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Effect of Axle and Tire Configurations on Flexible Pavement Response

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Abstract. The aim of this research is to analyse flexible pavement mechanistic response to axle configurations and tire variations with the help of KENPAVE program based on field survey conducted in Cipularang Highway Km. 97. Each tire load was obtained from the axle load divided by the number of tires. Vertical compressive strain was used to analyze rutting damage while horizontal tensile strain was used to analyze fatigue damage. The results showed that on single axle single tire, the biggest strain value is at the center of the tire. Single axle dual tires obtains biggest strain at the tire radius. Tandem and tridem axle dual tires obtain biggest strain values at ½ distance between tires. Vertical and horizontal strain value on the vehicles are not only influenced by vehicle loading but also axle configuration. Number of allowable repetitions is inversely proportional to vertical and horizontal strain value, which means that the bigger vertical strain value is, the number of vehicle reps that can cross the road without causing rutting damage will be smaller.

1. Introduction

The aim of this research is to analyse flexible pavement mechanistic response to axle configurations and tire variations with the help of KENPAVE program based on field survey conducted in Cipularang Highway Km. 97.

Flexible pavement design is influenced by different environment condition at each location or region, so that there are many methods used for flexible pavement design by referring to standard theoretical basis, one of them is mechanistic empirical method. Critical pavement responses such as stresses and strains are determined by utilizing multilayer elastic then correlated with pavement field performance through empirical models [1].

Road infrastructure from years to years experiences increase in loading either from the side of traffic volume and vehicle axle load. Tire pressure can have a surprisingly great effect on stresses and strains in the upper parts of pavement structures, pavement fatigue and rutting. Therefore, the road must be able to support well from the capacity aspect and bearing strength. Road infrastructure that could not withstand the burden of traffic passing through will cause damage to the road, so that the stress and strain will be at the critical value [2].

2. Method and Data

In order for conducting an effective and efficient research, coherent research method is needed, so that every activity step that is done can be more directed to achieve goal and desired result. The method used in this research are as follows:
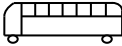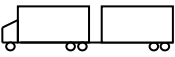
2.1. Vehicle Data Collection

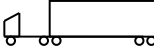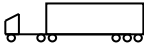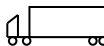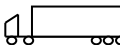A field survey was conducted in Cipularang Highway Km. 97 to get types of vehicle and the volume of each type. In general, the data are needed to determine the Average Daily Traffic (ADT) of the road segment. The ADT then used to calculate Equivalent Single Axle (ESA) for 20 years of pavement design life. This research used only commercial vehicles (> 5 tonnes) [3].

Types of vehicle was needed to determine axle configuration and tire load. The other characteristics like distance between tires, width of axles, distance between axles, contact radius, and tire pressure were determined based on commercial vehicle catalogue of each vehicle. Among vehicles, all do not cause equal damage because of differences in wheel loads, number and location of axles, types of suspensions and tires, and other factors. The interface between the tire and pavement is generally assumed to be circular contact area and the relationship between tire inflation pressure and contact area. Vehicle, axle, and tire characteristics of each vehicle are shown on Table 1 [4] [5].

Table 1. Vehicle, axle, and tire characteristics.

Vehicle Figure	Tire Code	Tire Type	Load per Tire (Tonne)	Tire Pressure (Kpa)	Tire Radius (cm)	Tire Spacing (cm)	Axle Spacing (cm)
	1a	Single Axle Single Tire	2	700	9,44	0	0
	1b	Single Axle Single Tire	2	700	9,44	0	0
	2a	Single Axle Single Tire	2,5	760	10,13	0	0
	2b	Single Axle Dual Tires	2,3	660	10,43	31,8	0
	3a	Single Axle Single Tire	2,5	760	10,13	0	0
	3b	Single Axle Dual Tires	2,525	760	10,18	31,8	0
	4a	Single Axle Single Tire	3,625	830	11,68	0	0
	4b	Tandem Axle Dual Tires	2,25	660	10,32	31,8	120
	5a	Single Axle Single Tire	4	850	12,12	0	0
	5b	Tandem Axle Dual Tires	2,25	660	10,32	31,8	120
	5c	Tandem Axle Dual Tires	2,25	660	10,32	31,8	120
	6a	Single Axle Single Tire	2,75	760	10,63	0	0
	6b	Tandem Axle Dual Tires	2,25	660	10,32	31,8	120
	6c	Tandem Axle Dual Tires	2,25	660	10,32	31,8	120
	7a	Single Axle Single Tire	3	830	10,62	0	0
	7b	Tandem Axle Dual Tires	2,125	660	10,03	31,8	137
	7c	Tridem Axle Dual Tires	2,25	660	10,32	31,8	137
	8a	Single Axle Single Tire	3	830	10,62	0	0
	8b	Single Axle Dual Tires	1,75	660	9,10	31,8	0
	8c	Tandem Axle Dual Tires	2,375	660	10,60	31,8	120
	9a	Single Axle Single Tire	3	830	10,62	0	0
	9b	Single Axle Single Tire	3,5	700	11,47	0	0
	9c	Tridem Axle Dual Tires	2	660	9,73	31,8	120

2.2. Flexible Pavement Design

To determine pavement design, traffic parameters are needed, such as: determining design life, ADT, vehicle type, axle type, and vehicle damage factor, so that ESA value can be obtained. ESA value is used to determine pavement structure based on 2017 Pavement Design Guide. Pavement type selection used in 3B design chart and layer characteristics such as modulus and Poisson Ratio can be seen in Table 2.

Table 2. Pavement structure and characteristics.

Layer	Thickness (mm)	Modulus (Mpa)	Poisson's Ratio
AC WC	40	1100	0,4
AC BC	60	1200	0,4
AC Base	245	1600	0,4
Granular Base Class A	300	1100	0,45
Subgrade	∞	600	0,45

2.3. Strain Response using KENPAVE Program

Analysis of strain response on each axle configuration and tire type can be reviewed through the grouping from Table 1 with the help of analysis softwares such KENPAVE, Abacus, Circly, Bisar, Ansys, etc. KENPAVE program is a software for pavement planning and divided into four separated programs and added with several programs such as LAYERINP and KENLAYER for flexible pavement that can show the mechanistic response of pavement such as strain, stress, and deflection. This study used vertical compressive strain above the subgrade and horizontal tensile strain below the asphaltic layer [6] [7].

Data needed for input into the KENPAVE Program are data on pavement structures that are interrelated with the planning of pavement thickness mechanistic methods of the theory of multilayer system. The data input needed are elastic modulus, poisson ratio, thickness of pavement layers, and load condition. The critical response caused by axle and tire configuration can be easily determined by comparing responses at various points along the transverse direction. Figure 1 shows point of analysis for each type of axle configuration to know strain critical point location [1].
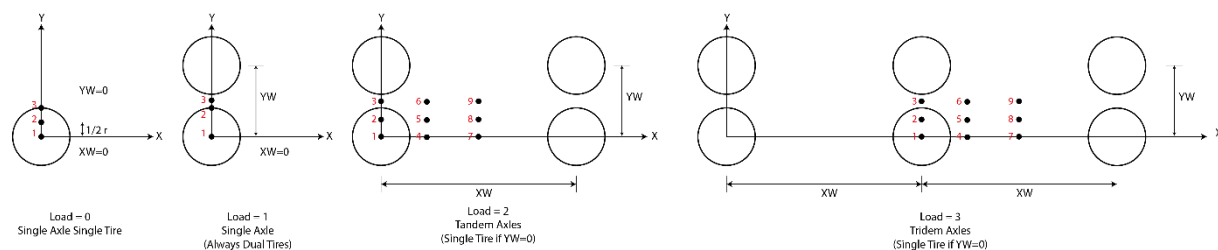

Figure 1. Axle schematics for mechanistic response analysis locations.

2.4. Flexible Pavement Distress Modelling

Fatigue is a fracture phenomenon caused by repeated application of tensile strains that are less than the strength of the material. Traditional asphalt concrete (AC) cracking models assume cracking begins at the bottom of the asphalt layer and propagates upward to the surface [bottom-up]. Permanent deformation, also known as rutting, is the failure of a pavement due to poor consolidation or lateral movement of layer materials due to repeated vehicle loads [8] [9].

Vertical compressive strains are used to predict rutting distress with the number of allowable repetitions to prevent rutting, symbolized with Nd. Horizontal tensile strains are used to predict fatigue cracking distress with the number of allowable repetitions to prevent fatigue cracking, symbolized with Nf. Asphalt Institute equations are used to determine Nd and Nf. Any Nd or Nf number below the actual number of repetitions means that fatigue cracking or rutting will form on the road pavement because pavement is not adequate enough to bear the traffic load [10],

3. Result and Discussion

3.1. Vertical Compressive and Horizontal Tensile Strain on Different Axle Configurations

The result from KENPAVE for Vertical Compressive and Horizontal Tensile Strain of each axle configuration with the response points based on Fig 1 are shown on Figure 2 and 3.

Based on Figure 2 and 3, each axle for each tire variation has maximum vertical compressive and horizontal tensile strain value. This value will be used in the calculation for rutting and fatigue damage predictions. Vertical compressive and horizontal tensile strain values on the tandem axle dual tires (c) and tridem axle dual tires (d) increase from point 1 to 3, 4 to 6, and 7 to 9. In addition, there is a decrease in vertical compressive strain values from point 3 to 4 and 6 to 7. This shows that the point that is located closer to the centre of tire spacing will experience an increase in the vertical strain value, whereas the

point that is located closer to the centre of axle spacing will experience a decrease. Some tire variation from each axle configuration has same strain values because of the similar loading and pressure.
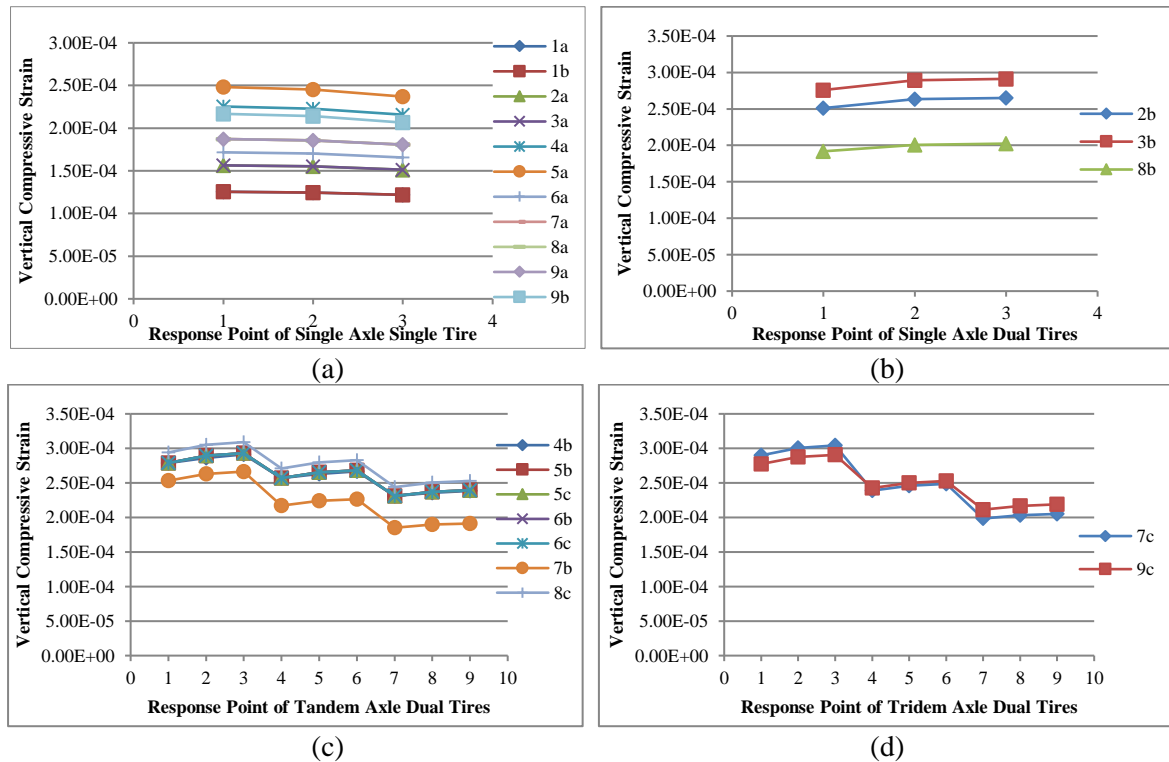

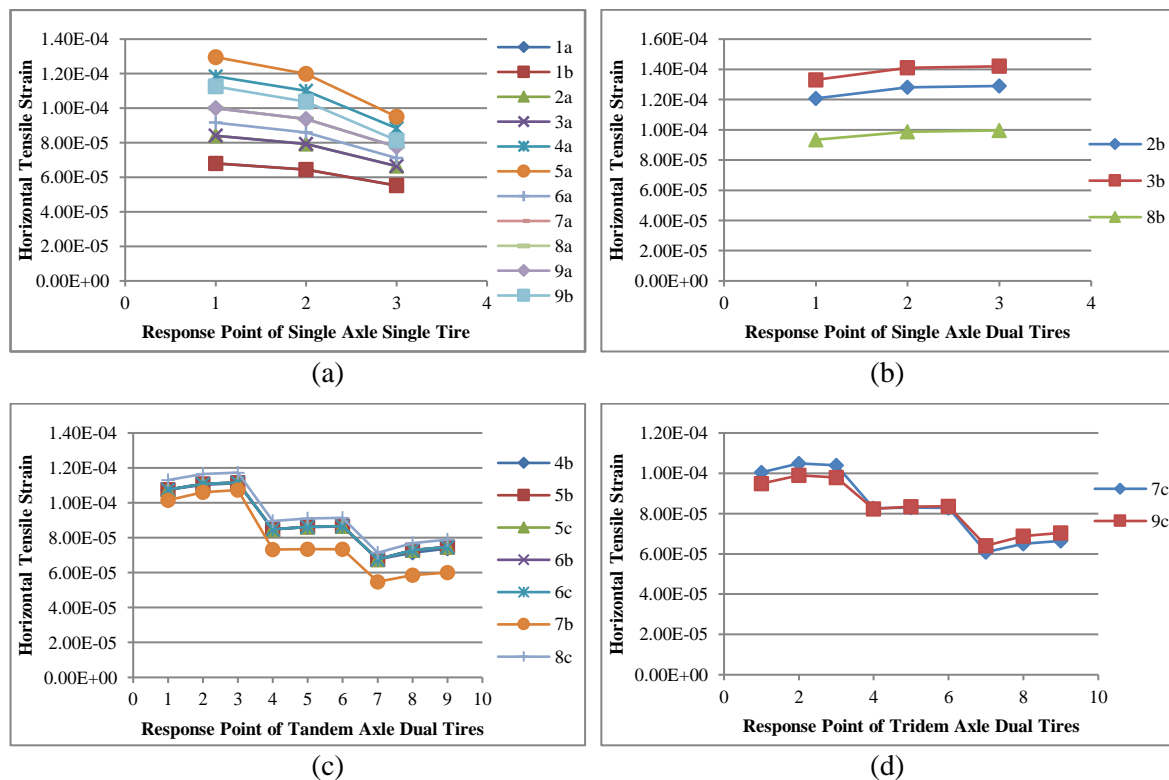**Figure 2.** Vertical compressive strain on difference axle and tire configurations.

Figure 3. Horizontal tensile strain on difference axle and tire configurations.

3.2. Vertical Compressive and Horizontal Tensile Strain on Different Vehicles

Analysis result from each axle type and tire is then combined in accordance with the vechicle type in Cipularang Highway Km 97 as shown on Figure 4.
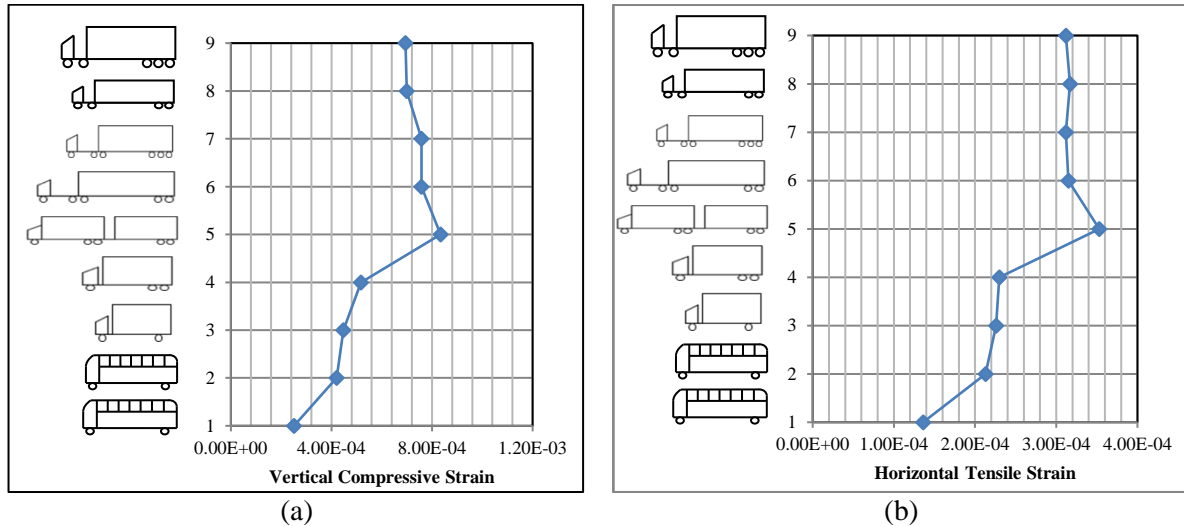

(a)   (b)

Figure 4. Strains on difference vehicles.

Vertical and horizontal strain value for each commercial vehicle can be obtained by adding the strain values from front, middle, and rear axles. From Figure 4, if referring based o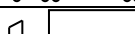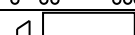n vehicle loads, vehicle number 7 has higher total loads than vehicle number 5. However, vertical (a) and horizontal (b) strain value turns out to be smaller because vehicle number 7 has tridem rear axle which has larger contact areas than tandem axle, so that the damage level is smaller than the number 5 vehicle whose rear axle is tandem. Same goes between vehicle number 8 and 9.

Vehicle number 3 and vehicle number 4 has a load difference of more than 10 tonnes but the strain value produced is not too much different. This is because vehicle number 4 has a rear tandem axle so that the damage level is smaller than the number 3 vehicle whose rear axle is single.

3.3. Nd and Nf on Different Vehicles

Road pavement needs to permit repetitions for commercial vehicles so that the vertical and horizontal strain values will not cause rutting and fatigue damage [2]. Table 3 shows a comparison between the number of permit reps and actual reps.

Table 3. Nd and Nf compared to actual repetitions.

Vehicle Figure	Tire Code	Vehicle Load (Tonne)	Actual Repetitions	Nd	Nf
	1a and 1b	8	1,039,076	154,945,950	291,780,257
	2a and 2b	14.2	12,599,343	19,577,027	22,914,708
	3a and 3b	15.1	10,751,613	15,267,329	16,375,935
	4a and 4b	25.25	4,512,808	8,608,212	14,825,061
	5a, 5b, and 5c	44	199,990	1,271,191	1,305,944
	6a, 6b, and 6c	41.5	73,909	1,862,938	2,491,357
	7a, 7b, and 7c	50	421,717	1,862,938	2,630,294
	8a, 8b, and 8c	32	1,486,879	2,576,122	2,403,521
	9a, 9b, and 9c	37	443,455	2,635,942	2,630,294

The number of allowable repetitions (Nd) and (Nf) is inversely proportional to the horizontal strain value, meaning that the greater the horizontal strain value, the number of vehicle reps that can cross the road without causing rutting fatigue will be smaller. It can also be seen that the pavement used will not experience groove damage because the actual repetition value is below the Nd and Nf.

4. Conclusion

a. On single axle single tire, the biggest strain value is at the center of the tire. Single axle dual tires obtains biggest strain at the tire radius. Tandem and tridem axle dual tires obtain biggest strain values at ½ distance between tires.

b. Vertical and horizontal strain value on the vehicles are not only influenced by vehicle loading but also axle configuration.

c. Number of allowable repetitions is inversely proportional to vertical and horizontal strain value, which means that the bigger vertical strain value is, the number of vehicle reps that can cross the road without causing rutting damage will be smaller.

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