibility.html (accessed Dec. 08, 2022).

L. basri Said, S. M. H, and Sriwati, "PENGARUH PERTUMBUHAN KENDARAAN DAN KAPASITAS JALAN TERHADAP KEMACETAN DI RUAS JALAN PERINTIS KEMERDEKAAN," vol. 3, no. 1, pp. 79–86, 2019, doi: 10.31219/OSF.IO/KPW6E.

A. P. Widiastuti, "Analisis Perbandingan Desain Struktur Perkerasan Lentur Menggunakan Metode Empiris Dan Metode Mekanistik Empiris Pada Ruas Jalan Legundi-Kanigoro-Planjan," Universitas Islam Indonesia, 2018.

E. Aburkaba, R. Muniandy, and N. Thamer, "Comparison of Flexible Pavement Performance Using Kenlayer and Chev PC Software Program," *Aust. J. Basic Appl. Sci.*, vol. 7, no. 9, pp. 112–119, 2013.

Y. H. Huang, *Pavement Analysis and Design*, 2nd Editio. Upper Saddle River: Pearson Education, Inc., 2004.

S. S. Adlinge and P. a K. Gupta, "Pavement Deterioration and its Causes," *Mech. Civ. Eng.*, pp. 9–15, 2009, [Online]. Available: www.iosrjournals.org.

L. A. Al-Khateeb, A. Saoud, and M. F. Al-Msouti, "Rutting prediction of flexible pavements using finite element modeling," *Jordan J. Civ. Eng.*, vol. 5, no. 2, pp. 173–190, 2011.

Bina Marga, *MANUAL DESAIN PERKERASAN JALAN No 2/M/BM/2017*. Direktorat Jendral Bina Marga, 2017.

Bina Marga, *Suplemen MDPJ No. 01/S/MDP2017 2020*, no. 01. Jakarta: Direktorat Jendral Bina Marga, 2020.

T. A. Rind, N. A. Memon, and A. S. Qureshi, "Analysis and Design of Flexible Pavement Using Empirical-Mechanistic Based Software (KENPAVE)," *Int. Conf. Sustain. Dev. Civ. Eng. MUET, Pakistan*, no. March, pp. 120–125, 2017.

A. Rahmawati and M. Adiyasa, "Analysis of Remaining Service Life for Flexible Pavement Using Mechanistic-Empirical Methods," *Int. J. GEOMATE*, vol. 21, no. 85, pp. 145–153, 2021, doi: 10.21660/2021.85.j2203.

J. Putra and A. N. Tajudin, "Desain Ulang Dan Analisis Respons Struktural Perkerasan Lentur Pada Jalan PANTURA RUAS TANGERANG-SERANG," *JMTS J. Mitra Tek. Sipil*, vol. 4, no. 1, pp. 23–31, 2021, doi: 10.24912/jmts.v0i0.10504.

I. Farida and G. Noer Hakim, "Ketebalan Perkerasan Lentur Dengan Metode AASHTO 1993 Dan Manual Perkerasan Jalan 2017," *J. Tek. Sipil Cendekia*, vol. 2, no. 1, pp. 59–68, 2021, doi: 10.51988/vol1no1bulanjulitahun2020.v2i1.30.

A. Chegenizadeh, M. Keramatikerman, and H. Nikraz, "Flexible pavement modelling using Kenlayer," *Electron. J. Geotech. Eng.*, vol. 21, no. 7, pp. 2467–2479, 2016.

A. Mishra and D. Patel, "Analysis of Structural Deformation in Flexible Pavement using KENLAYER Programme," *Int. Res. J. Eng. Technol.*, vol. 6, no. 8, pp. 1168–1173, 2019, [Online]. Available: www.irjet.net.

PT. PP, "Laporan Hasil Uji Dynamic Cone Penetration," 2020.

BBPJN Jawa Timur Bali, "Data LHR BTS KOTA BLITAR - BTS KOTA WLINGI (JAM)," 2020.

T. B. S. Pambudi, "Pemodelan Trip Distribution dan Trip Assignment pada Jalan Tol Gempol Pasuruan," p. 174, 2017, [Online]. Available: http://repository.its.ac.id/2756/.

S. Sukirman, *Perencanaan Tebal Struktur Perkerasan Lentur*, vol. 53, no. 9. 2010.