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SIMPLIFIED MECHANISTIC – EMPIRICAL ANALYSIS OF FLEXIBLE PAVEMENT

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ABSTRACT

Pavement stress-strain analysis is an ideal tool for analytical modelling of pavement behaviour and thus, constitutes an integral part of pavement design and performance evaluation. It is the fundamental basis for the mechanistic design theory. Predicting pavement response by simplified procedure analysis by relying on equivalency factors using axle load spectrum which is obtained from Weigh-In-Motion (WIM) data is aimed for this study. The framework for computing the structural response of the standard axle group loads on a pavement structure by using a layered elastic computer program and calculation of pavement responses for axle load distribution for different axle groups and axle types by using the theoretical analysis. From the study, the summary of the obtained results are as follows: (1) axle load distribution was developed for the four considered axle configurations; (2) Single axle with single tyre has the greatest destructive impact followed by the tridem axle with dual tyres (TRDT) and next by TADT. The least destructive axle group type is the Single Axle with Dual tyre SADT.The predicted pavement response by theoretical analysis indicates that the critical tensile strains obtained results are all greater than the critical vertical strains. At the heaviest axle load, from 70KN, for both SAST and SADT; from 140KN for TADT; and from 210KN, the critical strains have the greatest magnitude by SAST and followed by SADT and next by TADT. The least critical tensile strain is from the TRDT.

Keywords: Multilayer Elastic theory, Layered elastic Computer Program, Standard Axle load, Axle load Distribution, Theoretical Analysis

INTRODUCTION

Unlike empirical procedures, the M-E design method is more adaptable to changing loading, material, construction, and environmental conditions. In the M-E method, the design is performed with different transfer equations for all types of distress modes (rutting, fatigue cracking, etc.) (Behiry, 2012; Mashayekhi et al., 2011; Muniandy et al., 2013).

The mechanical part of the M-E design methods is based on basic material mechanics, and stress, strain and displacement values (outputs) are calculated at any depth of the cross section depending on traffic loads, environmental loads and layer characteristics (inputs) on the road (Ankit and Abhinav, 2014; Mousa et al.,2015). In the empirical part, these mechanical responses are converted to service life by transfer equations (pavement life estimation models) (Behiry, 2012). Burmister's layered theory (Huang, 2007; Singh and Sahoo, 2020), is one of the most practical methods for mechanical analysis of flexible pavements. In this theory, the layers are defined as linear elastic with the modulus of elasticity (E) and Poisson's ratio (υ). The Burmister theory can also be used in mechanical analysis of multi-layered systems containing viscoelastic and nonlinear layers with some modifications (Huang, 2007).

The induced states of stresses and strains in the pavement, due to traffic loading and environmental conditions, were predicted using the theory of mechanics (Burmister theory) implemented in several computer softwares. The development of a future pavement design methodology must answer to these challenges and not remain in simple analysis based on the load equivalence factors that are implemented worldwide and at present, constitutes a simplified tool to characterize road traffic (Pereira and Pais, 2017).

Premature failure in flexible pavement has long been a problem in many roads with the large increase in truck axle load. To fully utilize each pavement material in a cost-efficient manner, a pavement should generally have a design, striking a reasonable balance between the rutting and fatigue modes of distress. (Ankit and Abhinav, 2014). In the analysis of flexible pavement, axle loads on the surface of the pavement produce two different types of strains which are believed to be most critical for design purposes. These are the horizontal tensile strains; ε_t at the bottom of the bitumen layer, and the vertical compressive strain; ε_v at the top of the subgrade layer. If the horizontal tensile strain ε_t is excessive, cracking of the surface layer will occur and the pavement will fail due to fatigue. If the vertical compressive strain ε_v is excessive, permanent deformations are observed at the surface of the pavement structure (from overloading the subgrade) and pavement fails due to rutting (Ankit and Abhinav, 2014).

Instead of analysing the stresses and strains due to each axle-load group, a simplified and widely accepted procedure is to develop equivalent factors and convert each load group into an equivalent 18-kip (80-kN) single-axle load. It should be noted that the equivalency between two different loads depends on the failure criterion employed. Equivalent factors based on fatigue cracking could be different from those based on permanent deformation. Therefore, the use of a single equivalent factor for analysing different types of distress is empirical and should be considered as approximate only. (Huang, 2007). The EALF is based on the fixed vehicle procedure of converting the number of repetitions of a given axle load, single, tandem, or tridem, into an equivalent number of repetitions of an 18-kip (80-kN) single-axle load. The values of EALF depend on the failure criterion employed. The EALF based on fatigue cracking is different from that based on permanent deformation. The use of a single value for both modes of failure is approximate at best. The most widely used method for determining the EALF is that which uses the empirical equations developed from the AASHO Road Test. (Huang, 2007).

METHODOLOGY

Pavement Sections

The main material data utilized in this study was obtained from the secondary data obtained from the works of (Claros et al., 1986) for the elastic pavement structural data that were used in the development of the mechanistic-empirical analysis and design framework.

Assume Pavement Configurations and Material Properties

The Nigerian overlay design methodology research served as a primary source of data for the material properties and pavement geometry in Table 2.1. In addition to Table 2.1, Load stress for typical Nigerian Roads is adopted as (PSI/KPA) (80/552) from the same source.

Table 1: Input for Elastic Pavement System

LAYER	MATERIAL	ELASTIC MODULUS PSI /KPA	POISSON'S RATIO	THICKNESS IN/CM
1	WEARING COURSE	70,000/ 4,830,000	0.300	2.000 / 5.08
2	BINDER'S COURSE	200,000/ 1,380,000	0.350	2.800 / 7.112
3	STONE BASE	65,000 /448,500	0.400	8.100/ 20.574
4	SUB-BASE	45,000 /310,500	0.450	5.200 / 13.208
5	SUB-GRADE	42,000/ 289,800.	0.450	SEMI-INFINITE

Source: (Claros et al., 1986)

Truck Traffic Load Data

This involves the standard axle load for each axle load group and axle load distribution for the non-standard axle group loads.

Standard Axle load: The standard axle is defined as a single axle with dual wheels that carries a load of 8.2 tonnes. Loads on the axle configurations given above that cause the same amount of damage as the standard axle are given in Table 2.2.

Table 2: Axle Loads Which Cause Equal Damage (Unity)

AXLES CONFIGURATION	SAST	SADT	TADT	TRDT
LOAD (KN)	53	80	135	181

Source: (Austroads,2012)

Non- standard Axle Load: Axle load study and Review and Update of Design Standards for Federal Roads, Nigeria, served as a primary source of truck Traffic data for the data collection for axle load study (Stewart Scott International (2007)). The independent axle load surveys have become the main source of up-to-date vehicle weight data, as there have no recent data on weighbridge operations is available. The Weigh-In-Motion System (WIM) Data contains Vehicle Classification and axle group load data. Traffic survey conducted as secondary data by (Stewart Scott International (2007)). On Kaduna - Zaria Northbound and Zaria - Kaduna Southbound. This traffic data was captured by a portable weigh-in-motion (WIM) System on Kaduna - Zaria Roadway with the following details: (i) Number of axles; (ii) Gross Vehicle Mass (GVM); and (iii) Individual axle weights, recorded in "TONS".

Determination of EALF

The AASHTO equations for computing EALF are described by the AASHTO Equivalent Factors in which the following regression equations based on the results of road tests can be used for determining EALF. The EALF magnitude for each axle load group was determined by using Equation 1 and 2 respectively.

EALF (LEF) FOR FLEXIBLE PAVEMENT: AASHTO EQUIVALENCY FACTORS

The following regression equation is one of the most widely used methods for determining EALF (LEF) obtained from the AASHTO Road Test:

$$\text{Log}\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18+1) - 4.79\log(L_x+L_2) + 4.33\log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \quad (1)$$

$$G_t = \log\left(\frac{4.2-p_t}{4.2-1.5}\right) \quad ; \quad \beta_x = 0.4\,\frac{0.081(L_x+L_2)^{3.23}}{(SN+1)^{5.19}\,(L_2)^{3.23}}$$

Where, W_{tx} = the number of x-axle load application at the end of time t,

W_{t18} = the number of 18kip (80KN) single axle load application to time t,

Lx = the load in kip on one single axle, one set of tandem axles, or one set of tridem axles,

L2 is the axle code = 0 for steering axle; 1 for single axles, 2 for tandem axles, and 3 for tridem axles (Huang (2007)).

SN = structural number - a function of thickness, modulus of each layer, and drainage condition of base and sub-base.

Pt = terminal serviceability – which indicates the pavement conditions to be considered as failures, β18= the value of βx when Lx = 18 and L2=1

$$\text{EALF} = \frac{W_{t18}}{W_{tx}} \quad (2)$$

Practically, EALF is not very sensitive to pavement thickness and SN equal to 5 may be used for most cases and a P_t value of 2.5 can be used by AASHTO. (Huang (2007)).

Pavement Reaction (Strains)

The KENLAYER computer program was used to calculate the tensile strain at the bottom of the asphalt layer and the compressive strain at the top of the subgrade soil, instead of the traditional ELSYM5 computer program used by NEMPADS. The basic design input is the standard axle load magnitude for each axle type. These computed strains are incorporated in the fatigue cracking and rutting models to estimate the pavement life for different axle weights. Different axle loads are considered in this research.

Simplified Procedure for Computing Critical Strains

Instead of analysing the stresses and strains due to each axle load group, as contained in the developed axle load spectra above, a simplified and widely accepted procedure is to develop equivalent factors and convert each load group into an equivalent 18-KIP (80-KN) single - axle load. It should be noted that the equivalent between two different loads depends on the failure criterion employed. Equivalent factors based on fatigue cracking could be different from those based on permanent deformation. Therefore, the use of a single equivalent factor for analysing different types of distresses is empirical and should be considered as approximate only. (Huang (2007)).

Theoretical Analysis

The many factors involved make it impossible to select an appropriate EALF that can be applied to all situations. For a truly mechanistic design method, each load group should be considered individually, instead of using an equivalent single axle load. Deacon (1969) conducted a theoretical analysis of EALF by layered theory based on an assumed f_2 of 4, or

$$EALF = \frac{W_{t18}}{W_{tx}} = (\frac{\epsilon_x}{\epsilon_{18}})^4 \qquad (3)$$

In which ϵ_x is the tensile strain at the bottom of asphalt layer due to an x-axle load and ϵ_{18} is the tensile strain at the bottom of asphalt layer due to an 18-kip (80-kN)axle load, and it is considered that the use of 4 for compressive strains respectively. Mechanistic-empirical distress prediction procedures could offer such alternative .The mechanistic-empirical distress prediction is based on the combination of the fatigue and permanent deformation characteristics of the pavement materials from the exponential results with the calculated primary pavement responses through KENLAYER (Huang (2007)).

Fatigue Damage (Flexible)

Deacon (1969) conducted a theoretical analysis of EALF by layered theory based on an assumed f2 of 4,

For f_2 = 4:

$$EALF = \frac{W_{t18}}{W_{tx}} = (\frac{\varepsilon_{tx}}{\varepsilon_{t18}})^4 = (\frac{L_x}{18})^4 \qquad (4)$$

This implies that Equation **4, is $\mathbf{EALF^{0.25}\ X \varepsilon_{t\,(std)} = \varepsilon_{t(Li)}}$**

EALF for the entire load carried by axle group type (KN) has been calculated using Equation 1 and 2.

Rutting Damage (Flexible)

For f_2=4.

$$EALF = \frac{W_{t18}}{W_{tx}} = (\frac{\varepsilon_{cx}}{\varepsilon_{c18}})^4 = (\frac{L_x}{18})^4 \qquad (5)$$

This implies that Equation 4 is $EALF^{0.25}$ X $\varepsilon_{v(std)} = \varepsilon_{vi}$

EALF for the entire load carried by axle group type (KN) has been calculated using Equation 1 and 2

RESULTS AND DISCUSSIONS

The following sections discuss the outcomes of these results:

Axle Load Distribution

The distribution of axle loads by axle configuration (i. e., steering, single, tandem, and Tridem) is compiled from WIM data output. The vehicle class distribution and the detailed axle configurations extracted from each of the observed vehicle trucks were significant parameters required for the axle load distribution.

Vehicle Class Distribution

The frequency of each of the vehicle types by axle classification is shown in Table 3 on the Kaduna-Zaria Roadway.

Table 3: Vehicle Class Distribution for Kaduna-Zaria Roadway

Categories of truck and transit vehicle types by axle classification	SOUTHBOUND AXIS		NORTHBOUND AXIS	
	Truck Count and Weighed on the Southbound Axis	Frequency (%)	Truck Count and Weighed on the Northbound Axis	Frequency (%)
2-Axle Truck	18	20.93	19	19.19
3-Axle Truck	11	12.79	10	10.1
4-Axle Truck	50	58.14	56	56.57
5-Axle Truck	7	8.14	12	12.12
6-Axle Truck	0	0	2	2.02
TOTAL	86	100	99	100

SOUTHBOUND AXIS: ZARIA-KADUNA ROADWAY;
NORTHBOUND AXIS: KADUNA-ZARIA ROADWAY.

Total number of truck vehicles counted and weighed on the southbound axis is 86No, and 99No is the total number of truck vehicles counted and weighed on the northbound axis. In all the vehicle truck analyzed, 6-Axle truck is not available on the southbound axis whereby on the northbound axis, it is very scanty, with a frequency of 2.02%.However, on both axis of the Kaduna-Zaria roadway, the 4-axle truck is significantly higher than all other axle truck types, and next is the 2-Axle truck on both of the axis. On the southbound axis, the truck vehicle 3-Axle and 5-Axle are minimally followed each other, and on the northbound, the truck vehicle 5-Axle and 3-Axle are minimally followed each other.

Axle Configuration Composition

Axle configuration is defined by the number of axles sharing the same suspension system and the number of tires in each axle. Multiple axles involve two, three, or four axles spaced 1.2 to 2.0 meters apart, and are referred to as tandem, triple, or quad, respectively. They are treated differently from single axles because they impose pavement stresses/strains that overlap (Papagiannakis and Massad, 2008; Huang 2007; Highway Design Manual: 613-2012).therefore, the composition of the different axle types as contained in each surveyed vehicle type is shown in Table 4.

Table 4: Axle Configurations Composition from Vehicle Class Distribution for Kaduna-Zaria Roadway

Categories of truck and transit vehicle types by axle classification	SOUTHBOUND AXIS					NORTHBOUND AXIS				
	Trunk Counted	SAST	SADT	TADT	TRDT	Truck Counted	SAST	SADT	TADT	TRDT
2-Axle Truck	18	18	18	-	-	19	19	19	-	-
3-Axle Truck	11	11	-	11	-	10	10	-	10	-
4-Axle Truck	50	50	50	50	-	56	56	56	56	-
5-Axle Truck	7	7	-	14	-	12	12	1	22	1
6-Axle Truck	0	0	-	-	-	2	2	-	2	2
TOTAL	86	86	68	75	-	99	99	76	90	3

SAST: Single Axle with Single Tyre(Steering Axle)
SADT: Single Axle with Dual Tyres
TADT: Tandem Axle with Dual Tyres
TRDT: Tridem Axle with Dual tyres.

Based on the axle configurations composition, on both axis, the SAST, has the same magnitude of the observed vehicle truck, because each of the truck vehicle counted are been steered by this axle. Therefore, the magnitude of the SAST is significantly similar to the observed truck vehicle surveyed. From the analysed obtained results, the TADT has the highest magnitude of axle types on both axis, this is based on the reason that the 3-Axle truck; 4-Axle truck; 5-Axle truck; and 6-Axle truck vehicle, all contained TADT configuration in all the composition. The TRDT is very scanty on the Kaduna – Zaria roadway, because it is not available on all the Axle truck observed on the southbound axis and only 3No on the northbound axis from the 5-Axle truck vehicle (1-1-3) and 6-Axle truck vehicle (1-2-3)

Arithmetic Average Axle Load Magnitude

Arithmetic Average Axle Load Magnitude.: From the analysis of the output WIM Data, the arithmetic averages (Default value) of all the obtained axle loads for each axle type were estimated. This is shown on Table 5 as below.

Table 5: Arithmetic Average Load Magnitude on Kaduna-Zaria Roadway.

AXLE CONFIGURATIONS	SOUTHBOUND AXIS	NORTHBOUND AXIS
SAST	54.64	60.62
SADT	59.55	109.67
TADT	99.26	193.13
TRDT	0	333.36

In line with the obtained results as contained in Table 5, the obtained default value on the northbound axis were all heavier than on the weighed axle loads for each axle types on the southbound axis. The reason is that manufactured and construction items are been transported on the Kaduna-Zaria (northbound axis) roadway, whereby, on the Zaria-Kaduna (southbound axis), agricultural products were been transported.

Table 3 through Table 5 are the obtained results from the utilized traffic information used in this study that is mainly for Kaduna-Zaria roadway only, but cannot be used for any other roadway. The definition pattern can only be adopted.

Axle Load Distribution for the four different axle configurations.

Traffic loads are characterized in terms of load spectra that are the actual number of applications by axle configuration and axle weights. In this study, this is based on disaggregate axle load information (i.e., load spectra). These are presented in Figure 1 through Figure 4, for the four different axle configurations under consideration, and herein is presented below.

Axle Load Distribution for Single Axle with Single Tyre (SAST)

The count shown in Figure 1 represents the total number of WIM data records within the range of the corresponding bin for SAST. The count value was calculated using the corresponding bin number as the lower bound and the subsequent bin as the upper bound. For example, in the sample output in Figure 1, the count value corresponding to Bin 20KN represents the number of SAST while total weight is greater than 20KN but less than or equal to 30KN. Axle spectra depicted in Figure 1 for SAST is the statistical distributions of axle weights, by axle type, which comprise a traffic stream, on the southbound axis (SB) and northbound axis (NB) obtained results for the Kaduna-Zaria roadway. On both of the axis on the roadway, the axle weight range is between 10KN and 120KN. The first three heaviest axle weights on the axle weights on the SB axis are 50KN (39No); 40KN (16No); and 30KN (9No), whereby, on the NB axis, the first three heaviest axle weights are 60KN (32No); 50KN (18No); and 70KN (15No).

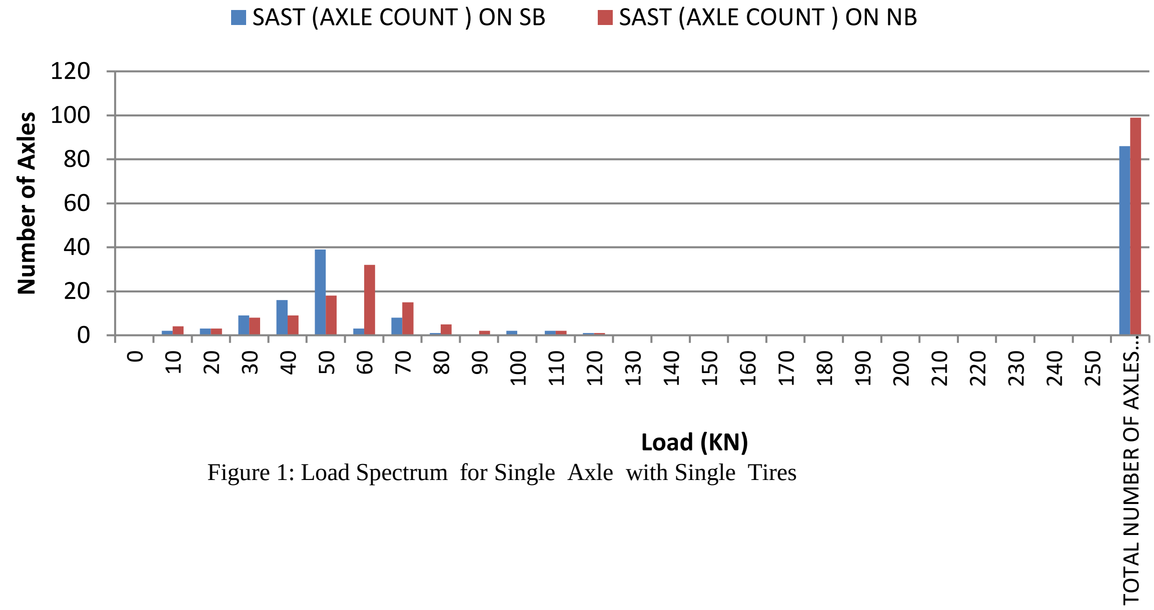


Figure 1: Load Spectrum for Single Axle with Single Tires

Axle Load Distribution for Single Axle with Dual Tyres (SADT)

The count shown in Figure 2 represents the total number of WIM data records within the range of the corresponding bin for SADT. The count value was calculated using the corresponding bin number as the lower bound and the subsequent bin as the upper bound. For example, in the sample output in Figure 2, the count value corresponding to Bin 50KN represents the number of SADT while total weight is greater than 50KN but less than or equal to 60KN. Axle spectra depicted in Figure 2 for SADT is the statistical distributions of axle weights, by axle type, which comprise a traffic stream, on the southbound axis (SB) and northbound axis (NB) obtained results for the Kaduna-Zaria roadway. On both of the axis on the roadway, the axle weight range is between 10KN and 170KN on the SB axis and between 10KN and 210KN on the NB axis. The first three heaviest axle weights on the axle weights on the SB axis are 40KN (31No); 50KN (10No); and 30KN (8No), whilst on the NB axis, the first three heaviest axle weights are 120KN (11No); 130KN (9No); and 6No (30KN; 40KN; 100KN; and 110KN).

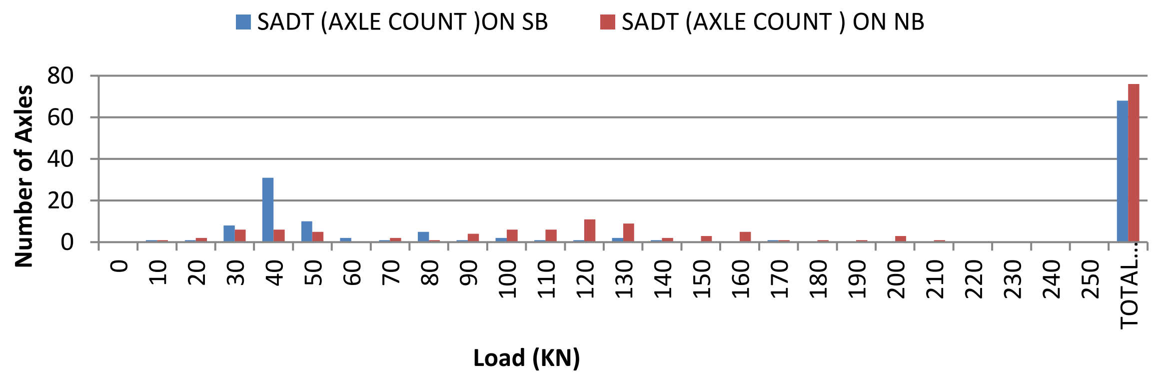


Figure 2: Load Spectrum for Single Axle with Dual Tires

Axle Load Distribution for Tandem Axle with Dual Tyres (TADT)

The count shown in Figure 3.3 represents the total number of WIM data records within the range of the corresponding bin for TADT. The count value was calculated using the corresponding bin number as the lower bound and the subsequent bin as the upper bound. For example, in the sample output in Figure 3.3, the count value corresponding to Bin 100KN represents the number of TADT while total weight is greater than 100KN but less than or equal to 120KN. Axle spectra depicted in Figure 3.3 for TADT is the statistical distributions of axle weights, by axle type, which comprise a traffic stream, on the southbound axis (SB) and northbound axis (NB) obtained results for the Kaduna-Zaria roadway. On both of the axis on the roadway, the axle weight range is between 20KN and 340KN in the SB axis and between 0KN and 380KN in the NB axis. The first three heaviest axle weights on the axle weights on the SB axis are 60KN (31No); 80KN (13No) ; and 40KN(11No), whilst on the NB axis, the first three heaviest axle weights are 220KN(15No); 140KN(11No); and 8No(180KN; 240KN; 100KN; and 110KN

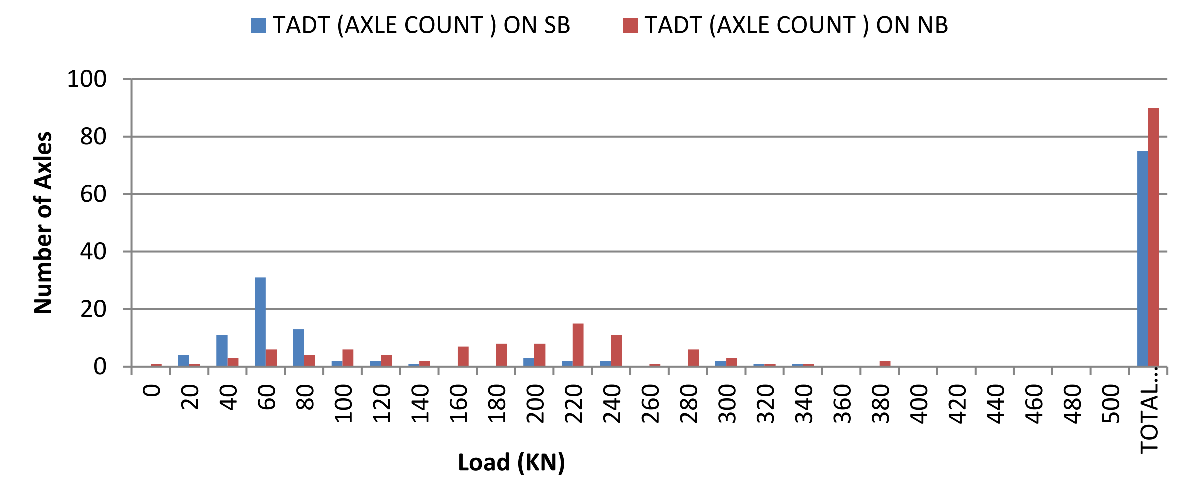


Figure 3: Load Spectrum for Tandem Axle with Dual Axles

Axle Load Distribution for Tridem Axle with Dual Tyres (TRDT)

The count shown in Figure 3.4 represents the total number of WIM data records within the range of the corresponding bin for TRDT. The count value was calculated using the corresponding bin number as the lower bound and the subsequent bin as the upper bound. For example, in the sample output in Figure 3.4, the count value corresponding to Bin 270KN represents the number of TRDT while total weight is greater than 270KN but less than or equal to 300KN. Axle spectra depicted in Figure 3.4 for TRDT is the statistical distributions of axle weights, by axle type, which comprise a traffic stream, on northbound axis (NB) obtained results for the Kaduna-Zaria roadway, because there is no counted and weighed TRDT on the southbound axis. On the northbound axis (NB) obtained on the Kaduna-Zaria roadway only, there is 2No 270KN and 1No 390KN.

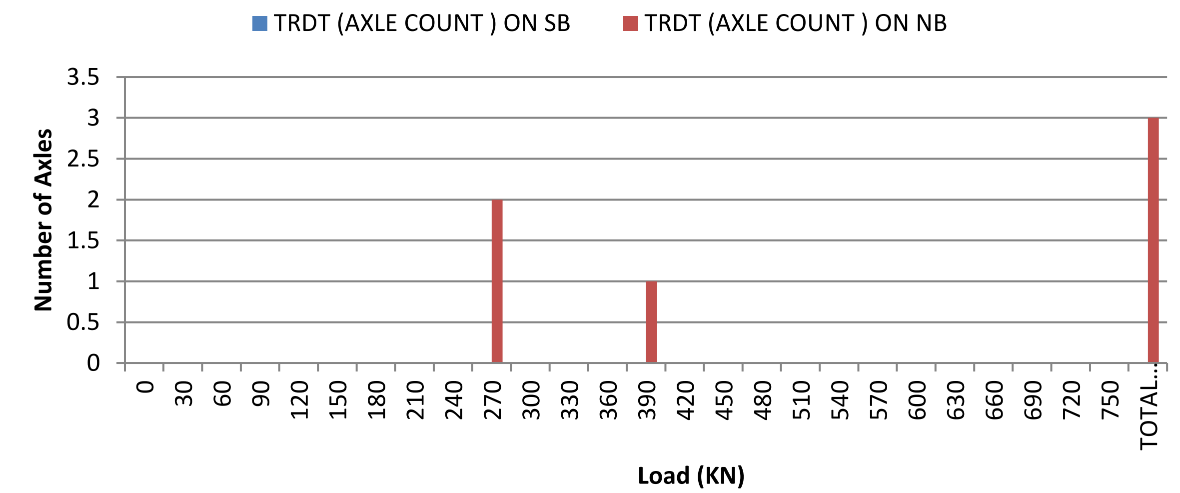


Figure 4: Load Spectrum for Tridem Axle with Dual Tires

Determination of Equivalent Axle Load Factor (EALF)

EALF are determined for each of the axle load ranges for the four different axle configurations from the output (WIM) data, according to Equations 2.1 and 2.2. The axle load ranges for each of the four different axle configurations are from the obtained results for the axle distribution for each of the axle configurations presented in Figures 3.1 through figure 3.4.The significant defining factor adopted are that each of the axle configurations are considered as one set; axle codes that have different values for each axle load groups; and the axle load ranges from the developed axle load distribution for each axle type. The determined EALF for each axle load ranges for each axle configurations utilizing regression equations based on the results of AASHO road tests are presented below:

Equivalent Axle Load Factor (EALF) For axle load Magnitude of Single Axle with Single Tyre (SAST):

EALF for axle load magnitude for SAST is calculated according to Equation 1 and 2, with the axle code '0' adopted for SAST in accordance to AASHO Road Tests, and the axle load ranges adopted from the obtained results as plotted in Figure 3.1. Figure 5 presents the EALF for the load spectrum with single axle with single tyre (SAST) on the Kaduna-Zaria roadway. The figures show that this axle group loads increase dramatically with increase the axle load ranges. The magnitude of the EALF is between 0 and 222.224 for the corresponding axle load spectrum between 0 and 250KN.

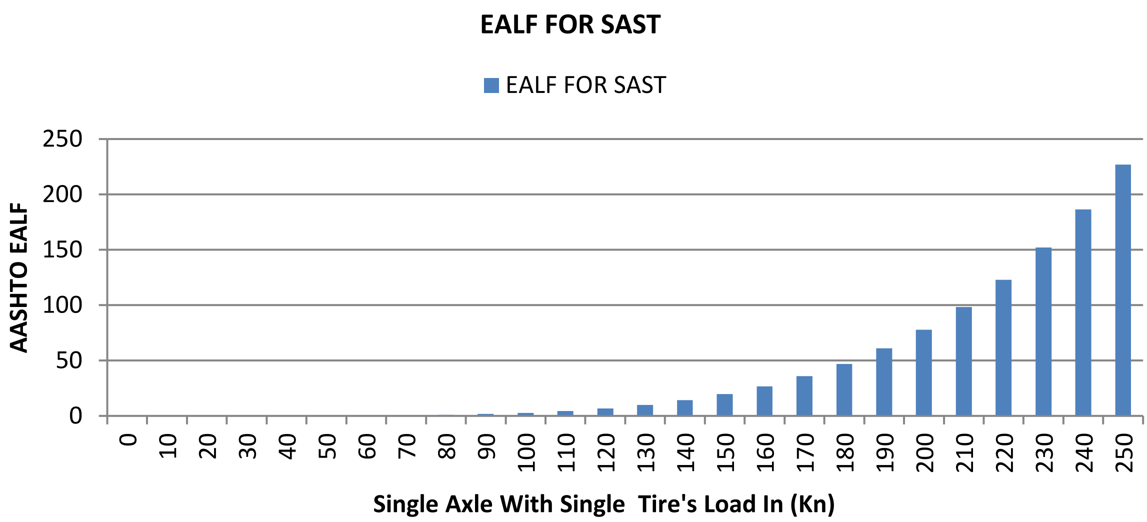


Figure 5: Aashto EALF for single axle with single tire

Equivalent Axle Load Factor (EALF) for axle load Magnitude of Single Axle with Dual Tyres (SADT)

EALF for axle load magnitude for SADT is calculated according to Equation 1 and 2, with the axle code '1' adopted for SADT in accordance to AASHO Road Tests, and the axle load ranges adopted from the obtained results as plotted in Figure 2. Figure 6 presents the EALF for the load spectrum with single axle with dual tyre (SADT) on the Kaduna-Zaria roadway. The figures show that this axle group loads increase dramatically with increase the axle load ranges. The magnitude of the EALF is between 0 and 87.879 for the corresponding axle load spectrum between 0 and 250KN

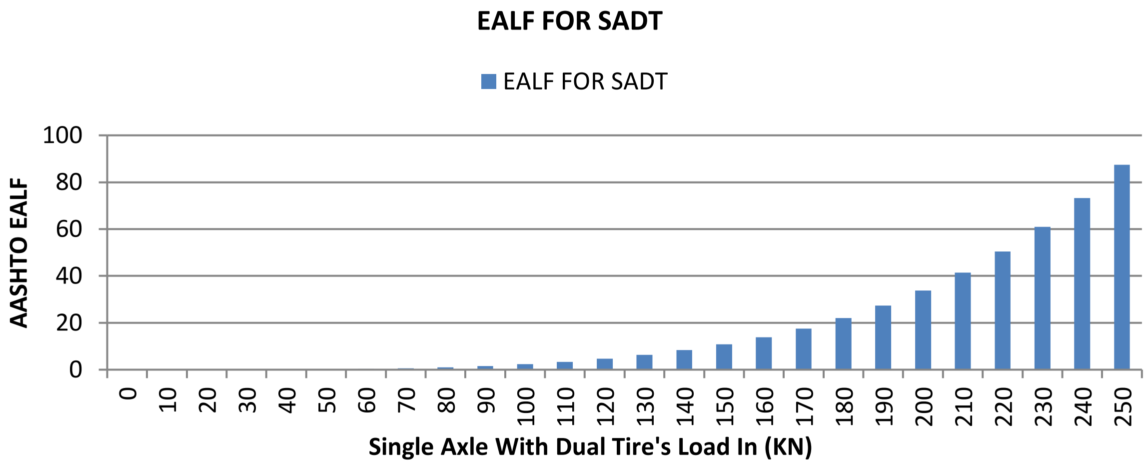
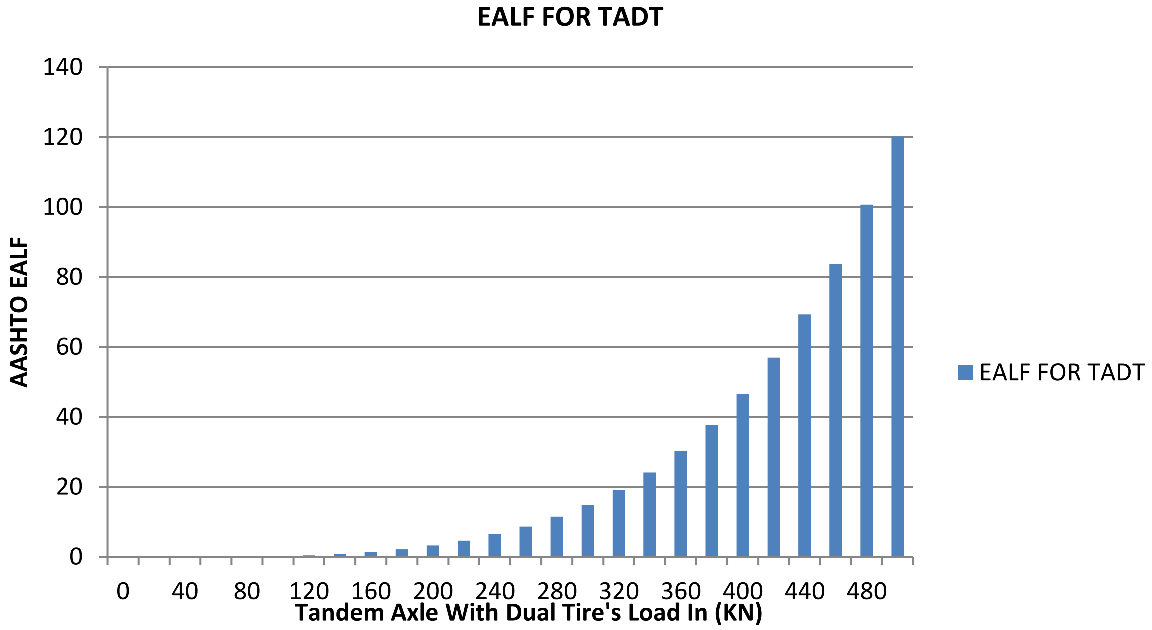


Figure 6: AASHTO EALF for single axle with dual tires

Equivalent Axle Load Factor (EALF) For axle load Magnitude of Tandem Axle with Dual Tyres (TADT)

EALF for axle load magnitude for TADT is calculated according to Equation 1 and 2, with the axle code '2' adopted for TADT in accordance to AASHO Road Tests, and the axle load ranges adopted from the obtained results as plotted in Figure 3.3. Figure 7 presents the EALF for the load spectrum with tandem axle with dual tyre (TADT) on the Kaduna-Zaria roadway. The figures show that this axle group loads increase dramatically with increase the axle load ranges. The magnitude of the EALF is between 0 and 120.881 for the corresponding axle load spectrum between 0 and 500KN



Figue 7: AASHTO EALF for tandem axle with dual tires

Equivalent Axle Load Factor (EALF) For axle load Magnitude of Tridem Axle with Dual Tyres (TRDT)

EALF for axle load magnitude for TRDT is calculated according to Equation 1 and 2, with the axle code '3' adopted for TRDT in accordance to AASHO Road Tests, and the axle load ranges adopted from the obtained results as plotted in Figure 3.4. Figure 8 presents the EALF for the load spectrum with tridem axle with dual tyre (TRDT) on the Kaduna-Zaria roadway. The figures show that this axle group loads increase dramatically with increase the axle load ranges. The magnitude of the EALF is between 0 and 145.667 for the corresponding axle load spectrum between 0 and 750KN

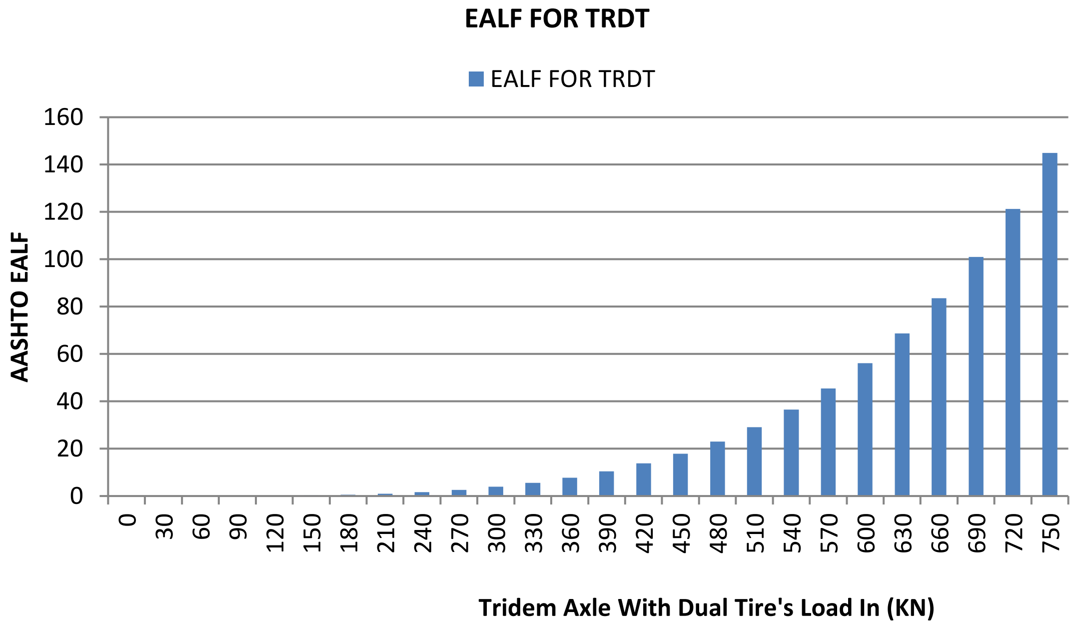


Figure 8: AASHTO EALF for tridem axle with dual tires

Computed Critical Strain for Standard Axle Load Magnitude

Critical strains were calculated for each of the standard axles by using the multilayer elastic analysis which is performed using the KENLAYER software. The obtained results were presented in Table 6. The critical tensile strains decreases as the axle configuration increased, however, the vertical strain trend differently, with the vertical strain obtained from the SADT, is significantly highest and whereby, obtained results of the vertical strains decreases for other axle load groups because the strains were directly under the tires, while the same contact pressure was used for the contact radius calculation for all the four different axle configurations.

Table 6: Calculated Critical Strain for Standard Axle Load Magnitude with Equal Damage Magnitude of Unity (1):

Axles Configuration	Standard Axle Load Magnitude for each axle type(KN)	Output Tensile Strain ε_t	Output Vertical Strain (ε_v
SAST	53	1.86E-04	1.39E-04
SADT	80	1.83E-04	1.44E-04
TADT	135	1.64E-04	1.33E-04
TRDT	181	1.52E-04	1.18E-04

SAST: Single Axle with Single Tyre; SADT: Single Axle with Dual Tyres; TADT: Tandem Axle with Dual Tyres; TRDT: Tridem Axle with Dual Tyres.

Computed Critical Strains by Theoretical Analysis

Critical tensile strains under the bottom of the asphalt were calculated for each of the axle load ranges for the four different axle groups' loads, according to Equation 4 and the critical compressive vertical strains at the top of the subgrade soils were all calculated according with Equation 4. The basic inputs are the critical pavement strains for each of the standard axle load magnitude for the four different axle configurations and obtained results summary for the determined EALF for each of the axle load ranges. The effects of the axle load magnitude for the four different axle configurations are presented below.

Effect of Axle Load Magnitude for Single Axle with Single Tyre (SAST) On Critical Pavement Strains.

Tensile strain at the bottom of asphalt layer is calculated according to Equation 4.Compressive vertical strain on the top of subgrade soil is calculated according to Equation2.5.These inputs are adopted as follows: (1) The predicted pavement response for the standard axle load magnitude are adopted from Table 6 for SAST, whereby the obtained results of tensile strains and compressive strains are adopted. The determined EALF for each of the axle load ranges for SAST are adopted from Figure 5.

Figure 9 present the relationship between tensile strain on the bottom of asphalt layer and the compressive strain on the top of subgrade soil versus axle load for SAST .The figure show that the tensile and compressive strain increase with increasing the axle load. Based on the theoretical analysis applied for determining the critical strains for each of the axle load ranges for each of the axle type, the obtained results for the tensile strains is greater than the vertical strains for all the considered axle load ranges. This is because the output critical pavement strains for tensile strains is greater than the vertical strains for the standard axle load magnitude for SAST

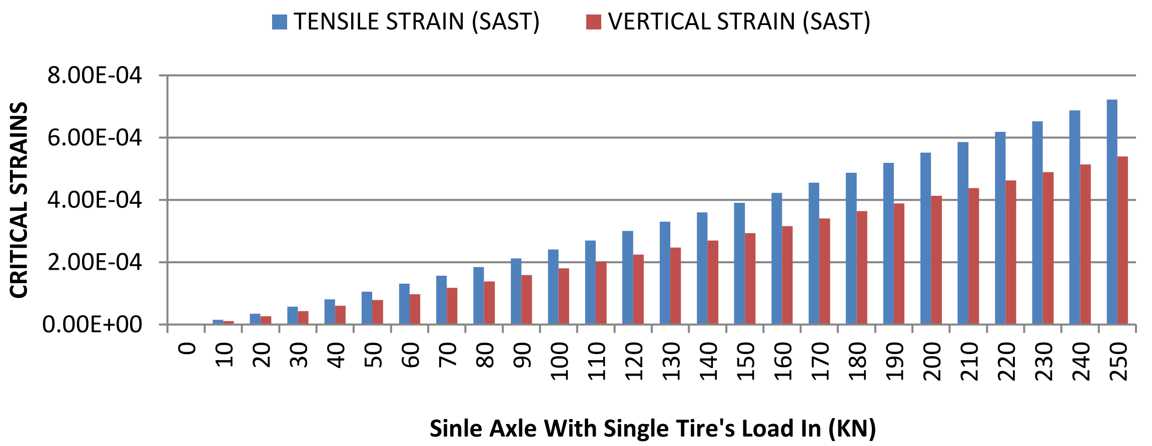


Figure 9: Pavement reaction (critical strains) for single axle with single tire from theoretical analysis

Effect of Axle Load Magnitude for Single Axle with Dual Tyres (SADT) On Critical Pavement Strains

Tensile strain at the bottom of asphalt layer is calculated according to Equation 4.Compressive vertical strain on the top of subgrade soil is calculated according to Equation2.5.These inputs are adopted as follows: (1) The predicted pavement response for the standard axle load magnitude are adopted from Table 6 for SADT, whereby the obtained results of tensile strains and compressive strains are adopted. The determined EALF for each of the axle load ranges for SADT are adopted from Figure 6.

Figure 3.10 present the relationship between tensile strain on the bottom of asphalt layer and the compressive strain on the top of subgrade soil versus axle load for SADT .The figure show that the tensile and compressive strain increase with increasing the axle load. Based on the theoretical analysis applied for determining the critical strains for each of the axle load ranges for each of the axle type, the obtained results for the tensile strains is greater than the vertical strains for all the considered axle load ranges. This is because the output critical pavement strains for tensile strains is greater than the vertical strains for the standard axle load magnitude for SADT

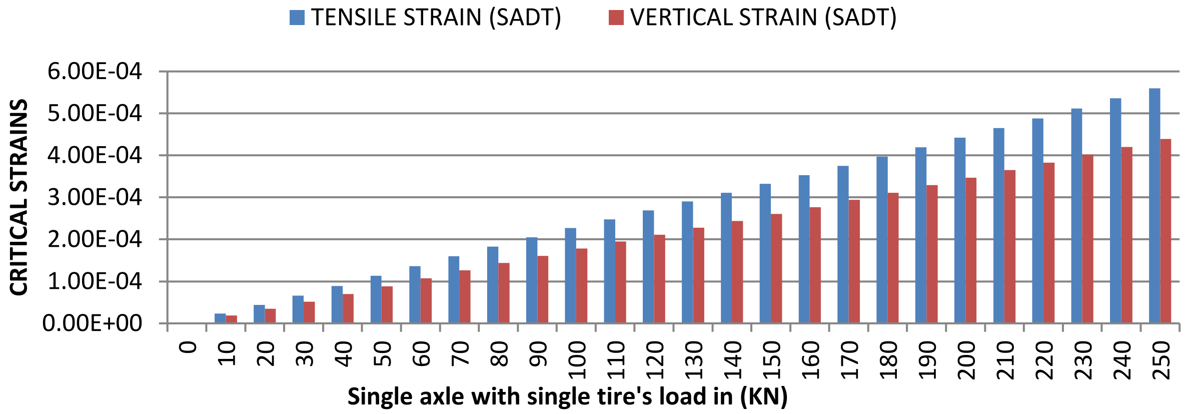


Figure 10: Pavement reaction (critical strains) for single axle with dual tires from theoretical analysis.

Effect of Axle Load Magnitude for Tandem Axle with Dual Tyres (TADT) On Critical Pavement Strains

Tensile strain at the bottom of asphalt layer is calculated according to Equation 4.Compressive vertical strain on the top of subgrade soil is calculated according to Equation2.5.These inputs are adopted as follows: (1) The predicted pavement response for the standard axle load magnitude are adopted from Table 6 for TADT, whereby the obtained results of tensile strains and compressive strains are adopted. The determined EALF for each of the axle load ranges for TADT are adopted from Figure 7.

Figure 11 present the relationship between tensile strain on the bottom of asphalt layer and the compressive strain on the top of subgrade soil versus axle load for TADT .The figure show that the tensile and compressive strain increase with increasing the axle load. Based on the theoretical analysis applied for determining the critical strains for each of the axle load ranges for each of the axle type, the obtained results for the tensile strains is greater than the vertical strains for all the considered axle load ranges. This is because the output critical pavement strains for tensile strains is greater than the vertical strains for the standard axle load magnitude for TADT

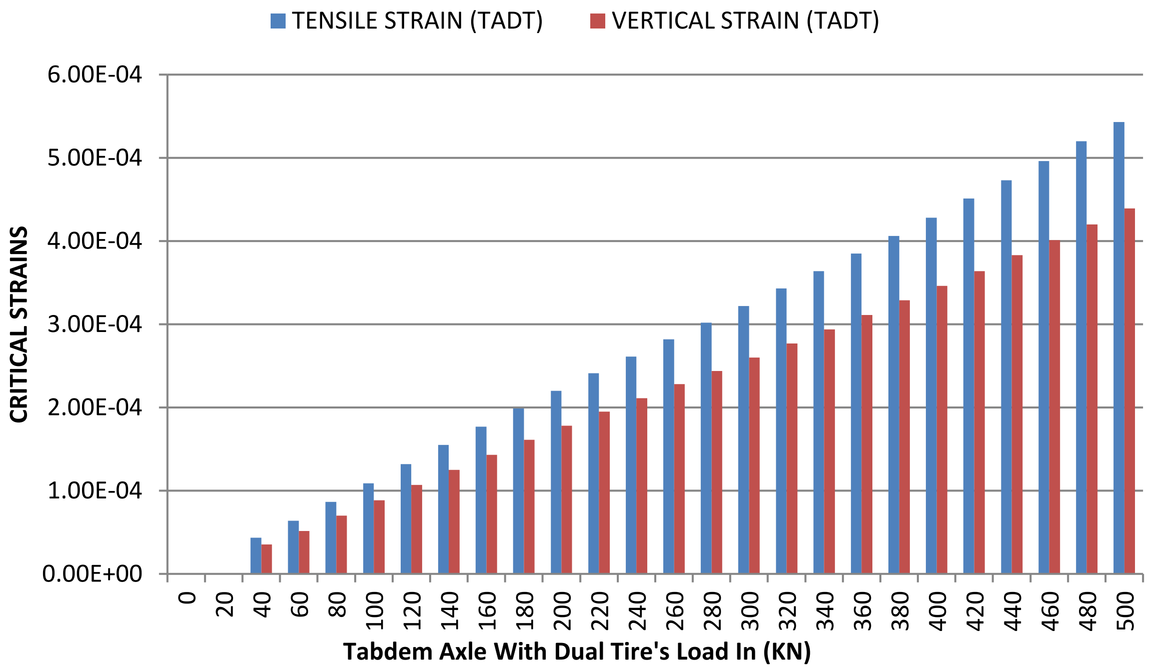


Figure 11: Pavement reaction (critical strains) for tandem axle with dual tire's load from theoretical analysis

Effect of Axle Load Magnitude for Tridem Axle with Dual Tyres (TRDT) On Critical Pavement Strains

Tensile strain at the bottom of asphalt layer is calculated according to Equation 4.Compressive vertical strain on the top of subgrade soil is calculated according to Equation2.5.These inputs are adopted as follows: (1) The predicted pavement response for the standard axle load magnitude are adopted from Table 6 for TRDT, whereby the obtained results of tensile strains and compressive strains are adopted. The determined EALF for each of the axle load ranges for TADT are adopted from Figure 8.

Figure 12 present the relationship between tensile strain on the bottom of asphalt layer and the compressive strain on the top of subgrade soil versus axle load for TRDT .The figure show that the tensile and compressive strain increase with increasing the axle load. Based on the theoretical analysis applied for determining the critical strains for each of the axle load ranges for each of the axle type, the obtained results for the tensile strains is greater than the vertical strains for all the considered axle load ranges. This is because the output critical pavement strains for tensile strains is greater than the vertical strains for the standard axle load magnitude for TRDT

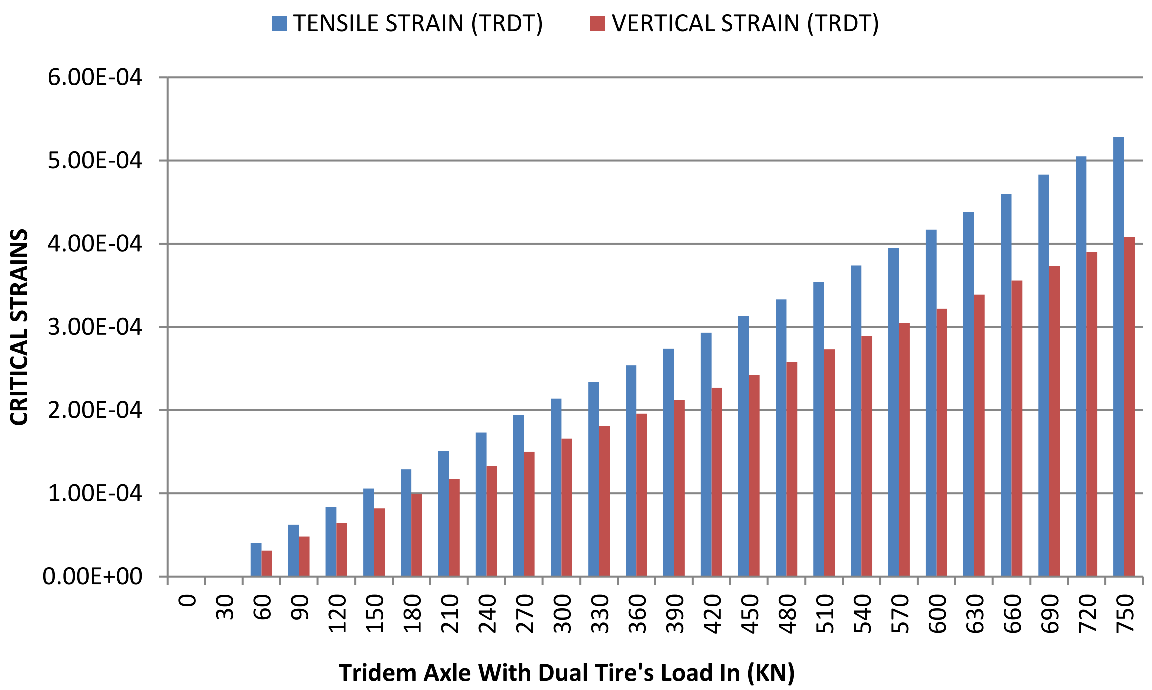


Figure 12: Pavement reaction (critical strains) for tridem axle with dual tires from theoretical analysis.

CONCLUSION

From this study, the most important axle weight, since it has a dramatic effect on pavement damage, Therefore, it is concluded from the empirical study that the damage per pass for each of the considered axle configurations shows that the SAST is the most destructive while followed by the TRDT and the next is the TADT.The least destructive axle is the SADT.

Analysing the stresses and strains due to each axle-load group, and the principle of superposition applied in the elastic layer theory, the axle group load that all has the same damage magnitude, the SAST, predicted the greatest magnitude critical tensile strain while the TRDT with the heaviest standard axle weight predicted the least magnitude critical tensile strain.

With the same standard axle magnitude, contact pressure and the same contact radius, with the same damage magnitude of unity (1), the output vertical strain for the SADT has the greatest magnitude and followed by SAST and the next is the TADT. The least magnitude is obtained by the TRDT.

Based on the theoretical analysis applied of determining the critical strains for each of the axle load ranges for each of the axle type, the following conclusions were drawn as thus:

The obtained results for the tensile strains are greater than the vertical strains for all the considered four different axle configurations.

For the obtained critical tensile strains results, the established trend indicates that at the heaviest axle group loads between 70KN and 250KN for SAST and SADT; and between 140KN and 500KN for TADT; and between 210KN and 750KN for TRDT, the SAST has the greatest magnitude, follow by SADT and next by TADT. The least magnitude critical tensile strains are obtained by TRDT.

For the obtained critical vertical strains results, the established trend indicates that at the heaviest axle group loads between 70KN and 250KN for SAST and SADT; and between 140KN and 500KN for TADT; and between 210KN and 750KN for TRDT, the SAST has the greatest magnitude, follow by SADT and TADT that has the same magnitude. The least magnitude critical tensile strains are obtained by TRDT.

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