Rigid pavement optimization by using empirical mechanistic method and Kenpave software

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Abstract. This research was undertaken on TNC Main Road to CBD project with the aim to find an optimum design, by using Manual Perkerasan Jalan 2017 and Kenpave software. The existing pavement was redesigned to achieve a design life of 40 years, instead of 20 years. The design was also compared with other alternative designs that were obtained from past research study. The analysis was done by comparing the maximum stress values, maximum deflection values, and material cost per meter. It can be concluded for this study that the pavement modification using slag aggregates in concrete mixture as the surface layer was the most optimum pavement design as it has the lowest maximum stress and deflection values, and thus lowest cracking index and longer designed life, with a reasonable construction material cost.

Keywords: Rigid Pavement, Kenpave, Concrete, Life cycle cost, Deflection

1. Introduction

The basic design of rigid pavement consists of layers of subgrade, foundation and concrete slab. However, by adjusting the soil properties at the project site, modification of the subsoil was carried out to overcome these conditions. In the TNC Main Road to CBD project, which was developed by PT CFLD Tangerang New Industry City Development, due to the nature of the soil which tends to be muddy, a limestone was added to the foundation layer. This was done so that limestone can absorb water in the soil so that the CBR value of the soil can be achieved. This research study aims to assess a number of alternative rigid pavement designs to optimize the design by comparing the performance and the cost related to the design to adjust the designed life of the pavement from 20 years to 40 years. This study compared two design methods, which are the Manual Perkerasan Jalan No. 04/SE/Db/2017 (MPJ 2017) [1] and the software Kenpave-Kenslabs.

The design method used in the MPJ2017 is an Empirical Mechanistic method which is currently being used extensively in various developing countries. The pavement structure analysis is carried out using mechanical principles whose output is used to predict the performance of the structure based on empirical experience. To get optimal results, the Empirical Mechanistic method requires detailed and accurate input of material parameters and traffic loads that require extensive testing both in the field and in the laboratory. As a relatively new approach to the community environment, further study and development to this method are still needed. Among them are the development of software for analysis.
and, very urgently, the calibration of the output of mechanical analysis of pavement performance especially for the Indonesian climate and the condition of vehicle loads that are almost out of control (Ministry of Public Works and Public Housing Directorate General of Highways, 2017).

The Kenpave Program is a pavement planning design program developed by Dr. Yang H Huang, P.E. of Civil Engineering University of Kentucky. This program is written in the Visual Basic programming language and can be run with a version of Windows 95 or above[2]. The Kenpave program accompanying Yang Huang's Second Edition "Pavement Analysis and Design," is divided into four programs namely Layerinp, Kenlayer, Slabsinp and Kenslabs. Layerinp and Kenlayer are flexible pavement analysis programs based on multi-layer system theory. While Slabsinp and Kenslabs is an analysis program for rigid pavement based on the finite element method. This study uses the Kenslabs Kenpave program section to analyze the output of the Kenslabs running program which includes stress (s), deflection (w), index cracking, and design life (planned life). The Kenpave-Kenslabs program is based on the finite element method, where concrete slabs are divided into rectangular finite elements with a large number of nodes. Both the wheel load and the subgrade reaction are applied to the plate as a vertically concentrated force at the node[3].

2. Research Methodology

Figure 1 shows the steps used to conduct this research, starting from literature review and continued with data collection, both from the project owner and from past studies. The data collected was then analysed by using MPJ 2017 and then Kenpave modelling. After the pavement strength results were obtained, the output was analysed and compared with the cost related to constructing each alternative design.

![Fig. 1. Research Flowchart](image-url)
This study aims to redesign the existing pavement to extend its service life from 20 years to 40 years. The data used for this study was obtained from the owner of the project, PT CFLD Tangerang New Industry City Development, including project charter, pavement layer design, and technical specification, as shown in Figure 2.

![Fig.2. Existing Pavement Design](image)

A number of alternatives were also considered and the data was obtained from literature review. The research matrix is shown in Table 1. For the modified design, the aggregates used for the concrete were substituted by Ground Granulated Blast Furnace (GGBF). Three other alternative designs were obtained from past research studies. It can be seen that subgrade varies for each design. The existing pavement was evaluated by using MPJ 2017 and Kenpave software, while other designs were evaluated by using Kenpave software. The analysis will be divided into two load configurations, which are single axle double tire and tandem axle double tire.

### Table 1. Research Matrix

|                  | Existing Pavement | Modified Design | Alternative Design 1 [4] | Alternative Design 2 [5] | Alternative Design 3 [6] |
|------------------|-------------------|-----------------|--------------------------|--------------------------|--------------------------|
| **Surface**      | Concrete          | Concrete (Slag) | Concrete                 | Concrete                 | Concrete                 |
| **Base Course**  | Lean Concrete     | Lean Concrete   | Lean Concrete            | -                        | Lean Concrete            |
| **Subbase Course** | Aggregate A | Aggregate A     | Aggregate A              | Aggregate A              | -                        |
| **Subgrade**     | Silty clay        | Silty clay      | Clay                     | Sandy loam               | Fine Clay                |

### 3. Results and Discussion

#### 3.1. Pavement Design Based on MPJ 2017

Table 2 shows the pavement design results that were conducted by using MPJ 2017. It can be seen that there are some differences in the materials used for subbase course, base course, and surface layer. After the analysis was done, the 30 cm limestone aggregates that were used for the subbase course was replaced by Class A Aggregate with 17 cm thickness. This is due to the fact the aggregate would be able to withstand more load with smaller thickness. For the base course, the 40 cm Class A Aggregate and 5 cm lean concrete were replaced by 12 cm lean concrete. This was done because the Class A Aggregate has been used for the subbase course and the lean concrete is made to be thicker to ensure that the layer is flat. The concrete slab used for this research has
compressive strength of 37.35 MPa with 17 cm thickness, while the existing pavement used compressive strength of 30 MPa with 20 cm thickness. With higher compressive strength, the thickness of the concrete slab can be reduced.

Table 2. Design Parameter for Modified Design

| No | Item                  | Field Data                  | Re-design Result |
|----|-----------------------|-----------------------------|------------------|
| 1  | CBR Subgrade          | 6%                          | 6%               |
| 2  | Sub-Base              | Limestone, 30 cm thick       | Aggregate A, 15 cm thick |
| 3  | Base                  | Aggregate A, 40 cm thick and LMC, 5 cm thick | LMC, 10 cm thick |

Existing Pavement, JPCP

| 4  | Surface              | Concrete \( f_c \) 30 Mpa (K361,45), 20 cm thick | Concrete K450, 29 cm thick |
| 5  | Tie Bars             | Ø16 mm – 1200 mm, 750 mm length | Ø16 mm – 750 mm, 690 mm length |
| 6  | Dowels               | Ø32 mm – 300 mm, 450 mm length | Ø38 mm – 300 mm, 450 mm length |

Existing Pavement, JRCP

| 7  | Surface              | Concrete \( f_c \) 30 Mpa (K361,45), 20 cm thick | Concrete K450, 29 cm thick |
| 8  | Tie Bars             | Ø16 mm – 1200 mm, 750 mm length | Ø16 mm – 750 mm, 690 mm length |
| 9  | Dowels               | Ø32 mm – 300 mm, 450 mm length | Ø38 mm – 300 mm, 450 mm length |
| 10 | Steel Reinforcements | Ø12 mm – 380 mm | Ø12 mm – 350 mm |

3.2. Pavement Evaluation of Existing and Modified Design Using Kenpave-Kenslabs

The existing pavement and other alternative designs were analysed by using Kenpave software and the results are presented in Table 3. Based on the MPJ 2017 analysis, the concrete slab was 17 cm thick, while based on the Kenpave software, the concrete slab was 16.12 cm thick.

From the analysis results, there were some parameters obtained including concrete slab thickness, maximum stress, maximum deflection, and cracking index. The cracking index value for existing pavement as analysed by MPJ 2017 is 0, while when analysed with Kenpave software, the cracking index values are 4% and 3.5% with concrete slab thickness values are 17 cm and 16 cm, respectively, with designed life of 40 years. These values show that concrete slab thickness affects stress, deflection, cracking index, and design life.

Table 3. Analysis results

| Methods                | Concrete Quality | Thickness (cm) | Maximum Stress (kPa) | Maximum Deflection (mm) | Cracking Index (%) | Design Life |
|------------------------|------------------|----------------|----------------------|-------------------------|-------------------|-------------|
|                        |                  |                | Single Axle          | Double Axle             | Single Axle       | Double Axle |
| Existing Pavement      | K450             | 17             | 1968.69              | 1609.18                 | 0.611             | 1.424       | 0%          | 40       | Unlimited |
| (MPJ 2017)             |                  |                |                      |                         |                   |             |             |          |          |
| Existing Pavement      | K450             | 16.12          | 2139.88              | 1686.66                 | 0.632             | 1.443       | 4%          | 40       | 77       |
| (Kenpave)              |                  |                |                      |                         |                   |             |             |          |          |
| Modified               | K450             | 15.07          | 2097.28              | 1669.57                 | 0.627             | 1.439       | 3.5%        | 40       | 84       |
Design (Kenpave)

| Design                  | (Kenpave) | K450 | 20,00 | 1852.77  | 1554.86  | 0.596 | 1.411 | 0.1%  | 20  | 135 |
|-------------------------|-----------|------|-------|----------|----------|-------|-------|-------|-----|-----|
| Alternative Design 1 [4]|           |      |       |          |          |       |       |       |     |     |
|                         |           |      |       |          |          |       |       |       |     |     |
| Alternative Design 2 [5]|           |      |       |          |          |       |       |       |     |     |
|                         |           |      |       |          |          |       |       |       |     |     |
| Alternative Design 3 [6]|           |      |       |          |          |       |       |       |     |     |
|                         |           |      |       |          |          |       |       |       |     |     |

Figure 3 shows the maximum stress values for each design when loaded with single axle and tandem axle. Comparing the maximum stress values, the maximum stress values are higher when the pavement is loaded with single axle compared to when the pavement is loaded with tandem axle. It can be seen that for the existing pavement, there are slight differences between the values produced by MPJ 2017 and Kenpave software. This is due to the fact that both methodologies are using different approach to calculate the output. When comparing the maximum stress values for all designs produced by Kenpave software, it can be seen that the maximum stress occurred on the existing pavement. Changing the aggregate to slag aggregates for the modified design did lower the maximum stress. Alternative Design 3 has the lowest maximum stress compared to others.

Figure 4 shows the maximum deflection values for each design when loaded with single axle and tandem axle. In general, the maximum deflection values for tandem axle for all design variations were higher than the values for single axle. However, Alternative Design 3 has the lowest maximum deflection values compared to others for both single and tandem axles and there were no significant differences between the maximum deflection values between the existing pavement, modified design, and Alternative Design 1.
3.3. Material Cost

For each alternative design variation, the material costs to construct the pavement were calculated and compared. It can be seen, for the existing pavement designed by MPJ 2017, existing pavement designed by Kenpave, modified design, and Alternative Design 1, the material costs to build the pavement to be loaded with single axle were higher than to be loaded with tandem axle. The lowest construction cost occurred to construct the modified design loaded with tandem axle and the highest construction cost occurred to construct the existing pavement as designed with Kenpave software loaded with single axle.

3.4. Relationship between Parameters

Figure 6 and Figure 7 show the relationship between the construction cost and the maximum stress and maximum deflection values for each variation design. It can be seen that the JRCP has the highest cost, where the maximum stress for single axle configuration is smaller than the tandem axle configuration with just a slight difference in cost. JCPC pavement has a lower price, where the
maximum stress for single axle configuration is lower than the tandem axle configuration with small discrepancy in cost. Therefore, it can be said that adding reinforcement resulted in higher cost and the thicker the concrete slab, the lower the maximum stress for each axle configuration will be.

From Figure 7, it can be observed that JRPC pavement has the highest cost, where the maximum deflection for single axle configuration is lower than the tandem axle configuration with small difference in cost between them. JCPC pavement has a lower price, where the maximum deflection for single axle configuration is lower than the tandem axle configuration with small discrepancy in cost. Thus, it can be concluded that adding reinforcement onto the pavement caused the material cost to be higher and the thicker the concrete slab, the lower the maximum deflection for each axle configuration will be, and hence the index cracking becomes lower and designed life increases.
4. Conclusions

From the research results, it can be concluded that:

- Manual design of TNC Main Road to CBD based on MPJ 2017 with life cycle adjusted to 40 years results to: concrete slab (28.5 cm), tie bar (Ø16 mm–750 mm, length 690 mm), dowel (Ø38 mm–300 mm, length 450 mm), and reinforcement (Ø12 mm–350 mm).
- Kenpave model of TNC Main Road to CBD existing design is 25.13 cm thick with 0.082% cracking index per year and modified design is 20.76 cm thick with 1.248% cracking index per year.
- Concrete slab strength is affected by thickness and material used, wherein thicker slab causes smaller maximum stress and deflection, vice versa.
- Material cost is affected by thickness and material used, wherein thicker slab, and reinforcement usage causes bigger cost, vice versa.
- The most optimum pavement design (strength and cost-wise) is modified pavement using slag, which is the existing pavement redesigned with Kenpave software.

For future research project, it is recommended to consider vehicle velocity because, while the loading was assumed to be static herein, in reality, the loading could be dynamic. Additionally, it is necessary to do comparison using other software to understand sensitivity responds occurred in rigid pavement structure.

References

[1] Dirjen Bina Marga, “Manual Desain Perkerasan 2017.” 2017.
[2] K. Fadhlan and Z. A. Muis, “Evaluasi Perencanaan Tebal Perkerasan Lentur Metode Bina Marga Pt T-01-2002-B dengan Menggunakan Program Kenpave.” 2016.
[3] Y. H. Huang, Pavement Analysis and Design. Kentucky: Pearson Education, Inc., 2004.
[4] Ilpandari, “Analisis Desain Struktur Rigid Pavement Dengan Metode Empirik, Evaluasi Dengan Software Kenpave (Studi Kasus: Jalan Tol Semarang - Solobawean-Salatiga),” Universitas Islam Indonesia, 2018.
[5] C. Huan, “Evaluation Of Finite Element Sofware For Pavement Stress Analysis,” RyersonUniversity, 2005.
[6] Y. H. Parjoko, “Sensitivity Analysis of Concrete Performance Using Finite Element,” J. Civ. Eng. Forum, vol. XXI, no. 1, 2012.