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Flexible Pavement Mechanistic Response to the 2017 Indonesian Road Pavement Manual with Cement-Treated Base (CTB)

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Abstract. The empirical method, a method developed from experiments or experience, has historically been the usual planning method used in Indonesia for designing flexible pavement thickness. The newest pavement design manual in Indonesia, Bina Marga 04/SE/Db/2017 has introduced the mechanistic method, based on pavement responses such as strain, deflection, and stress. Research was conducted to evaluate the design chart in the manual with KENPAVE program assistance in order to know the mechanistic response for the cement-treated base (CTB) foundation. The loadings for 100%, 150%, and 200% are used to know pavement response to loading variations. Vertical and horizontal strain were reviewed as mechanistic responses. Vertical strain was used to analyse rutting, and horizontal strain was used to analyse fatigue. The research shows that as the California Bearing Ratio (CBR) value increases, the smaller the vertical strain value becomes. However, this was not the case with horizontal strain where the CBR value did not seem to influence the horizontal strain value. The added loading will increase pressure on the pavement so that compressive and tensile strains on the pavement will be higher.

1. Introduction

The structure of pavement usually consists of layers that are relatively weak at the bottom, and gradually stronger in the upper part. This arrangement allows available material to be utilized more economically. The functions of road pavement are to provide a flat/smooth surface for drivers and to distribute vehicle load adequately from the surface to the subgrade so that it protects the ground from excessive pressure. Pavement also works to protect the ground from weather distress.

In Indonesia, pavement design guidelines are issued by the Directorate General of Highway from the Ministry of Public Works and Housing. These guidelines include provisions for new construction, stage construction, and overlays. These guidelines have changed over the years. The 1987 Component Analysis, which refers to AASHTO 1979, was a design guideline in use for some time. When the 2002 Flexible Pavement Thickness Guideline, which refers to AASHTO 1993, was issued, that became the standard. In 2013, a new regulation, named the Pavement Manual, was developed with assistance by Australian Government, the latest version of which (with several revisions of Regulation 2013) was issued in 2017. Significant differences exist between the 2013 and 2017 versions, not the least of which is the use of an empirical method in 2013 and the use of empirical mechanistic methods in 2017. Empirical mechanistic methods have been used extensively in many developing countries. These methods require input material parameters and traffic load because the pavement responses, namely stress, strain and deflection, are considered.



The empirical mechanistic method is a relatively new approach in Indonesia, so it is necessary to conduct several research projects in order to support and develop this method. In addition, the output calibration mechanical analysis of road pavement, especially for the Indonesian climate and ungoverned vehicle loads, needs to be further investigated [1]. The purpose of this research is to use KENPAVE to evaluate the mechanistic method of pavement design, with standard loading and overloading, in the 2017 Pavement Manual.

1.1. Cement-Treated Base (CTB)

The cement-treated aggregate base (a mixture of aggregate, water, and cement) is a foundation layer which was developed utilizing techniques of cement soil construction. The gradation and controlled quality implementation method (mixing and spreading) resembles paving work with high carrying capacity. The reaction between cement and water will bind the aggregate particles, thus increasing the strength, stiffness, durability, and permeability of this material. [2, 3]

For roads with medium to heavy traffic, CTB is an effective material to use as the foundation layer as the cost is significantly less than using granular foundation. CTB can also reduce the amount of asphalt and granular materials and is, therefore, less sensitive to damage from moisture. [1]

1.2. Mechanistic empirical pavement method

Traffic loads, environmental conditions, and material properties of pavement can all cause responses in the forms of stresses, strains, or deflections. The relationships between these responses and their physical causes are typically described using mathematical models. In the mechanistic approach, empirical models are used when defining the relationships between the calculated responses and pavement failure. As a result, the number of loading cycles before failure can be predicted. This approach is called a mechanistic empirical based design method. This approach requires pavement designers to ensure that the design inputs are implemented correctly and to avoid inaccuracies in determining the values of stresses, strains, and deflections, which will subsequently be used in distress models [4,5].

1.3. Pavement Critical Point in Layered System

Flexible pavement is a layered system with superior strength characteristics in the upper layer compared to the layer below it. The theory of a Burmister layered system can be applied in planning, initially developing a two-layer system which can later be developed to a three-layer system. With technological advancement, that theory was further developed by Huang in that it can be applied to multilayer systems with any number of layers [6,7].

The values generated by modelling using multilayer systems are stress, strain, and deflection, the KENPAVE program can measure these values in several points of the pavement structure. Some of these points are used consistently in pavement analysis, such as deflection on the pavement surface, horizontal tensile strength on the bottom of the surface layer to predict fatigue, and vertical compressive strength on the upper subgrade layer to predict rutting [8].

2. Research method

2.1. Pavement Design

Road Pavement Design Manual Number 02/M/BM/ has provided a pavement design with various types of CBR subgrade, Cumulative Single Axle (CESA), and other materials in each layer. The structural design for the CTB foundation has an ESA value of 10 million to 500 million vehicles with a designed life of 20 years. As seen in Table 1, pavement designs are divided into five pavement structures.

Table 1. Pavement Designs

	F1	F2	F3	F4	F5
Cumulative Single Axle Loads (10^6)	> 10 - 30	> 30 – 50	> 50 – 100	> 100 – 200	> 200 – 500
AC WC	40 mm	40 mm	40 mm	50 mm	50 mm
AC BC	60 mm	60 mm	60 mm	60 mm	60 mm
AC Base	75 mm	100 mm	125 mm	160 mm	220 mm
CTB	150 mm	150 mm	150 mm	150 mm	150 mm
Class A aggregate foundation	150 mm	150 mm	150 mm	150 mm	150 mm
Subgrade support (compacted subgrade)	350 mm for CBR 2,5; 300 mm for CBR 3; 200 mm for CBR 4; 100 mm for CBR 5 ^a				

^aNo subgrade support needed for CBR above 5

2.2. Design Evaluation

Road Pavement Design Manual Number 02/M/BM/ will be evaluated for various CBR values (from 2,5 up to 15) and loading scenarios (100%, 125%, and 175%) with the mechanistic empirical method using the KENPAVE software. The pavement thickness shown in Table 2, critical point location, modulus for each layer (Table 2), and loads are inputted into KENPAVE. The outputs of vertical compressive and horizontal tensile strain are used in the analysis.

Table 2. Layer Modulus

Layer	Modulus for each CBR Value (Mpa)							
	2,5	3	4	5	6	8	10	15
AC WC	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
AC BC	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200
AC Base	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
CTB	500	500	500	500	500	500	500	500
Class A aggregate foundation	350	350	350	350	350	350	350	350
Subgrade support	130	120	101	80	0	0	0	0
Natural subgrade	25	30	40	50	60	80	100	150

2.3. Pavement Distress Model

The outputs issued from the KENPAVE program are pavement structure responses, such as vertical compressive and horizontal tensile strains that are later processed by using the rutting prediction, (Eq 1) and fatigue prediction models (Eq 2) [9].

$$Nd = 0,0685x\varepsilon t^{-5,671}xE^{-2,363} \quad (1)$$

Nd = Number of allowable ESA repetitions to prevent rutting; εv = Vertical compressive strain at the top layer of the subgrade

$$Nf = 6,15x10^{-7}x\varepsilon t^{-4} \quad (2)$$

Nf = Number of allowable ESA repetitions to prevent fatigue; εt = Horizontal tensile strain at the bottom of the asphalt layer; E = Surface layer modulus (psi)

The Shell Research formula is used to calculate the Nd and Nf values in this paper due to the fact that this formula has been found to have a reliability level of 44.5% compared to the Asphalt Institute formula which is only 19.9%. [10,11]

3. Result and discussion

Road Pavement Design Manual Number 02/M/BM/2017 has provided the pavement design with several types of CBR subgrade, ESA, materials, and layer thickness. The structure design for the CTB foundation has an ESA value from 10 million to 500 million vehicles with 20 years of design life. Besides the ESA value, several factors affect pavement design, such as the thickness of each pavement structure layer and layer material.

3.1. Vertical Compressive Strain and Rutting

Table 3. The Relationship of Vertical Compressive Strain to CBR and Loading Scenario

CBR	Vertical Compressive Strain ($\times 10^{-4}$)														
	FFF1			FFF2			FFF3			FFF4			FFF5		
	100%	150%	200%	100%	150%	200%	100%	150%	200%	100%	150%	200%	100%	150%	200%
2,5	3,11	4,67	6,23	2,87	4,31	5,75	2,66	3,98	5,31	2,33	3,49	4,65	1,96	2,94	3,92
3	3,17	4,76	6,34	2,91	4,37	5,83	2,68	4,03	5,37	2,34	3,50	4,67	1,96	2,93	3,91
4	3,35	5,03	6,70	3,06	4,58	6,11	2,79	4,19	5,59	2,40	3,60	4,81	1,98	2,98	3,97
5	3,61	5,41	7,22	3,27	4,90	6,53	2,96	4,44	5,93	2,52	3,78	5,04	2,05	3,08	4,11
6	4,03	6,05	8,06	3,62	5,43	7,24	3,27	4,90	6,53	2,75	4,12	5,50	2,21	3,32	4,43
8	3,52	5,28	7,04	3,17	4,75	6,33	2,86	4,29	5,72	2,41	3,62	4,82	1,95	2,92	3,89
10	3,14	4,71	6,29	2,83	4,24	5,66	2,56	3,84	5,11	2,16	3,24	4,32	1,75	2,62	3,50
15	2,51	3,76	5,01	2,26	3,39	4,52	2,05	3,07	4,10	1,74	2,60	3,47	1,41	2,12	2,82

In general, based on Table 3, the greater the CBR value, the lower the vertical compressive strain value obtained is. This is because the CBR value rises as the soil conditions improve, as seen on pavements with CBR values ranging from 6 to 15. However, with CBR values of 2.5 to 6, the vertical compressive strain values obtained are increasing due to subgrade support and a thicker base layer. The vertical compressive strain value increases in a lineal fashion, with the addition of load.

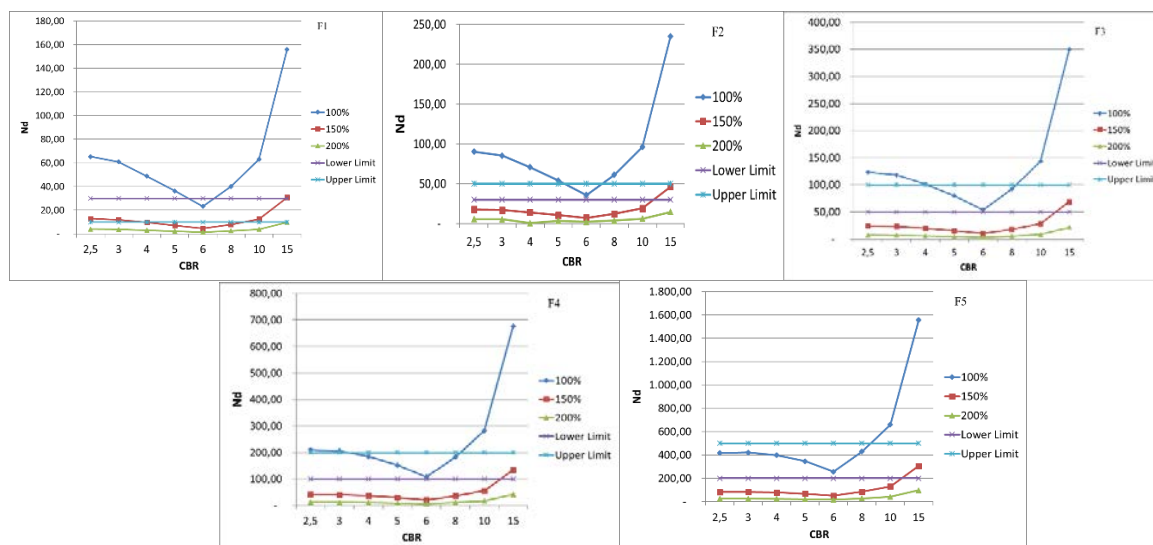


Figure 1. The Relationship of Nd Value

Pavements will experience rutting distress if the Nd value is smaller than the lower limit value, or the actual repetition, which is equal to 10 million. Based on Figure 1, F1 pavement design at 100% loading does not experience rutting damage. For 150% loading, rutting is found at CBR 4, 5, 6, and 8. The 150% load does not experience rutting at CBR 10 or 15. As for the 200% load, rutting distress is seen in all CBR subgrade variations due to the Nd value of less than 10 million.

In the F2 design, rutting will occur if the Nd value is smaller than the lower limit value of 30 million. In the F3, pavements will experience rutting if the Nd value is smaller than the lower limit value or the actual repetition of 50 million. In the F4 design, pavements will experience rutting if the Nd value is smaller than the lower limit value or the actual repetition of 100 million. In the F5, the pavement will experience rutting if the Nd value is smaller than the lower limit value or the actual repetition of 100 million. Based on Figure 4, the pavement design at 100% loading did not experience rutting. For 150% loading rutting occurs in the CBR 2.5, 3, 4, 5, 6, 8, and 10. As for 200 % loading, rutting occurred in all CBR values.

3.2. Horizontal Tensile Strain and Fatigue

Table 4. The Relationship of Horizontal Tensile Strain to CBR and Loading Scenario

CBR	Horizontal Tensile Strain ($\times 10^{-4}$)														
	FFF1			FFF2			FFF3			FFF4			FFF5		
	100%	150%	200%	100%	150%	200%	100%	150%	200%	100%	150%	200%	100%	150%	200%
2,5	3,11	4,67	6,23	2,87	4,31	5,75	2,66	3,98	5,31	2,33	3,49	4,65	1,96	2,94	3,92
3	3,17	4,76	6,34	2,91	4,37	5,83	2,68	4,03	5,37	2,34	3,50	4,67	1,96	2,93	3,91
4	3,35	5,03	6,70	3,06	4,58	6,11	2,79	4,19	5,59	2,40	3,60	4,81	1,98	2,98	3,97
5	3,61	5,41	7,22	3,27	4,90	6,53	2,96	4,44	5,93	2,52	3,78	5,04	2,05	3,08	4,11
6	4,03	6,05	8,06	3,62	5,43	7,24	3,27	4,90	6,53	2,75	4,12	5,50	2,21	3,32	4,43
8	3,52	5,28	7,04	3,17	4,75	6,33	2,86	4,29	5,72	2,41	3,62	4,82	1,95	2,92	3,89
10	3,14	4,71	6,29	2,83	4,24	5,66	2,56	3,84	5,11	2,16	3,24	4,32	1,75	2,62	3,50
15	2,51	3,76	5,01	2,26	3,39	4,52	2,05	3,07	4,10	1,74	2,60	3,47	1,41	2,12	2,82

Based on Table 4, in each load, the CBR values from F1 to F5 design increases and decreases the horizontal strain value, because the CBR value does not significantly affect the horizontal strain. Fatigue damage is located below the upper surface layer, so the CBR value is not too influential even though changes occur.

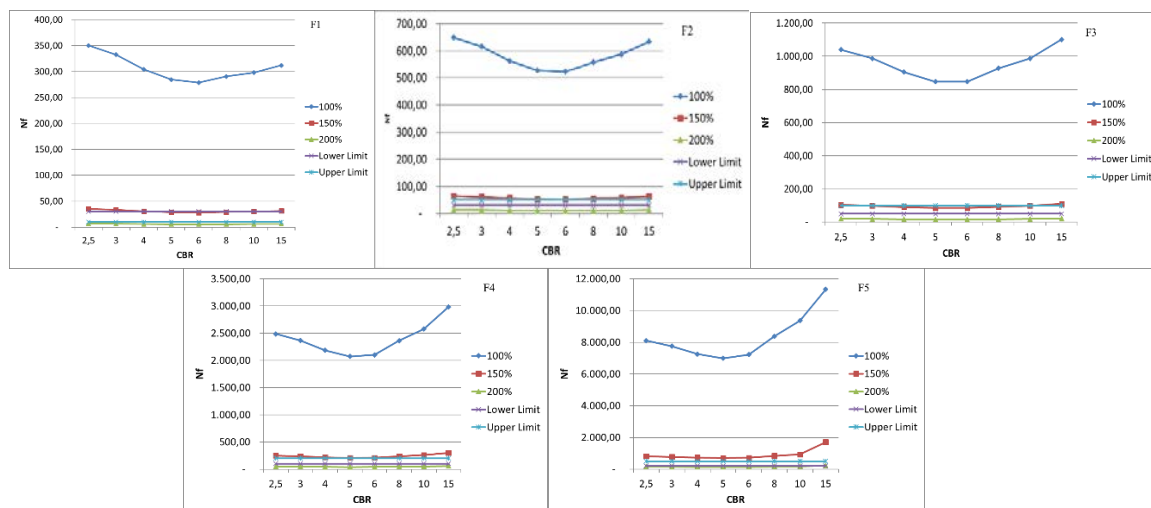


Figure 2. The Relationship of Fatigue Value to CBR

In F1, F2, F4 and F5 designs, the pavement will experience fatigue damage if the Nf value is smaller than the lower limit value. Based on Figure 2, the F1 design at 100% and 150% loading do not experience fatigue damage. Whereas with 200% loading, there is fatigue damage in all conditions of CBR subgrade. This shows that the F1 Pavement design is not designed for loads in excess of 200%.

In the F3 design, pavement will experience fatigue damage if the Nf value is smaller than the lower limit value. Based on Figure 13, F1 pavement design at 100% loading does not experience fatigue damage. With loading of 150%, fatigue damage is not experienced in CBR 2.5 or 15, whereas fatigue damage occurs at CBR 3, 4, 5, 6, and 8. For 200% loading, the grooves are damaged in all CBR values.

4. Conclusion

- Vertical compressive strain values are increased linearly with the addition of loads. This is seen in F1 pavement where normal loading conditions have a vertical strain value of $3.11\text{E-}04$, at 50% loading, a vertical strain value of $4.67\text{E-}04$ is seen, and when excess loading is 100%, there is a vertical strain value of $6.23\text{E-}04$. Likewise, with horizontal strain values.
- Subgrade support and CBR value greatly affect the vertical compressive strain value. In CBR 2.5 to 6 the vertical strain value increases as in F1 pavement from $3.11\text{E-}04$ to $4.03\text{E-}04$ because the thicker the repair, the thinner is the soil. Whereas the CBR 6 to 15 has decreased the vertical strain value as in F1 pavement from $4.03\text{E-}04$ to $2.51\text{E-}04$ because it has increased the CBR value of subgrade.
- The CBR value does not significantly affect the horizontal tensile strain value, because the rutting is located under the upper surface layer.
- The horizontal tensile strain value is affected by the thickness of the paved layer.

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