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Analysis of Axle Loadings on a Rural Road in Nigeria

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ABSTRACT: *This paper presents the outcome of the axle load survey on a section of a rural trunk road in Nigeria in order to quantify the contribution of overloaded goods vehicle to pavement failures and propose appropriate amelioration strategies for vehicle axle system modifications. Seven day classified traffic and axle load survey was conducted for the determination of ADT, percentage heavy vehicles and the imposed axle load at respective axle position for each of the traversing vehicle on the old Jos – Kaduna road, Kaduna State Nigeria. The proportion of the vehicle laden weight carried by each axle and the corresponding standard axle load (sal) was computed with the index model of power 4. The percentage and magnitude of overloaded axles were respectively determined as a measure of an addition to the influence of the dynamic effect of moving wheel loads on a flexible pavement in the structural damage analysis of a pavement. The studied pavement was overstressed up to five times beyond the Nigerian standard axle load of 80kN, which was too high and hence probably constitute the hindsight to frequent structural damage to road pavement failure in a typical developing country, Nigeria. It was recommended that routine axle load survey and control with weigh- in-motion weighing bridges to assure protection of the road against failure or a complete redesign of the chassis of heavy goods vehicles meant for developing countries be effected. The two options may be considered for a more effective and proactive means of assuring the life of pavements and asset value. Also a review of the legal axle from 8.0 to 13.6 tonnes for the developing countries should be considered.*

KEYWORDS*: Commercial Vehicle, Average Daily Traffic, Design life, Axle Load, Gross Weight and Gross Vehicle Weight, Dynamic loads*

I. INTRODUCTION

In pavement design, light vehicles are not considered to cause any significant damage to structural layers that constitute the pavement and so, in principle, they do not need to be counted accurately, indeed, they hardly need to be counted at all "(Howe, 1972)". In other words, vehicles of less than 1.5 tonnes empty weight or 3.0 tonnes laden weight (commercial vehicles), for example; motorcycles, cars, small (mini and midi) buses or small trucks with single rear tyres for structural damage assessment purposes are usually discarded, in Nigeria "(FGN, 2006)" and other British Commonwealth countries of India, Ghana, Kenya etc. Large buses, light to medium goods vehicles, heavy and very heavy articulated trucks should be weighed in the axle survey exercise because they constitute the significant damaging influence on the pavement. In fact it has been proved that damage increases sharply as the axle load exceed 1.5ton and that is the reason why vehicles of weight overt that value are usually considered (State of Florida, 2008). The Annual Average Daily Traffic (AADT or ADT) is the most widely used traffic statistic to indicate the level of traffic volume on a road and the knowledge of the composition of vehicles using a road and respective imposed wheel (axle) weight is therefore important in order to determine if the pavement was overstressed, eventually culminating the infrastructure collapse. The standard and legal axle in Nigeria and other commonwealth countries in the tropics and subtropics, (eg.Ghana, Kenya India) are 8 tonne (80kn).

"Forkenbrock and March (2005)", while reporting Stokes and Albert's argument for the need for Truck–Only Lanes, enumerated a list of benefits why specialised lanes be reserved in the mix traffic situations, which is also substantially in agreement with the Southern California Association of Governments' three conditions. The truck-only lanes would be most feasible when i) truck volumes exceeding 30% of the vehicle mix ii) one way traffic volumes greater than 1,800 vehicles per lane-hour during peak hours and iii) off-peak volumes in each direction exceeding1,200 vehicles per lane-hour. This observation pointed out, the general phenomenon that heavy truck traffic in low proportions constitutes much damage factor to the pavements, and needs be given the desired attention. Indeed pavement wear increases with axle weight, the number of axle loadings and the spacing within each axle group, such as for tandem-, tridem- axle groups, as well as suspensions, tyre pressure and type "(Hort et al., 2008)". It is therefore a common knowledge that pavements of rural freeways that carry heavy goods importation and exportation suffer structural breakdown too often and too soon in their life, because of the overloading of the trucks (Jones, 1977).

Addis et al. (1989), came up with an estimate of the dynamic effect of 15% and 25% respectively for the trailer twin axles and single front axle of vehicles, in addition to the total static axle load of moving vehicles on a good road, (built to normal standard in the United Kingdom), as would be measured by the weighing bridge with the vehicle at rest. The overloading of the axles is an additional source of the ominous overstressing from the dynamics of movement of vehicles on the pavement structures, which if not appropriately addressed will exacerbate rural road infrastructure collapse.

In developed countries, axle load survey is usually carried out to determine the axle load distribution of the heavy vehicles, the mean number of equivalent standard axles and other important information about the degree of overloading and hence appropriately manage the potentiality of road infrastructure collapse. Even in most of the occasions, trunk roads leading to docks, quarries, cement works, timber or oil extraction and mining areas; do experience significant differences in axle load between the two directions of flow of traffic, which implies the necessity to address the overloaded rural roads of the developing countries. The implication of the study therefore further amplifies the fact that wilfully over loaded trucks makes nonsense of the legal axle loads on rural and freeways. The concomitant control of level of the magnitude of imposed loads to protect the assets of the national road network is mandatory so that the asset value of the trunk roads is maintained.

II. MATERIAL AND METHOD

2.1 Study Area.

The axle load measurement was taken at the existing fixed weighing bridge located at the premises of Sunseed Nig. PLC, Dakace, Old Jos road, which passes by the frontage of the Federal College of Education Zaria through the Kongo Campus of the Ahmadu Bello University, Zaria Kaduna State Nigeria.

2.2 Study Procedure

At first, a reconnaissance survey was conducted to obtain the condition of the road, the category of vehicles plying, the inventory (width) of the road and other site suitability criteria for the conduct of traffic and axle survey. The traffic survey was then conducted for a month. The duration of one month was used to obtain data which would appropriately reflect the uniformity in activities of the community for the weekly circle. The traffic was grouped according to the classification in the latest edition of the Nigerian Highway Manual (Federal Ministry of Works, 2006). The axle survey was however conducted for only one week (7 days) and limited to the vehicles ordinarily considered to cause structural damage to the pavement. The vehicles in this category include the medium trucks (2 axles with twin rear tyres), heavy trucks with 2 or more axles; (2-axles for medium trucks, 3-axles for heavy trucks, and 4-axles for heavier trucks) and large buses. While weighing the axles, sampling coverage of each of the category of vehicle in appropriate portions to the flowing traffic stream was ensured. The complete procedure for the axle survey was as contained in Hartanto and Sastrowiyote, (1990) and also sequentially demonstrated in plates 1 - 2.

As a sample of the vehicle approaches the weighing bridge zone, the sensitive axle load weighing meter was adjusted to zero reading and the respective axle load for each axle position as well as the vehicle weight as displayed in other sections of the meter, (plate 2). The configuration of axles counted and weighed for the purpose of this research work is shown in figure 1. Each vehicle axle was then converted to 80 kN, the standard axle load; using equation (1). This process was repeated for all the categories of the vehicles having damage influence on the pavement, Parsley and Ellis, (2003) and Rolt (1981).

$$E.F = \left(\frac{Axle\ load\ (kN)}{80kN}\right)^4 \quad (1)$$

During the course of the data collection, the common errors that arose were strictly monitored. These errors include i) drivers of overloaded vehicles were avoiding the survey site as soon as they learn of the existence of survey officials ii) short duration of one or two days iii) the effect of traffic directional split and iv) the loaded and unloaded empty truck of the same type. Appropriate checking and supervisory roles at different level of responsibilities and vigilance was established throughout the axle measurement. Also at least one week of continuous measurement was adhered to, with adequate number of personnel.

Plate 1: Typical Nigeria Truck on Weighing Bridge

Plate 2: Axle weighing meter

III. ANALYSIS OF RESULTS AND DISCUSSION

3.1 Traffic Analysis

Table 1 presents the traffic survey data for a week. The average number of goods vehicles in the week = (5 x average weekday traffic) + Saturday + Sunday traffic, which was computed to be 534 ($\frac{3739}{7}$). In order to account for the non- commercial vehicles per day for the Average Daily Traffic (ADT), which was obtained to be approximately 1,000 passenger cars, the two figures were added to give the ADT of 1,534. This implies that the percentage trucks to total vehicle per day are 35 % (534/1534), and that the annual traffic loading on the rural road studied is 194,910 trucks, (534 x 365).

Table 1: Hourly vehicle count on the studied road

No. of commercial vehicles for each hour of the day							
Time	Mon.	Tue.	Wed.	Thur.	Fri.	Sat.	Sun.
06.00-07.00	45	21	17	20	22	15	0
07.00-08.00	36	43	24	45	50	20	0
08.00-09.00	50	54	48	46	67	16	1
09.00-10.00	60	62	46	61	69	21	3
10.00-11.00	58	59	65	63	64	23	6
11.00-12.00	44	53	38	50	57	26	2
12.00-13.00	42	47	45	50	33	24	0
13.00-14.00	46	49	42	45	40	20	4
14.00-15.00	57	50	43	49	39	22	5
15.00-16.00	49	59	53	55	44	29	7
16.00-17.00	54	63	61	56	41	32	3
17.00-18.00	24	49	54	54	44	22	4
18.00-19.00	23	27	41	38	19	16	5
18.00-20.00	28	20	23	19	17	13	2
20.00-21.00	5	11	12	6	21	14	3
21.00-22.00	7	5	11	4	9	11	5
Total 16-hr count	**628**	**672**	**623**	**661**	**636**	**324**	**50**

3.2. Axle load analysis.

Table 2 is the summary of the axle load measurement conducted, which reflects only those vehicles likely to cause damage to the pavement. The axles considered include those of large buses, 2-axles for medium trucks, 3-axles for heavy trucks and the 4-axles heavier trucks. The axle analysis was conducted under four different perspectives; i) the average standard equivalent factor per vehicle ii) the proportion of overloaded axles

iii) the magnitude (in unit of weight) of overloading relative to the legal axle and iv) the load distribution factors on the various axles of a truck. Also the standard axle is 80 kN on dual tyres at the two ends of the axle and designated as [2] a 40 kN weight on the single tyres for front axles, [1] in the axle configuration. (Fig.1).

Table 2: Data analysis for axle load survey

S/N	Vehicle Category	Total No of Vehicles (7 Days)	Axle Load (kN)				Equivalent Factor (E.F) per Axle E.F= $\left[\frac{AXLE\ LOAD}{80}\right]^4$				Total E.F	E.F x No. of Vehicle	Average. E.F (All Vehicles)
			AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 1	AXLE 2	AXLE 3	AXLE 4			
1	**Bus**	**780**	42.0	**54.6**	**54.5**	**-**	**0.075**	**0.216**	**0.215**	**-**	**0.506**	**394.68**	
2	**Medium Truck 2-Axles**	**507**	40.0	**-**	**45.3**	**-**	**0.063**	**-**	**0.103**	**-**	**0.166**	**84.162**	
3	**Heavy Trucks 3-Axles**	**511**	45.1	**62.3**	**47.3**	**-**	**0.101**	**0.368**	**0.122**	**-**	**0.591**	**302.0**	**11541.507 / 2483 = 4.684 = 5.0**
4	**Heavy Trucks 4-Axles**	**685**	58.7	**139.2**	**116.4**	**92.3**	**0.289**	**9.166**	**4.482**	**1.772**	**15.709**	**10760.66**	
	Total	**2483**										**11541.507**	

3.2.1. Average equivalent axle factors per vehicle.

From the axle weight conversion shown in table (2), it can be seen that an average vehicle on the road adopted as case study, possesses an average equivalent factor of 5.0 which is about five times the standard axle weight for road pavements. This implies that an average truck on this road, used as case study causes the same pavement damage as five standard axles of 80 kN would cause. It shows that, there is high degree of overloading on the said road which is one of the major causes of pavement deterioration. Also, the percentage of commercial vehicles that is causing structural damage to the pavement is 35% (535/1535).

3.2.2. Proportion of overloaded axles.

With the standard axle of 80 kN resting on dual tyres (designated as [2]) on axle configuration, it can be assumed that the axle on single tyres is 40 kN (designated [1]). In line with above assumptions to the data of table 2, the respective overloaded axles are computed as:-

Number of front axles [1]: Bus [122] (780) + for 3 – axle (511) + for 4 – axle (685) = 1976

Number of back and other axles [2]: 4 – axle 3(685) = 2055

Total number of truck axles = 3(780) + 2(507) + 3(511) + 4(685). = 7627.

Therefore, the proportion of overloaded axle for trucks = (1976+ 2055)/7627 = 4031/7627 =52.85% and 41.87 % for entire traffic.

3.2.3. Magnitude of axle overload.

For front axle [1], the percentage over load beyond the 40 kN for the 42, 45.1 and 58.7 are respectively 5, 12 and 47 %. For back and other axles [2], the percentage over load beyond the 80 kN for the 139.2, 116.4 and 92.3 kN are respectively 74.0, 45.5 and 15.4.

The magnitude of overloading of axles recorded for a goods vehicle range from 5 - 74%, with an average of 21.3 % for front and 45 % for the back and other axles.

3.2.4. Proportion of vehicle load per axle.

Table 3 gives the distribution of the vehicle laden and unlade loads over the respective axles. It varies for the number of axles and position in the vehicle chassis layout. The back and other axles carry the highest proportion of the load on the vehicle. The highest load on the axle is significant to be employed in the determination of the wheel load magnitude in the structural design of a pavement. A further analysis of the proportional distribution over the axles shows that this design wheel load can be estimated from the number of axles with equation 2 and respective modifications.

$$HAL = \beta VL/N \quad (2)$$

Where HAL is the highest axle load, VL is the load on the vehicle, N is the number of the axles on the vehicle and β is the modification factor which varies with N. The respective values are 13 -16, 12 - 19 and 20 – 45 % for the 2-, 3- and 4- axles.

Table 3: Computational detail of the load distribution for each of the various vehicles.

Vehicle/Axle Type	**Axle Load (kN)**				**Total Vehicle Weight (kN)**	**$\alpha i = Wi/\Sigma Wi \times 100$**			
	1	**2**	**3**	**4**		**1**	**2**	**3**	**4**
1.1	42.0	54.6			**96.6**	43.48	56.52	0.00	0.00
1.2	45.2	62.3			107.5	42.05	57.95	0.00	0.00
1.22	43.2	65.0	56.0		164.2	26.31	39.59	34.10	0.00
1.22	53.7	71.0	74.3		199.0	26.98	35.68	37.34	0.00
1.22 - 2.2	56.2	74.2	80.0		210.4	26.71	35.27	38.02	0.00
1.2 - 2.2	58.7	116.2	126.4	128.5	429.8	13.66	27.04	29.41	29.90
1.2 - 2.2	56.0	79.2	86.1	125.2	346.5	16.16	22.86	24.85	36.13

IV. DISCUSSION OF RESULTS.

4.1 Traffic Survey Data

As seen from the traffic count data (table 1), it is obvious that the movement of commercial/ goods vehicles is more during the weekdays and Saturdays. However, for Sunday where the total count of commercial vehicles amounted to just 50, which shows that there is a drop in the movement of goods and passenger haulage on Sundays. So, care must be taken when carrying out a traffic count to reflect the variation in the activities which is approximately the same in a weekly circle. Hence traffic counts should be carried out for a minimum period of 7-days to clearly show the prevalent traffic scenario on a typical rural road in Nigeria on a weekly basis.

4.2 The axle load data.

A total of 2483 goods truck vehicles of various categories were counted each possessing an average equivalent factor of 5.0 for the seven days of survey. This means that on the average, each goods truck on the road causes five times damage of the standard weight meant for road pavement which is far too high and excessive and can constitute the major reason for road the deterioration of pavements in Nigeria. The challenge needs to be more forcefully addressed.

4.3 Implication of the axle overload on design life

It is impossible to design a road pavement which does not deteriorate with time and traffic. The 5 .0 esa per vehicle per day can be used to determine the lifespan of a flexible pavement of a rural road in Nigeria.

4.4 Axle load overloading in quantity and volume.

The proportion (%) of axles overloaded on the studied rural road was computed to be 45 %. This value indicated that there is the need to introduce Trucks Only Lane because it exceeded the 30 % bench mark usually adopted for rural freeway by the American Federal Highway Administration, (Forkenberg and March, 2005). Both the front axles and the rear and other axles are all overloaded on the rural freeway to as much as 21 % and 45 % respectively. This finding implies that the wilfully imposed loads by the axles on the Nigerian pavement are as much as 11.5 tonnes, which is extremely higher than the 8 tonne legal axle weight. There is the strong reason to consider as important other alternative mode of hauling goods in the rural regions in such situation. The objective can be achieved by either i) modification of the goods vehicle chassis through the introduction of more axles to the trucks or ii) discourage road haulages of goods and promote the rail means of carriage more appropriately or iii) both taken together.

The highest distribution of the vehicle load over the axles (computed with equation 2) gives a fast method of estimating the maximum load to be imposed on the wheels and hence the contact pressure on the pavement. The contact stress is a major input in the mechanistic analysis of the structures of the pavement. Reflecting the findings of the study with the dynamic effect of vehicles in motion on the addition to the static load, it means that the heavy goods vehicles would impose more adverse loadings on the pavement beyond the standard 8 tonne by 36% (15 +21%) and 70% (45% + 25%) respectively for the front and rear axles of the trucks. The actual load to be safely carried by the pavement structure would be 13.6 tonnes (8 tonne x (100 + 70)/100).

4.5 Implication of the axle overload on pavement structure design

The AASHTO Design model for flexible and rigid pavement structures is expressed in terms of the total number of repetitions of an equivalent standard wheel loads, commonly 18 kips (80 kN) standard axle, and the structural number (SN) representing the inherent strength and geometry (thickness) of the various pavement layers. The provided structure from such design indicated a gross under-design when compared with the actually overloaded axles. The actual imposed wheel load pressure for an assumed typical tyre pavement contact area of 150 mm on the rural road was indeed 962 kpa against 565 kpa used in the design. Obviously thicker structures should be considered for the same traffic level, materials, and maintenance and construction practices. The implication of the axle overload is to modify the AASHTO Design models by applying a factor of (Log 136 kN/Log 80 kN) to appropriately compensate for an overloaded typical rural trunk road in Nigeria and other developing economy.

V. CONCLUSSION AND RECCOMENDATION

5.1 Conclusions

a) The average equivalent standard axle of 5.0 corresponding to an axle load of 400kN operates on a typical Nigeria rural trunk road which implied high degree of overloading of the road pavement.
b) About 53 per cent (52.9 %) of axles of the goods trucks on a rural road in Nigeria can be overloaded and only 42 % of entire traffic including the lighter passenger cars which confirms the need to create Trucks Only Lane for the rural roads.
c) Other mode of travel to haul the goods through the rural regions, such as rail or water, is overdue for serious consideration in a developing economy where disequilibrium and imbalanced in transportation mode usage and planning practices are adequate.
d) The front axles are 21 % overloaded in magnitude while the back and other axles are 45 % averagely overloaded thereby making it imperative to raise the legal static axle to at least 13.6 tons and also apply a modification factor to the AASHTO pavement design model.
e) Before pavement is constructed is necessary that the pavement is design, instead of the usual norms in Nigeria the ministry just specified certain thicknesses of pavement and hand it over to contractor for construction if this is done pavement will last longer than what is happening in the developing countries now.

5.2 Recommendations

1) There is need to revive the glory of the Nigerian railway transport system in order to ease the pressure of overstressing of road pavements or alternately the architecture of goods trucks be reconfigure to accommodate more axles.
2) Rigid pavement should be constructed in areas where traffic is dominated by heavy duty goods truck and vehicles and goods because of its capability in accommodating higher traffic wheel induced stress.
3) Routine and periodic maintenance practices, complemented with adequate control of access by the overloaded trucks should be encouraged in order to reduce the effect of the overloaded wheels on the pavement.
4) The global best practices in controlling the access of over loaded trucks through the effective operation of weighing bridges should be strongly enforced on Nigeria rural freeways, and other developing nations where regular axle load study and survey is not yet given the desired attention.
5) A modification model must be applied to the AASHTO design model for flexible and rigid pavements for rural trunk roads to account for excessive axle loadings due to dynamics nature of moving vehicles and wilful human overloading.

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