Comparative Study of Rigid Pavement Design of Solo-Yogyakarta-NYIA Kulon Progo Toll Road Using MDPJ 2017 and MDPJ 2024

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ABSTRACT

The Solo-Yogyakarta-NYIA Kulon Progo Toll Road is one of *Proyek Strategis Nasional* (PSN) that has an important role in the smooth movement of traffic. The infrastructure development process must be carefully considered, especially at the planning stage. This paper analyzes the design of rigid pavement planning using MDPJ 2017 and MDPJ 2024 to determine the difference in design results and can be the best alternative design proposal so that it can provide a reference for pavement performance performance. In addition, an empirical mechanistic analysis was conducted using KENSLAB in the KENPAVE program. The program outputs stress, deflection, and service life prediction. The analysis results show that MDPJ 2017 and MPDJ 2024 with JSKN value of 125,538,693,248 have the same rigid pavement thickness value of 305 mm and with KENSLAB analysis, a service life of 1000 years is obtained. MDPJ 2017 and MPDJ 2024 do not produce significant differences, there are only differences in the tie bar spacing and dowel diameter. The different tie bar spacing and dowel diameters have little effect on the value difference in the KENPAVE output. However, the design with MDPJ 2024 has a slightly higher value than MDPJ 2017. Thus, alternative designs are needed to make the pavement performance more effective and efficient, including 200 mm, 185 mm, and 180 mm thick. From several alternative pavement designs, it is concluded that the design that produces the most optimal performance is alternative 3 with a layer arrangement of 180 mm thick slab, 100 mm LMC, and 150 mm LPA with a predicted service life of 48.2 years.

Keywords: KENPAVE-KENSLAB, MDPJ 2017, MDPJ 2024, pavement performance, rigid pavement.

INTRODUCTION

Indonesian government programs that are carried out to encourage economic growth and improve people's welfare are called Proyek Strategis Nasional (PSN) [1]. One of the PSN that has been and is ongoing is the infrastructure development of the Solo-Yogyakarta-NYIA Kulon Progo Toll Road. The toll road connects Central Java Province and Yogyakarta Special Region, both of which are areas with high tourist interest. The large number of traffic movements originating from Solo to Yogyakarta and vice versa, the project is expected to accelerate the flow of transportation movements between regions so as to reduce traffic congestion.

The toll road infrastructure development process must be carried out and considered carefully, starting from planning and design, implementation, and maintenance. The initial stage that will determine the success of the project is during design planning and design desain [2].Thus, the expected construction results can be realized properly and be able to provide safety and comfort for its users. In addition, with careful planning, it is expected that the quality of construction can have an adequate level of service [3].

Rigid pavement is the preferred method for the Solo-Yogyakarta-NYIA Kulon Progo Toll Road project [4]. This type's decision is made taking into account the huge loads and heavy traffic. Long planning life, low deflection, and high pavement stiffness are benefits of utilizing rigid pavement [5]. Even yet, the cost of construction is comparatively higher than that of flexible pavement.

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Indonesia has several pavement design manuals, one of which is the manual issued by the Directorate General of Highways. The Manual of Pavement Design (MDPJ) currently has the latest version, MDPJ 2024, which is an update of MDPJ 2017. Not many pavement plans refer to the latest manual. Some previous studies that refer to MDPJ 2017 include [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17]. However, currently there are not many who have analyzed road pavement using MDPJ 2024. Thus, it is necessary to compare the design analysis using MDPJ 2017 with MDPJ 2024 to find out how much difference the results are, especially on rigid pavement.

Design analysis with reference to the manual is an empirical method. Empirical methods also need to be strengthened by using mechanistic-empirical methods to understand and predict the behavior of pavement structures. one way that can be done is by optimizing the use of KENPAVE software. Previously, there have been many studies using KENPAVE software to analyze flexible pavements such as [10], [11], [12], [13], [18], [19], [20]. However, there are still few studies that use KENPAVE to analyze rigid pavements. Some of these studies are [[8], [21], [22], [23], [24], [25]. This paper aims to compare rigid pavement designs using MDPJ 2017 and MDPJ 2024 which are then analyzed with KENPAVE. The hope of this paper is that it can be used as a reference for decision makers to get the optimal design in accordance with the desired construction quality.

RESEARCH METHODS

Rigit Pavement Design

Rigid pavement design planning is carried out with reference to MDPJ 2017 [26] dan MDPJ 2024 [27].In general, the calculation formula of both is not much different, there are only differences in the determination of tie bar spacing and dowel diameter. The rigid pavement plan life has been set at 40 years. In this study, a design was carried out with pavement types in the form of Joint Plain Concrete Pavement (JPCP) and Joint Reinforced Concrete Pavement (JRCP). JPCP is a rigid pavement with unreinforced concrete that has a slab size close to a square and is limited by transverse joints. Meanwhile, JRCP is a reinforced concrete pavement that is rectangular in shape and bounded by transverse joints.

Road Characteristics Data

The secondary data used refers to the research of [4] sourced from PT Adhi Karya (Persero). The data are as follows.

1. Design life : 40 years
2. Road Type : 4 lanes 2 directios
3. Concrete Quality : K-450
4. CBR : 10.5%

Average Daily Traffic Data

The average daily traffic data used in rigid pavement analysis refers to the research of [4] which can be seen in Table 1.

Table 1. Average Daily Traffic Data

Vehicle Class	Axis Configuration and Type	Year	
		2020	2024
2	1.1	7608	9177
3	1.1	2106	2540
4	1.1	1068	1288
5a	1.1	74	89
5b	1.2	59	71
6a	1.1	628	758
6b	1.2	1037	1251

Continued **Table 1.** Average Daily Traffic Data

Vehicle Class	Axis Configuration and Type	Year	
		2020	2024
7a	1.22	759	916
7b	1.22-22	47	57
7c	1.22+22	50	60

Source: [4]

KENPAVE's Mechanistic-Empirical Analysis

Rigid pavement analysis using KENPAVE is performed in the KENLAYER option. Input data required are values of concrete slab thickness, concrete and subgrade modulus, Poisson ratio, tie bar and dowel diameter, tie bar and dowel spacing, concrete quality, and traffic volume [28].The program outputs stress values, cracking index, and predicted pavement service life [28].

RESULT AND DISCUSSION

Rigit Pavement Design

The rigid pavement design analysis of the Solo-Yogyakarta-NYIA Kulon Progo Toll Road begins with determining the value of the Number of Commercial Vehicles (JSKN) based on the values in Table 1. The JSKN value with MPDJ 2017 and MDPJ 2024 produces the same value of 125,538,693.248. These results were used to determine design requirements, such as dowel requirements, concrete slab thickness, foundation layers, and drainage layers listed in Design Chart 4 in each manual. The design of rigid pavement layers can be seen in Figure 1.

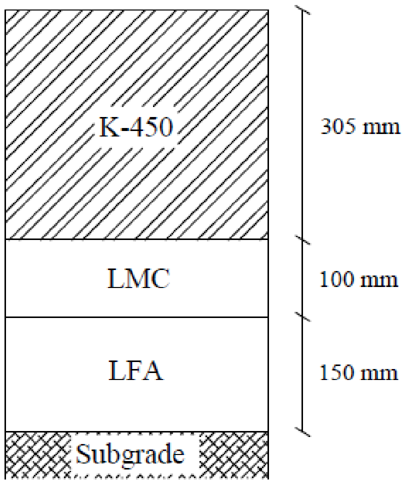

Figure 1. Rigid pavement design MDPJ 2017 and MDPJ 2024

Table 2. summarizes the full findings of the stiff pavement design analysis utilizing MDPJ 2017 and MDPJ 2024.

Table 2. Recapitulation of rigid pavement design

Parameters	MDPJ 2017	MDPJ 2024
Dowels	Yes	Yes
Thickness (mm)	305	305
Foundation layer LMC (mm)	100	100
Drainage Layer (mm)	150	150
Concrete	K-450	K-450

Continued **Table 2.** Recapitulation of rigid pavement design

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Joint Plain Concrete Pavement (JPCP)		
Tie bar	Ø16 mm - 750 mm Length 700 mm	Ø16 mm - 700 mm Length 700 mm
Dowels	Ø36 mm - 300 mm Length 450 mm	Ø38 mm - 300 mm Length 450 mm
Joint Reinforce Concrete Pavement (JRCP)		
Tie bar	Ø16 mm - 750 mm Length 700 mm	Ø16 mm - 700 mm Length 700 mm
Dowels	Ø36 mm - 300 mm Length 450 mm	Ø38 mm - 300 mm Length 450 mm
Steel Reinforcemnt	Ø12 mm - 550 mm	Ø12 mm - 550 mm

Note : Ø is diameter

Table 2. shows that the pavement design with MDPJ 2017 and MDPJ 2024 does not produce much difference with either JPCP or JRCP types. The difference is only in the tie bar spacing, namely in MDPJ 2017 the tie bar spacing is set at 750 mm while MDPJ 2024 the tie bar spacing is set at 700 mm. Another difference is in the dowel diameter value with a 305 mm thick concrete slab in MDPJ 2017 resulting in a diameter of 36 mm, while MDPJ 2024 the dowel diameter value is 38 mm. Thus, MDPJ 2024 updates the dowel diameter value to be larger and shortens the tie bar distance.

KENPAVE's Mechanistic-Empirical Analysis

The results of rigid pavement calculations obtained were input into the KENPAVE program in the KENSLAB option. Comparison of program output on manual standard conditions and alternative designs can be seen in **Table 3.**

Table 3. KENPAVE analysis result comparison

Methods	Type	Design	Grade of Concrete	Thickness (mm)	Max. Stress (kPa)		Cracking Index (%)	Service Life (Years)	
					Single Axle	Tandem Axle		Design	KENSLAB Evaluation
MDPJ 2017	JPCP and JRCP	MDPJ 2017	K400	305	1065.182	977.98	0	40	1000
		Alternative 1	K400	200	1840.600	1376.70	0.1402	40	713.29
		Alternative 2	K400	185	2028.424	1517.60	1.2086	40	82.74
		Alternative 3	K400	180	2098.026	1571.20	2.0752	40	48.19
MDPJ 2024	JPCP and JRCP	MDPJ 2024	K400	305	1065.203	977.94	0	40	1000
		Alternative 1	K400	200	1840.593	1376.73	0.1402	40	713.37

Continued **Table 3.** KENPAVE analysis result comparison

Methods	Type	Design	Grade of Concrete	Thickness (mm)	Max. Stress (kPa)		Cracking Index (%)	Service Life (Years)	
					Single Axle	Tandem Axle		Design	KENSLAB Evaluation
MDPJ 2024	JPCP and JRCP	Alternative 2	K400	185	2028.434	1517.60	1.2087	40	82.74
		Alternative 3	K400	180	2098.007	1571.27	2.0749	40	48.2

Based on **Table 3.** the outcomes of stress, cracking index, and design life are significantly impacted by the thickness of the concrete slab. The pavement types JPCP and JRCP demonstrate that while the stress and cracking index increase with decreasing concrete slab thickness, the service life diminishes. These results are in line with the research of [[8], [21], [22]. A service life study of 1000 years (unlimited) is produced for a 40-year pavement plan with a 305 mm concrete slab thickness. Thus, an alternative is needed to ensure the performance of the pavement in serving the traffic load. The proposed alternatives are 3 concrete slab thickness designs, including 200 mm, 185 mm, and 180 mm. A visualization of the layer thickness of each design and alternative can be seen in **Figure 2.** MDPJ 2017 and MDPJ 2024 do not produce significant differences in the KENPAVE program output despite differences in tie bar spacing and dowel diameter values. thickness of 305 mm.

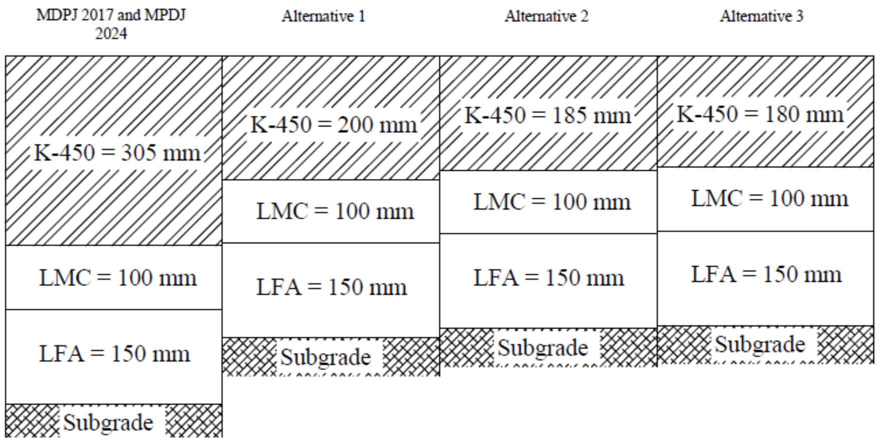

Figure 2. Visualization of rigid pavement design thickness

The highest stress value occurs at the design thickness of MDPJ with a concrete slab In MDPJ 2017, the maximum single axle stress is 1,065.182 KPa and the tandem axle stress is 997.975 KPa. Likewise, in MDPJ 2024, the maximum stress value obtained was 1065.203 KPa and the tandem axle stress was 977.938 Kpa. Meanwhile, the cracking index produced by both is 0% with a service life of 1000 years. this is too far from the designed life so it is less effective. The results of the two manuals do not have a significant difference.

Table 3. also shows that the highest stress values are generated with pavements that have a concrete slab thickness of 180 mm for both MDPJ 2017 and MDPJ 2024. The stress value of MDPJ 2017 single axle is 2098.096 KPa and tandem axle is 1571.201 KPa. Meanwhile, the cracking index value is 2.0752% and the service life is 48.19 years. from the MDPJ 2024 analysis, the maximum stress value generated on the single axle is 2098.007 KPa and the tandem axle is 1571.267 KPa. The cracking index with MDPJ 2024 is 2.0749% and the service life is 48.2 years. Significant differences in design outcomes are also not observed between the two manuals. Meanwhile, an illustration of the maximum strain value can be seen in **Figure 3.**

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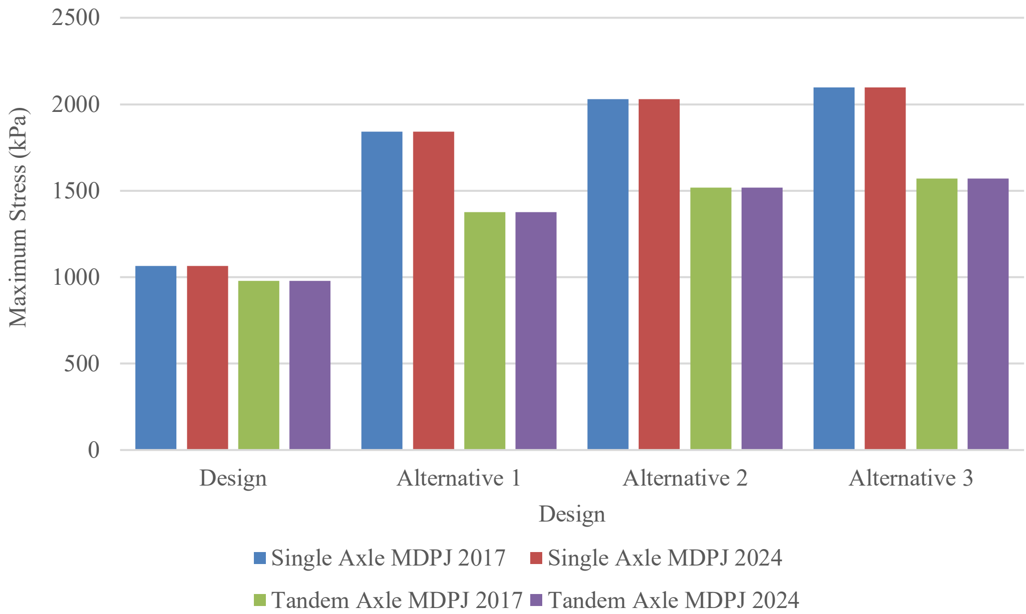

Figure 3. Maximum stress value of kenpave

Figure 3. illustrates that the pavement experiences a greater maximum stress value when subjected to a single axle load as opposed to a tandem axle load. This is because single axle loads tend to give a higher load response at one point. Unlike the tandem axle which will divide the load distribution through two wheels so as to reduce the load concentration at one point. These results are also in line with the research of [8], [21], [22].

In addition to the stress, cracking index, and service life of the pavement, there are also deflection values of each concrete slab thickness. Deflection values were analyzed at 3 locations of the pavement in receiving loads, namely corner loading, interior loading, and edge loading. The detailed analysis results and recapitulation of the maximum deflection values can be seen in **Table 4.** and **Table 5.** The results are also represented in **Figure 4.**

Table 4. Deflection analysis results

Design	Thickness (mm)	Located	Deflection (mm)	
			Single Axle	Tandem Axle
MDPJ 2017 and MDPJ 2024	305	Corner Loading	8.716×10^{-6}	2.639×10^{-5}
		Interior Loading	1.936×10^{-7}	1.461×10^{-7}
		Edge Loading	0.595	2.275
Alternative 1	200	Corner Loading	1.593×10^{-5}	5.279×10^{-5}
		Interior Loading	6.588×10^{-7}	4.951×10^{-7}
		Edge Loading	1.202	4.701
Alternative 2	185	Corner Loading	1.779×10^{-5}	5.894×10^{-5}
		Interior Loading	8.259×10^{-7}	6.201×10^{-7}
		Edge Loading	1.366	5.368
Alternative 3	180	Corner Loading	1.849×10^{-5}	6.126×10^{-5}
		Interior Loading	8.942×10^{-7}	6.712×10^{-7}
		Edge Loading	1.429	5.623

Table 5. Maximum deflection

Design	Thickness (mm)	Located	Max. Deflection (mm)

			Single Axle	Tandem Axle
MDPJ 2017 and MDPJ 2024	305	Edge Loading	0.595	2.275
Alternative 1	200	Edge Loading	1.202	4.701
Alternative 2	185	Edge Loading	1.366	5.368
Alternative 3	180	Edge Loading	1.429	5.623

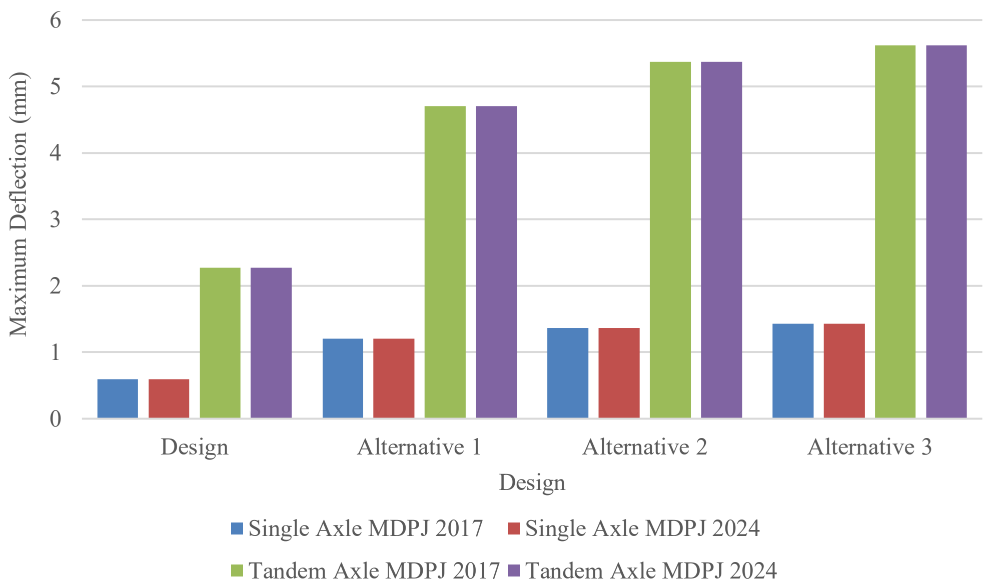

Figure 4. Maximum deflection value of kenpave

Table 4. Table 5. and **Figure 4.** show that the deflection of rigid pavement at corner loading, interior loading, and edge loading locations for each thickness and alternative design will result in different deflection responses. In general, the maximum value of deflection occurs at edge loading. Of the four concrete plate thicknesses, the lowest maximum deflection value occurs in the 305 mm thick design of 0.595 mm for single axle loads and 2.275 mm for tandem axle loads. Meanwhile, the highest maximum deflection value occurred in the 180 mm thick concrete slab design with results of 1.429 mm for single axle load and 5.623 mm for tandem axle load. Deflection values occur more with loading due to tandem axle vehicles because the number of axles is greater than that of a single axle [22]. This is in line with the decreasing value of concrete slab thickness that will result in cracking index and service life close to the pavement design. Considering a few of these factors, alternative design 3, with a concrete slab thickness of 180 mm, LMC 100 mm, and LFA 150 mm, is suggested as a way to optimize pavement performance in accordance with the anticipated age.

CONCLUSION

Based on the results and discussion, it can be concluded that the pavement design of Solo-Yogyakarta-NYIA Kulon Progo Toll Road using MDPJ 2017 and MDPJ 2024 does not have much difference in design results. Some of the differences are only in the tie bar spacing value and dowel diameter with both JPCP and JRCP pavement types. The results of the MDPJ 2024 analysis are

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slightly better than those of MDPJ 2017. The 305 mm thick pavement concrete slab produces a KENPAVE output service life of 1000 years (unlimited) so alternative 3 is proposed with a concrete slab thickness of 180 mm, LMC 100 mm, and LFA 150 mm which produces a predicted service life of 48.2 years. this is because it is more effective and efficient in withstanding stress, deflection, and service life in accordance with the specified design life

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