Mechanistic - Empirical Flexible Pavement Analysis Using Load Spectra

*David O. Awosanya, Abdulfatai A. Murana and Adekunle T. Olowosulu
Department of Civil Engineering. Ahmadu Bello University, Zaria, Nigeria
{awosanyaolugbenga2015 | fatinoyi2007 | atolowosulu}@gmail.com

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ORIGINAL RESEARCH

Abstract- Prediction of pavement response based on the elasticity theory and multi-load response determined by superimposition of the tire stresses is at the heart of the mechanistic-empirical design procedure. The main focus was that the response of the pavement was modelled in such a way that tensile and compressive strains were predicted based on axle load spectra analysis for an elastic multi-layered system that was subjected to axle load spectra using a layered elastic analysis software program, KENLAYER (in conjunction with the input software LAYERINP and graphic software LGRAPH), which is part of the computer package called KENPAVE. To summarize the tensile and compressive strains results obtained for a Single Axle with Single Tire (SAST) from this study, the critical axle load magnitude for 100 kN is $226x10^{-6}$mm/mm and $237.70x10^{-6}$mm/mm respectively. For a Single Axle with Dual Tires (SADT), the critical axle load magnitude of 140kN is $243.00x10^{-6}$mm/mm and $244.00x10^{-6}$mm/mm respectively. For Tandem Axles with Dual Tires (TADT), the critical axle load magnitude of 240kN is $231.00x10^{-6}$mm/mm and $231.00x10^{-6}$mm/mm respectively. For Tridem Axle with Dual Tires (TRDT), the critical axle load magnitude of 360kN is $226.60x10^{-6}$mm/mm and $229.70x10^{-6}$mm/mm respectively. The influence of axle load range is more pronounced for TADT, followed by TRDT. On the other hand, the smallest one is SADT, and SAST is closest to TRDT.

Keywords- Multi-layer Elastic theory, Layered Elastic Computer program, Axle load distribution.

1 INTRODUCTION

The elastic layer theory is major in stress and displacement generated in a circular loads within the elastic layered system (Deng, 2003; Olowosulu, 2005). This is mainly used for mechanistic-empirical design procedure that has the following basic assumptions: （1） Every layer is made of homogeneous isotropic linear elastic material composition（2）soil base in the horizontal direction and downward depth direction are infinite, and thickness of pavement layers on it are limited, but their horizontal direction are unlimited; （3 ）there are vertical loads on the upper surface of the pavement, and the contact surface of loads and the pavement is a circle, on which the pressure is evenly distributed; （4）The contact surface between each layer is assumed to be fully continuous Sufficient frictional resistance or partially continuous or completely smooth (no friction resistance) (Suo, 2006; Wang 1990; Papagiannakis and Massad, 2008; Huang, 2007).

Furthermore, Priest and Timm, (2006) reported that each component can be improved upon as M-E pavement design evolves. For example, traffic estimates in 18-kip equivalent single axle loads (ESAL) can be used, as was done with the 1993 AASHTO Design Guide and prior. Yet, converting traffic data to ESAL is no longer necessary and is often an invalid oversimplification (Ioannides, 1992). Designers can now take advantage of theoretical models and their ability to calculate response under any tire configuration, load, and tire pressure (Timm et al., 1998). Therefore, many M-E procedures utilize load spectra, which describes the modeled traffic data by axle type, frequency of load magnitude, and tire pressure.

*Corresponding Author

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Highway Design Manual (2012) reported that axle load spectra are an alternative method of measuring heavy vehicle loads in mechanistic -empirical design method. Axle load spectra is a representation of normalized axle load distribution developed from weigh-in-motion (WIM) data for each axle type (single, tandem, tridem, and quad) and truck class (FHWA vehicle classes 5 through 13). Axle load spectra do not involve conversion of projected traffic loads into equivalent single axle loads (ESALs), instead traffic load applications for each truck class and axle type are directly characterized by the number of axles within each axle load range. The use of load spectra is being encouraged for use in M-E design because they take full advantage of the ability to compute pavement response such as stress under specific loading conditions. In this way, many different types of loading conditions can be accommodated without relying on equivalency factors and having the results subject to their limitations (Timm and Newcomb, 2002).

The use of Weigh-in-Motion systems has allowed improved data to be acquired for defining axle load spectra: Defining the significant traffic input that is critical to the output from the multilayer linear elastic solutions that allows computing pavement response such as stress under specific loading conditions without relying on equivalency factors, eliminating some empiricism from the M-E design procedures, refining the pavement response, which is a key input to the distress models. This work aimed at predicting pavement response from axle load spectra obtained from Weight-In-Motion (WIM) data. The objective of this study is to obtain an accurate pavement response by using traffic information in pavement design by an adequate traffic characterization and pavement analysis.

1.1 Nigerian Empirical Mechanistic Pavement Analysis and Design Systems (NEMPADS)

NEMPADS is a framework for Mechanistic- Empirical Pavement Design for tropical climate. Part 1 consists of the development of input values, which include traffic, climate and material. Geotechnical analysis is also performed in this part to determine the strength and stiffness of the sub-grade. Part 2 of the design process is structural/performance analysis, each component of the design procedure is developed specially for Nigeria environment, that was based upon information obtained from overlay design method-design manual for Nigeria and utilized ELSYM5 as the mechanistic pavement model. Two major components in NEMPADS that required to be refine, that were (1) traffic data are required in the M-E pavement design procedure. It is expressed in terms of 8, 200 kg (80kN) equivalent single axle loads (ESALs) and secondly, simplified procedure for prediction of pavement response in the prediction pavement performance (Olowosulu, 2005).

2 Methodology

The methods adopted in this research includes the disaggregation of traffic information incorporated into a truly mechanistic analysis for an accurate pavement response. KENLAYER was used instead in ELSYM5, and a comparison of obtained solutions for multiple wheels was made for validation.

2.1 Collection of Data and Procedures

The collection of data involves the inputs required for carrying out a mechanistic pavement design procedure are presented as follows:(a) Secondary data for the study: (i) Comprehensive site–specific truck traffic information on Kaduna-Zaria roadway, (ii) Pavement configuration and material properties(b) Traffic information obtained from literature review: The research procedures implemented in this research involves the analysis of traffic data for the development of the load spectra for the axle load distribution (ALD). The flexible pavement analysis involves the calculation of the wheel load magnitude and contact radius for each of the actual captured axle load from the site-specific WIM system.

2.1.1 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 1.

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)

2.1.2 Truck Traffic Load Data

Truck traffic information was obtained from the secondary data of the Traffic survey that was conducted by Stewart Scott International (2007) on Kaduna - Zaria Northbound (NB-AXIS) and Zaria - Kaduna Southbound (SB-AXIS). 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.

2.2 Research Procedure

Different axle loads are considered from four different axle load groups in this research; from the secondary data obtained by the work of Stewart Scott International (2007) on the Kaduna-Zaria roadway and other necessary variables obtained from literatures Huang (2007). A comparison of solutions was made between KENLAYER and ELSYM5 for validation according to the reported work of Kopperman et al., (1986).

2.2.1 Loading Requirements

The KENLAYER considers the loading magnitude and configuration and the number of Load Repetitions for a given configuration. In considering the effects of vehicular and traffic in pavement design, the main procedures that is considered in the KENLAYER Software for flexible pavement analysis is the Variable Traffic and Vehicle: This procedure best suits the mechanistic methods of design, as both traffic and vehicle are considered individually by dividing the loads into a number of groups, and the stresses, strains, and deflections under each load group determined separately and used for design purposes. The KENLAYER employs the Variable Traffic and Vehicle procedure of estimating load due to the inconsistency in equivalency for the various criteria used in determining the ESLF and ESWL, making predictions quite difficult (Huang, 2007).

2.2.2 Wheel Spacing

Wheel spacing default from literatures are given in Table 2

Table 2. Dual Wheel Spacing and Axle-Axle Distance for Each Load Group

No	Group	No of axles in the outer wheel path	Dual wheel spacing (YW)	Axle – axle distance (XW)
1	SAST	1	0	0
2	SADT	2	34	0
3	TADT	4	34	137
4	TRDT	6	34	137

Source: Huang, (2007) and Timm et al., (1999)

2.2.3 Contact Pressure

An average contact pressure 80Psi (552KPA) (Secondary data) was adopted for all the four different axle configurations from the work of Claros et al., (1986), for this study. SAST: Single Axle with Single Tire; SADT: Single Axle with Dual Tires; TADT: Tandem Axle with Dual Tires; TRDT: Tridem Axle with Dual Tires.

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2.2.4 Wheel Load Magnitude

In this study, the usual practice that the wheel load is equal to the axle load divided by the number of wheels on the axle, is not done because results from other researchers shows that this is not true. Molenaar (2009) shows that camber of the pavement surface results in an unequal sharing of the axle load over both wheel groups of the axle. The wheel group on the verge side of the road carries 52% of the load while the wheel group near the centre line of the road carries 47%. The number of tires in the outer path which is essential in the layer theory was considered and the camber analysis that relates the pavement roughness and the vehicle camber was also considered, for the distribution of axle load magnitude as contained in the camber analysis. Therefore, using the axle load ranges as obtained in the developed axle load distribution for each of the four different axle configuration, wheel load is calculated as follows:

$$P = \frac{Axle\ gross\ load\ (KN)X0.52}{Number\ of\ wheels\ on\ the\ outer\ wheel\ path} \qquad (1)$$

Number of wheels on the outer wheel path as contained in column 3 of Table 2.

2.2.5 Contact Area between Tire and Pavement (Contact Radius)

In this study, the principle of superposition for a realistic wheel load configuration was utilized, with all the four considered axle configurations, with the assumption that the tire imprint has a circular shape and carries uniformly distributed vertical stress that is equal to the tire inflation pressure. and contact radius is calculated as follows:

$$a = \sqrt{\frac{P}{i\pi}} \qquad (2)$$

Where a = Contact radius, P = (Wheel load): Total load on the tire as determined in Equation 1 above, i = tire pressure (Papagiannakis and Massad, 2008; Oguara, 2004; Huang, 2007)

2.3 Comparison with Available Solutions for Multiple Wheels

The elastic layer theory program was run by KENLAYER with the same data input used by ELSYM5 to determine the vertical compressive strain and tensile horizontal strain as used in the work done by Claros et al. (1986). Comparisons of the two results by ELSYM5 and KENLAYER were made to confirm the veracity of solutions from KENLAYER in accordance with the work of Kopperman et al. (1986).

2.4 M-E Methods for Flexible Pavement Analysis Output

The mechanistic resulting pavement reactions for each axle load and each axle type was computed by using the KENLAYER Software in which the stresses and strains were analysed due to each axle-load group. The stress under specific loading conditions without relying on equivalency factor was obtained.

3 Results and Discussions

Multilayer elastic analysis is performed using the KENLAYER Software. The different variables discussed in the previous section are considered. The resulting pavement strains under single tire and a set of dual tires are investigated. The following sections discuss the outcomes of these results.

3.1 Analysis of Axle Load Spectra (ALS) Data

The ALS for the roadway was developed which provide the load distribution of steering axles, other single axles, tandem axles and tridem axles. Load spectra are presented in Table 3, for the different axle types which contains the number of axles for each axle type. From Table 3, northbound axis has very high axle load magnitude while southbound axis has the lowest values. The main reason was that industrial and construction commodities were transported from the southern region into the other parts of the country, while agricultural materials were transported towards the southern part of the country, from the northern region of Nigeria.

3.2 Resultant Wheel Loads

Wheel load from each axle type is calculated according to Equation 1. Table 4 presented the wheel loads on the four different wheel configurations considered in this study. This table indicates that as the axle load magnitude increases, the wheel load for each group is increasing.

3.3 Contact radius (cm)

The contact radius for each determined wheel load for each axle type, are calculated according to Equation 2. Table 5 present the resulting contact radius (cm) for each axle load for each axle type. The observed trend is that the contact radius increases as the axle load magnitude for each axle type with increasing axle load magnitude, with the significance of the number of axles sharing the same suspension system and the number of tires in each axle.

3.4 Comparison of Solutions between ELSYM5 and KENLAYER

NEMPADS was developed by Olowosulu (2005), utilizing ELSYM5, to model the pavement response. However, KENLAYER, is substituted instead of ELSYM5, and comparison of the two software applications is conducted before utilizing KENLAYER, in this research study for modelling the pavement response. KENLAYER Software was run on the elastic layer theory program that was previously ran by ELSYM5, determined by Claros et al., 1986.Tensile strain ε_t =2.101E-04; Vertical strain ε_v =1.887E-04. Comparing the two results yields 0.38% in the Tensile Strain and 0.16% in the Vertical Strain, which are both less than 2%, as specified by (Kopperman et al., 1986).

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Table 3. Axle Load Distribution for the Four Different Axle Configurations

	Single Axle with Single Tire (SAST)			Single Axle with Dual Tire (SADT)			Tandem Axle with Dual Tire (TADT)			Tridem Axle with Dual Tires (TRDT)		
S/n	Axle load range for SAST (kN)	No of axles on the SB-axis	No of axles on the NB-axis	Axle load range for SADT (kN)	No of axles on the SB-axis	No of axles on the NB-axis	Axle load range for TADT (kN)	No of axles on the SB-axis	No of axles on the NB-axis	Axle load range for TRDT (kN)	No of axles on the SB-axis	No of axles on the NB-axis
1	0	0	0	0	0	0	0	0	1	0	0	0
2	10	2	4	10	1	1	20	4	1	30	0	0
3	20	3	3	20	1	2	40	11	3	60	0	0
4	30	9	8	30	8	6	60	31	6	90	0	0
5	40	16	9	40	31	6	80	13	4	120	0	0
6	50	39	18	50	10	5	100	2	6	150	0	0
7	60	3	32	60	2	0	120	2	4	180	0	0
8	70	8	15	70	1	2	140	1	2	210	0	0
9	80	1	5	80	5	1	160	0	7	240	0	0
10	90	0	2	90	1	4	180	0	8	270	0	2
11	100	2	0	100	2	6	200	3	8	300	0	0
12	110	2	2	110	1	6	220	2	15	330	0	0
13	120	1	1	120	1	11	240	2	11	360	0	0
14	130	0	0	130	2	9	260	0	1	390	0	1
15	140	0	0	140	1	2	280	0	6	420	0	0
16	150	0	0	150	0	3	300	2	3	450	0	0
17	160	0	0	160	0	5	320	1	1	480	0	0
18	170	0	0	170	1	1	340	1	1	510	0	0
19	180	0	0	180	0	1	360	0	0	540	0	0
20	190	0	0	190	0	1	380	0	2	570	0	0
21	200	0	0	200	0	3	400	0	0	600	0	0
22	210	0	0	210	0	1	420	0	0	630	0	0
23	220	0	0	220	0	0	440	0	0	660	0	0
24	230	0	0	230	0	0	460	0	0	690	0	0
25	240	0	0	240	0	0	480	0	0	720	0	0
26	250	0	0	250	0	0	500	0	0	750	0	0

Table 4. Wheel Load Magnitude

Axle load range for SAST(KN)	WHEEL load magnitude for SAST (KN)	Axle load range for SADT (KN)	Wheel load magnitude for SADT (KN)	Axle load range for TADT (KN)	Wheel load magnitude for TADT (KN)	Axle load range for TRDT (KN)	Wheel load magnitude for TRDT (KN)
0	0	0	0	0	0	0	0
10	5.2	10	2.6	20	2.6	30	2.6
20	10.4	20	5.2	40	5.2	60	5.2
30	15.6	30	7.8	60	7.8	90	7.8
40	20.8	40	10.4	80	10.4	120	10.4
50	26	50	13	100	13	150	13
60	31.2	60	15.6	120	15.6	180	15.6
70	36.4	70	18.2	140	18.2	210	18.2
80	41.6	80	20.8	160	20.8	240	20.8
90	46.8	90	23.4	180	23.4	270	23.4
100	52	100	26	200	26	300	26
110	57.2	110	28.6	220	28.6	330	28.6
120	62.4	120	31.2	240	31.2	360	31.2
130	67.6	130	33.8	260	33.8	390	33.8
140	72.8	140	36.4	280	36.4	420	36.4
150	78	150	39	300	39	450	39
160	83.2	160	41.6	320	41.6	480	41.6
170	88.4	170	44.2	340	44.2	510	44.2
180	93.6	180	46.8	360	46.8	540	46.8
190	98.8	190	49.4	380	49.4	570	49.4
200	104	200	52	400	52	600	52
210	109.2	210	54.6	420	54.6	630	54.6
220	114.4	220	57.2	440	57.2	660	57.2
230	119.6	230	59.8	460	59.8	690	59.8
240	124.8	240	62.4	480	62.4	720	62.4
250	130	250	65	500	65	750	65

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Table 5. Contact Radius (cm)

Wheel load magnitude for SAST(KN)	Contact radius for SAST (CM)	Wheel load magnitude for SADT(KN)	Contact radius for SADT (CM)	Wheel load magnitude for TADT(KN)	Contact radius for TADT (CM)	Wheel load magnitude for TRDT(KN)	Contact radius for TRDT (CM)
0	0	0	0	0		0	0
5.2	5.47	2.6	3.87	2.6	3.87	2.6	3.87
10.4	7.74	5.2	5.47	5.2	5.47	5.2	5.47
15.6	9.48	7.8	6.71	7.8	6.71	7.8	6.71
20.8	10.95	10.4	7.74	10.4	7.74	10.4	7.74
26	12.24	13	8.66	13	8.66	13	8.66
31.2	13.41	15.6	9.48	15.6	9.48	15.6	9.48
36.4	14.49	18.2	10.24	18.2	10.24	18.2	10.24
41.6	15.49	20.8	10.95	20.8	10.95	20.8	10.95
46.8	16.42	23.4	11.61	23.4	11.61	23.4	11.61
52	17.31	26	12.24	26	12.24	26	12.24
57.2	18.16	28.6	12.84	28.6	12.84	28.6	12.84
62.4	18.97	31.2	13.41	31.2	13.41	31.2	13.41
67.6	19.74	33.8	13.96	33.8	13.96	33.8	13.96
72.8	20.48	36.4	14.49	36.4	14.49	36.4	14.49
78	21.20	39	14.99	39	14.99	39	14.99
83.2	21.90	41.6	15.49	41.6	15.49	41.6	15.49
88.4	22.57	44.2	15.96	44.2	15.96	44.2	15.96
93.6	23.23	46.8	16.42	46.8	16.42	46.8	16.42
98.8	23.86	49.4	16.87	49.4	16.87	49.4	16.87
104	24.48	52	17.31	52	17.31	52	17.31
109.2	25.09	54.6	17.74	54.6	17.74	54.6	17.74
114.4	26.68	57.2	18.16	57.2	18.16	57.2	18.16
119.6	26.26	59.8	18.57	59.8	18.57	59.8	18.57
124.8	26.82	62.4	18.97	62.4	18.97	62.4	18.97
130	27.37	65	19.36	65	19.36	65	19.36

Table 6. Results of Axle Load Spectra on Output of Pavement Response (Induced Critical Strains)

Axle Confi-guration	Single Axle with Single Tire (SAST)			Single Axle with Dual Tires (SADT)			Tandem Axle with Dual Tires (TADT)			Tridem Axle with Dual Tires (TRDT)		
S/N	Axle Load Ranges for SAST	Bottom of AC Tensile Strain (ε_t) x 10^{-06}	Top of Subgrade Compressive Strain (ε_v) 10^{-06}	Axle Load Ranges for SADT	Induced Tensile Strain at the bottom of Asphalt Layer (ε_t) x 10^{-06}	Induced Vertical Strain at the top of the Subgrade Soils (ε_v) 10^{-06}	Axle Load Ranges for TADT	Induced Tensile Strain at the bottom of Asphalt Layer (ε_t) x 10^{-06}	Induced Vertical Strain at the top of the Subgrade Soils (ε_v) 10^{-06}	Axle Load Ranges for TRDT	Induced Tensile Strain at the bottom of Asphalt Layer (ε_t) x 10^{-06}	Induced Vertical Strain at the top of the Subgrade Soils (ε_v) 10^{-06}
1	0	0	0	0	0	0	0	0	0	0	0	0
2	10	53.90	26.96	10	34.78	18.86	20	37.40	20.50	30	34.51	20.28
3	20	105.60	53.17	20	68.20	36.99	40	73.30	40.20	60	67.66	39.77
4	30	136.90	78.60	30	94.60	55.37	60	93.90	60.00	90	93.46	53.93
5	40	160.00	103.40	40	117.00	73.29	80	102.00	79.80	120	116.00	79.30
6	50	178.40	127.30	50	136.80	91.27	100	136.00	99.10	150	134.90	97.95
7	60	192.00	150.30	60	153.30	108.80	120	142.00	119.00	180	152.40	117.90
8	70	203.80	173.50	70	168.00	126.30	140	168.00	137.00	210	166.60	135.80
9	80	213.00	195.50	80	183.10	143.50	160	176.00	157.00	240	181.00	156.00
10	90	219.80	216.80	90	195.40	160.80	180	193.00	175.00	270	191.90	173.00
11	100	226.00	237.70	100	206.80	177.70	200	205.00	194.00	300	204.10	193.10
12	110	230.20	258.10	110	217.10	194.70	220	214.00	212.00	330	212.80	209.70
13	120	234.00	273.10	120	226.50	211.10	240	231.00	231.00	360	226.60	229.70
14	130	236.90	297.00	130	235.50	227.80	260	240.00	248.00	390	240.00	247.90
15	140	239.00	316.00	140	243.00	244.00	280	253.00	267.00	420	253.00	266.00
16	150	240.90	333.90	150	250.70	260.10	300	266.00	284.00	450	265.50	283.30
17	160	244.00	352.00	160	258.00	276.00	320	278.00	321.00	480	278.00	301.00
18	170	243.20	369.00	170	264.40	292.00	340	288.00	329.00	510	289.40	318.30
19	180	244.00	386.00	180	270.00	307.00	360	301.00	337.00	540	300.00	335.00
20	190	244.20	402.30	190	276.20	323.10	380	309.00	353.00	570	316.00	352.40
21	200	244.00	418.00	200	282.00	338.00	400	321.00	371.00	600	320.00	369.00
22	210	244.00	434.10	210	286.00	353.90	420	327.00	387.00	630	329.60	386.20
23	220	244.00	450.00	220	292.40	369.00	440	339.00	405.00	660	338.00	403.00
24	230	243.20	464.30	230	296.40	384.20	460	343.00	420.00	690	346.40	419.40
25	240	243.00	479.00	240	300.00	399.00	480	354.00	438.00	720	354.00	436.00
26	250	241.80	492.80	250	305.00	413.70	500	357.00	452.00	750	361.00	451.70

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3.5 Computed Critical Strains by Mechanistic Approach using KENLAYER

Table 6 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 a single tire and a set of dual tires. Theis table show that the tensile and compressive strain increase with increasing the axle load. Critical strains were computed for each of the axle load ranges for each of the four different axle configurations by using the multilayer elastic analysis which was performed using the KENLAYER software.

From Table 6, axle load groups with the associated induced strains were coloured in blue, showing the threshold of changing from the reduced vertical strains to the greater vertical strains over the tensile strains, whereby, the red colours indicate the commencement on increased vertical strains over the tensile strains. This implies that the lighter axle load magnitudes for each axle configuration had a significant impact on the tensile strain magnitude and the heavier axle load magnitude, for each axle configurations have a significant impact on the vertical strains at the top of the subgrade soils.

The effect of steering axle load on pavement structure, as indicated in Table 6, whereby, the tensile strain reaches a maximum of 244 x 10^{-6} mm/mm, at an axle load magnitude of 200kN, and the tensile strain commences to decrease as the axle load magnitude is increasing. The response output generated at critical locations are presented, and the summary of the obtained results for Single Axle with Single Tire (SAST), the critical axle load magnitude of 100kN is ε_t =226x10^{-6}mm/mm and ε_v =237.70x10^{-6}mm/mm from Figure 1; For Single Axle with Dual Tires (SADT), the critical axle load magnitude of 140kN is ε_t =243.00x10^{-6}mm/mm and ε_v =244.00x10^{-6}mm/mm from Figure 2.; For Tandem Axle with Dual Tires (TADT), the critical axle load magnitude of 240kN is ε_t =231.00x10^{-6}mm/mm and ε_v=231.00x10^{-6}mm/mm from Figure 3 ; For Tridem Axle with Dual Tires (TRDT), the critical axle load magnitude of 360kN is ε_t =226.60x10^{-6}mm/mm and ε_v =229.70x10^{-6}mm/mm from Figure 4. The effect of the axle load range is more pronounced on the TADT follow by the TRDT; while the least is the SADT, whereby SAST is next to TRDT.

4 Conclusions

The following conclusions were drawn from this study; (i) Site specific surveyed and collection of actual traffic data by weigh-in-motion (WIM) was carried out for the purpose of providing adequate definition of traffic data for each roadway and to make significant contribution to (M-E) design procedure, to NEMPADS by eliminating empiricism in the mechanistic-empirical design procedure and for predicting the damage and improving pavement performance. (ii)The elastic layer theory is widely used in stress analysis of elastic multi-layered system, especially in the application of computer technology, making the calculation more precise, without relying on equivalency axle load factor from the regressions analysis from the AASHO Road Tests. (iii) According to Timm et al (1998), theoretical models are available with capability to calculate response under any tire configuration, load, and tire pressure. Huang (2007); (Papagiannakis and Massad, 2008); Timm et al., (1999) and Report 1-26 established the implementation the use of elastic layer programs (ELP) and the multiple wheel capability of ELP whereby the M-E approaches dissect the load effects into its components: wheel load magnitude, contact area between tire and pavement, and tire spacing.

Development of axle load spectra was for the determination of traffic load applications for each truck class and axle type are directly characterized by the number of axles within each axle load range, as implemented by Molenaar (2009); Timm et al., (1999); and Highway Design Manual (2012). The effort of Molenaar (2009) has implemented for the determination of wheel load magnitude, whereby the camber of the pavement surface results in an unequal sharing of the axle over both wheel groups of the axle was a key determinant for an accurate wheel load magnitude for each of the axle-load groups.

NCHRP 1-37A established the capability of a single tire inflation as input and whereby utilizes it for all axle configurations for the purpose of computing an effective contact radius required in the structural models considered in this study. Huang (2007); Papagiannakis and Massad (2008); and Timm et al., (1999) established the capabilities of the multi-layer elastic theory to determine pavement response by analysing the stresses and strains due to each axle -load group for flexible pavement analysis. Information on the load groups and their related tire pressure values, dual wheel spacing and axle-axle distance for each load group.

(iv)Comparing all the various dual axles, the effect of the axle load range is more pronounced on the TADT follow by the TRDT; why the least is the SADT.

5 Recommendations

The following recommendations are made for future research for Nigerian environment: 1). Knowledge on axle and wheel loads is important but even more so is knowledge on the contact pressures. Wheel loads come in different sizes and shapes, and each of them produces a different contact pressure distribution. Improvement of conducted surveys to characterize loading mechanisms and their magnitudes, which included a measure of tire inflation, because it was generally found that tire inflation pressures varied according to tire type, size, and manufacturer. One final issue deal with the dependence of tire pressure on wheel load, local survey should be conducted to determine the average tire inflation pressure. 2). For analysis of surface damage like ravelling, rutting, and surface cracking, an as detailed as possible modelling of the actual loading conditions should be used. The data provided by WIM data give useful guidance in doing so. 3). It is recommended, wherever feasible, that continuous permanent WIM stations be placed to accurately measure truck traffic data in Nigeria compared to the portable WIM System that has reliability issues. 4.) The assumptions used in the KENLAYER analysis must be localised for a more reliable and environmentally specific outputs.

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