Calculation of Realistic ESAL Values for Future Design of Rural Roads

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Abstract- The pavement structure is subjected to recurrent vehicle loads throughout its design life. If the vehicle is overloaded over the limitations set by the authorities, substantial damage to the pavement structure will occur before the design life is reached. Therefore, a study was done for the Equivalent Single Axle Load calculations (ESAL) and road structural design to examine the influence of heavy vehicular loadings. The research was based on the results of the famous American Association of State Highway and Transportation Officials (AASHTO) road test of 1961, whose findings are still widely used in road design today. The research was carried out on three rural roads: Topi Road Sawabi, KDA Road Kohat, and Nasir Bagh Road Peshawar, Pakistan. Data on average daily traffic was collected and anticipated for the next 20 years. After that, the ESALs were determined. The structural number was determined according to the AASHTO design guide from 1993. The thicknesses of road layers were determined using structural numbers. As a result of the findings, it was discovered that huge trucks cause greater pavement damage than passenger automobiles. These vehicles are sometimes overloaded over the limits set by the authorities, causing damage to the pavement structure. It is vital to have a good check and balance on the load limitations set by the involved authorities to protect the pavement structure from adverse impacts.

Keywords- Average annual daily traffic, Daily Traffic, ESAL, Pavement damage, Pavement design

1 Introduction

Throughout the existence of road structure i.e. pavement, base and subgrade are exposed to vehicular loads and environmental loads (snow, rain and high temperature) which ultimately causes damage to the road pavements. By vehicular loads we mean all type of loads that are coming from traffic volume. Traffic volume consist of Cycle and Motor Cycle up to Hino Trucks and Trailers. Overloaded trucks and trailers do far more damage to the pavements. The level of damage of lighter vehicles is very less it's the heavy vehicles which reduces the design life of pavement very much. Overloaded trucks injure asphalt and concrete pavements through rutting and fatigue ultimately affects serviceability and reduction in the design life respectively [1]. Overloaded trucks cause fatigue, rutting and pre-mature pavement failures. [2] conducted a study on California state highway to evaluate heavy truck impacts on the maintenance cost. They found that the impact on maintenance cost by one heavy vehicle is same as by 90 passenger cars.

The degree of damage is determined by the type of base tire (dual or wide), tire pressure, axel spacing, axle weight, and the intensity of overloading [3]. While the reaction of the pavements to the traffic loads is determined by the thickness of the pavement, the kind of traffic carried by the road, the kind of pavement, and the sub-grade stiffness value [4].

Raheel [5] conducted a study to find the realistic values of equivalent single axle loads (ESALs) and the thicknesses for the different layers of the road section. They collected data for a period of three months from weigh-in-motion (WIM) stations installed at National highway N5 Attock, Panjab, Pakistan. They observed that heavy class vehicles were overloaded by above 200% of the maximum allowed gross vehicle mass (GVM) set by the National Highway Authority

(NHA) as shown in Table-1. Further, they concluded that the impact caused by these heavy vehicles can be reduced by increasing pavement thickness. An increase of 10 cm to 20 cm in thickness of the pavement layer can reduce the impact by 48% to 48% respectively.

This research work will provide realistic results which will be very helpful in future for the concerned department of roads construction for the re-construction of these roads. So that these roads will complete its design life without any failure under the future loads.

2 Background of the study

2.1 Equivalent single axle load (ESALs):

It is not difficult to calculate and identify the wheel load for the specific vehicle in road design, rather, it is the default to determine what sort and kind of axle the particular pavement will be subjected to during the design life. Furthermore, it is the damage to the pavement that is of major concern, not the wheel weight. The most traditional and ancient way is to convert the combined axle weight to the conventional 18,000-lb equivalent single axle load. It was simple to depict the entire traffic from a single number in its early phases (the early 1950s and 1960s AASHTO road test).

2.2 Load equivalency factor (LEFs):

The Load Equivalency Factors (LEFs) are the results of the ESAL equation. The primary purpose of the factor is to link diverse load combinations to the standard 18,000-lb single axle load. For turning flexible ESALs into stiff ESALs, the AASHTO design guide from 1993 proposes a factor of 1.5. To convert stiff ESALs to flexible ESALs, a multiplier of 0.67 is used.

2.3 Estimating ESALs:

The first step in designing pavement structure is estimating the ESALs that will be encountered over its design life. The ESAL estimate contains the following components: traffic count, heavy vehicle count or estimate, traffic growth rate during the design life of the pavement, selection of suitable LEF to convert truck traffic into ESALs, and ESAL estimate.

3 Research significance

Due to overloading, the road pavements in Pakistan fail prematurely. To avoid this, we need to design the thicknesses of pavements based on practical ESALs. In the past, negligible work is done to count realistic traffic volume and estimate the practical impact of the vehicular load in terms of ESALs. This research is therefore an attempt to determine ESALs for the collected data.

4 Data collection

Three rural roads were used to collect data: Topi Road Sawabi, KDA Road Kohat, and Nasar Bagh Road Peshawar. The data was manually collected for three days, from 7:00 a.m. to 7:00 p.m., for a total of 12 hours. Vehicles were counted in both directions.

5 Methodology

The data was manually collected for a period of 12 hours per day, from 7:00 a.m. to 7:00 p.m. Monday, Wednesday, and Friday were the days for collecting. A watch, clipboard, pencil, rubber, sharpener, and datasheet are used for manual counting. This method captures data that reflects the real-world scenario of road traffic. The information in Table-01 was gathered for three separate roadways.

Table-011: Data for the three roads along with Average per day and Peak per day values

Name of Road	Nasir Bagh Road Peshawar				
Data collection days	**Monday**	**Wednesday**	**Friday**	**Average Value/day**	**Peak Value/day**
Passenger cars	5239	4956	4567	1881	2656
Buses	7	11	14	64	73
2 AX Single (Bedford)	27	23	19	241	356
2 AX Single (Nisan/Hino)				98	122
3 AX Tandem				161	241
3 AX Single					
4 AX Single-Tandem				1	1
4 AX Tandem-Single					
4 AX Single				1	1
5 AX Sigle-Tridem				1	1
5 AX Tandem-Tandem				2	3
5 AX Single-Single-Tandem				1	1
5 AX Tandem-Single-Single					
6 AX Tandem-Tridem				1	1
6 AX Tandem-Single Tandem					

Name of Road	KDA Road Kohat				
Data collection days	**Monday**	**Wednesday**	**Friday**	**Average Value/day**	**Peak Value/day**
Passenger cars	1535	1412	1257	1401	1535
Buses	7	6	6	6	7
2 AX Single (Bedford)	217	257	230	234	257
2 AX Single (Nisan/Hino)					
3 AX Tandem	4	4	3	4	4
3 AX Single					
4 AX Single-Tandem					
4 AX Tandem-Single					
4 AX Single					
5 AX Sigle-Tridem					
5 AX Tandem-Tandem					
5 AX Single-Single-Tandem					
5 AX Tandem-Single-Single					
6 AX Tandem-Tridem					
6 AX Tandem-Single Tandem					

Name of Road	Topi Road Swabi				
Data collection days	**Monday**	**Wednesday**	**Friday**	**Average Value/day**	**Peak Value/day**
Passenger cars	2656	2092	894	4921	5239
Buses	73	54		11	14
2 AX Single (Bedford)	356	245	123	26	33
2 AX Single (Nisan/Hino)	118	122	55		
3 AX Tandem	241	176	67		
3 AX Single					
4 AX Single-Tandem	1		1		
4 AX Tandem-Single					
4 AX Single		1			
5 AX Sigle-Tridem	1	1	1		
5 AX Tandem-Tandem	3		1		
5 AX Single-Single-Tandem		1			
5 AX Tandem-Single-Single					
6 AX Tandem-Tridem		1	1		
6 AX Tandem-Single Tandem					

Table-02: percentage composition values for each type of vehicle

Road	Percentage composition of passenger cars	Percentage composition of Buses	Percentage composition of Bedford	Percentage composition of 2Ax-Single	Percentage composition of 3Ax-Tandem
Topi Road Sawabi	76.71%	2.61%	9.83%	4%	6.57%
KDA Road Kohat	85.17%	0.36%	14.22%		
Nasir Bagh Road Peshawar	99.25%	0.22%	0.52%		

6 Results and design

6.1 ESALs Estimation

Table-03,04 & 05 shows total ESALs values for each axel load for each road. Whereas Tabel-06 shows total ESALs values for each road.

Table-03: Estimated ESALs for Topi Road Swabi

Vehicle type	Current Traffic A	Growth Factors B	Design traffic C	ESAL Factor D	Design ESAL E
Passenger cars	2656	14.49	14047186	0.0007	9833.03
Buses	73	14.49	386086.1	1.85	714259.2
2 AX Single(Bedford)	356	14.49	1882831	1	1882831
2 AX Single (Nisan/Hino)	122	14.49	645239.7	1	645239.7
3 AX Tandem	241	14.49	1274613	6.8109	8681252
4 AX Single-Tandem	1	14.49	5288.85	11.4879	60757.57
4 AX Single	1	14.49	5288.85	14.2373	75298.91
5 AX Sigle-Tridem	1	14.49	5288.85	13.108	69326.33
5 AX Tandem-Tandem	3	14.49	15866.55	13.4154	212856
5 AX Single-Single-Tandem	1	14.49	5288.85	16.1648	85493.35
6 AX Tandem-Tridem	1	14.49	5288.85	15.0356	79520.77

Table-04: Estimated ESALs for KDA Road Kohat

Vehicle type	Current Traffic A	Growth Factors B	Design traffic C	ESAL Factor D	Design ESAL E
Passenger cars	1535	14.49	8118385	0.0007	5682.869
Buses	7	14.49	37021.95	1.85	68490.61
2 AX Single (Bedford)	257	14.49	1359234	1	1359234
2 AX Single (Nisan/Hino)	0	14.49	0	1	0
3 AX Tandem	4	14.49	21155.4	6.8109	144087.2
4 AX Single-Tandem	0	14.49	0	11.4879	0
4 AX Single	0	14.49	0	14.2373	0
5 AX Sigle-Tridem	0	14.49	0	13.108	0
5 AX Tandem-Tandem	0	14.49	0	13.4154	0
5 AX Single-Single-Tandem	0	14.49	0	16.1648	0
6 AX Tandem-Tridem	0	14.49	0	15.0356	0

Table-05: Estimated ESALs for Nasir Bagh Road Peshawar

Vehicle type	Current Traffic A	Growth Factors B	Design traffic C	ESAL Factor D	Design ESAL E
Passenger cars	5239	14.49	27708285	0.0007	19395.8
Buses	14	14.49	74043.9	1.85	136981.2
2 AX Single (Bedford)	33	14.49	174532.1	1	174532.1
2 AX Single (Nisan/Hino)					
3 AX Tandem					
3 AX Single					
4 AX Single-Tandem					
4 AX Tandem-Single					
4 AX Single					
5 AX Sigle-Tridem					
5 AX Tandem-Tandem					

Table-06: Total ESALs values

Road	Topi Road Swabi	KDA Road Kohat	Nasir Bagh road Peshawar
Design ESALs (W18)	12516667	1577495	330909.1

Table-06 shows total design ESALs for each road. Column A of Table-05 represents the peak values of the traffic count. Column B of Table-05 represents the growth factor. The growth factor for KPK is usually taken at around 8% as per the statistical data. It can be calculated by referring to Appendix D of the AASHTO design guide. By looking into table D.20 of appendix D, for a 10years design period and 8% growth rate the growth factor is 14.4. The design traffic, column C of Table-05, can be calculated by multiplying column A and column B. The ESAL factors or LEF factors can be calculated by the power fourth rule. The design ESAL, column E of Table-05, can be calculated by multiplying the column C by column D. The total ESALs values in Table-06 are calculated by adding all the ESALs in Table-05.

6.2 Structural Number (SN), Each Layer Thickness, and Quantity calculations

Table-07 shows SN, Thicknesses and Quantity estimation. The Quantity estimation was done for a 24 feet cross section width with 6.5 feet shoulder on each side. Rates were taken according to Market Rate System (MRS)-2021 Pakistan. ASHTO equation for the design of flexible pavement is

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

We have taken the following values, MR (Asphalt) = 400,000 Psi, MR (Base) = 250,000 Psi, MR (Sub-Base) = 100,000 Psi, MR (Sub-Grade) = 14,000 Psi, ΔPsi = 2, So= 0.45, Zr= -0.524 (Table 19.8 AASHTO design guide 1993), Reliability =70%, CBR = 9.3%, Drainage Time = 01 Week, Moisture = 25%, So, m2 = m3 = 0.90 (Table 19.6 AASHTO design guide 1993).

Tabel-07: SN, Thicknesses, and Quantity Estimation

Road	ESAL	SN	Thickness (in)			Quantities per 100 cubic-ft			Cost per Km (Millions pkr)
			D1	D2	D3	D1	D2	D3	
Topi-Swabi Road	12,516,667	3.57	4	6	10	26,246	61,242	87,490	23.93
KDA Road Kohat	1,577,495	2.55	2	4	6	12,981	44,863	63,954	14.64
Nasir Bagh Road Peshawar	330,909	1.63	2	4	6	12,981	44,863	63,954	14.22

Typical cross sections of road are shown in figure-1, 2, and 3. Shown cross sections are drawn according to the thicknesses come out from calculations.

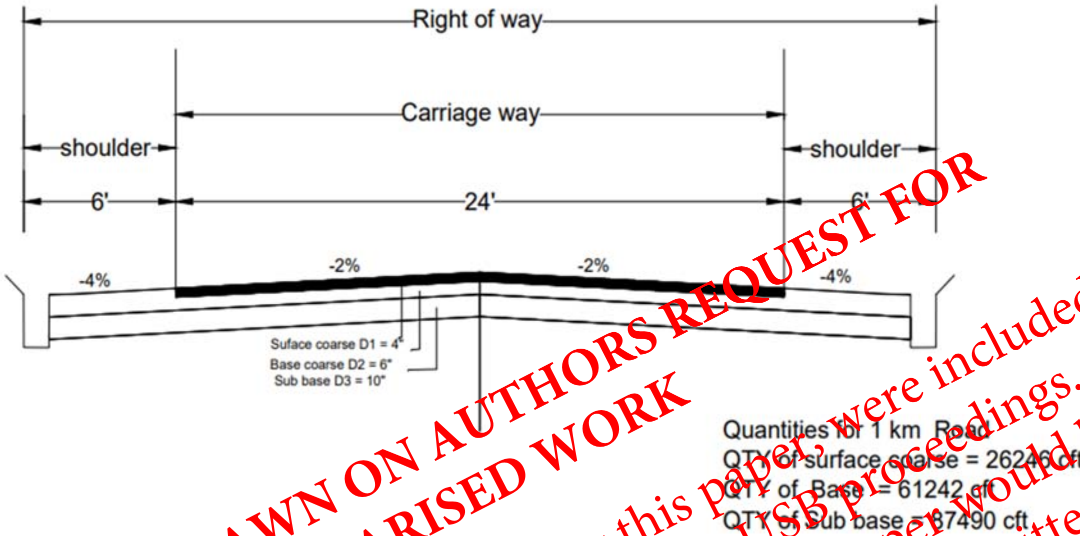

Figure-1 Typical Cross section of Topi Swabi Road Designed

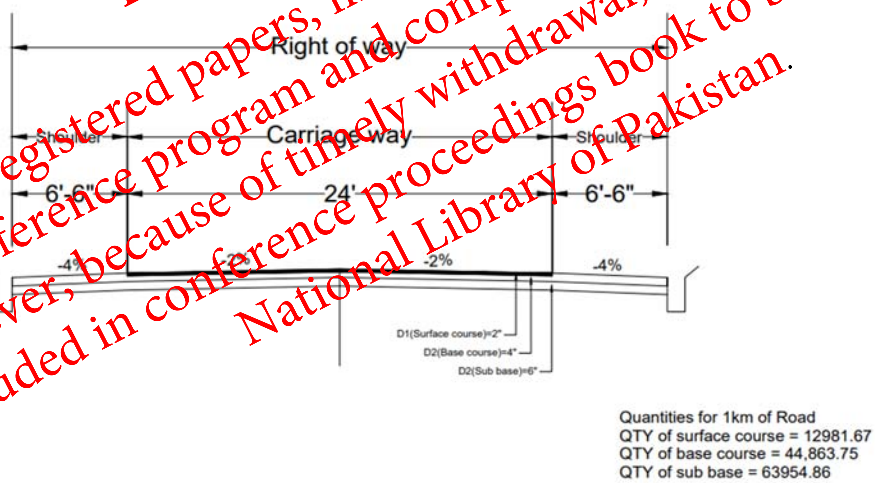

Figure-2 Typical Cross section of KDA Road Kohat

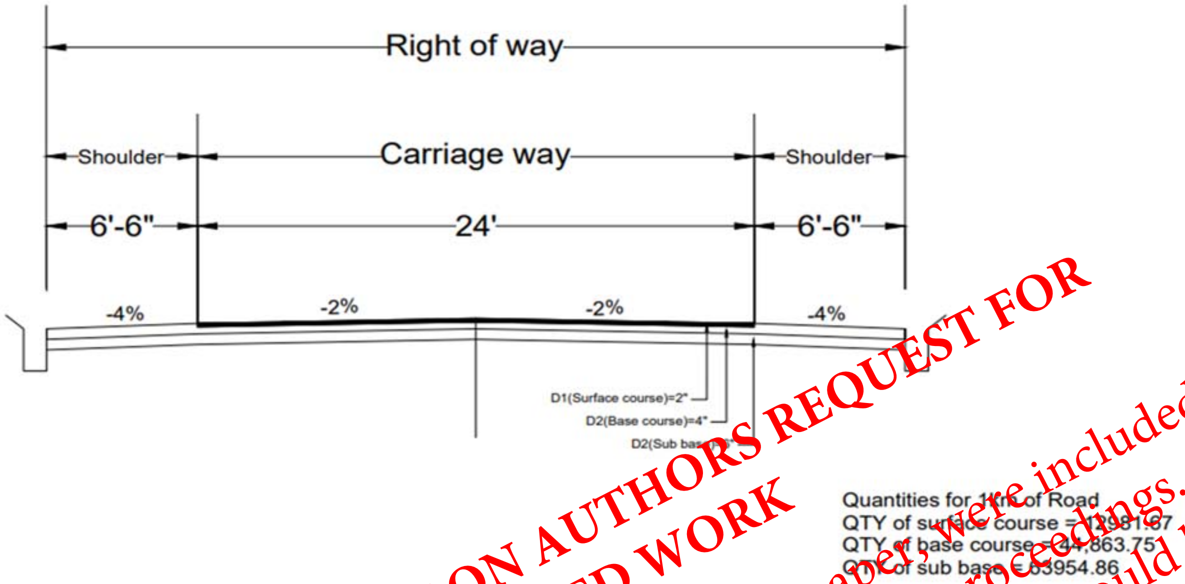

Figure-3 Typical Cross section of Nasir Bagh Road Peshawar

7 Implementations

All the rural roads in KP are widely design on the basis of thumb rule i.e. 2, 6, 6 in however this will not always be the case because after this research on rural roads it was found that for Topi road Swabi the total depth of road is 20 in but according to the rule of thumb it should be 14 in. So, it does not fulfill the strength criteria. Similarly, for KDA Road Kohat and Nasir-Bagh road Peshawar the total depth of the pavement is 12 in which is less than 14 in so it fulfills the strength criteria, but it becomes uneconomical. There are certain weight/load limits set by the authorities. However, the heavy vehicle drivers, to save time, overload the vehicle that exceeds the limits set by the authorities. So, there should be proper monitoring, enforcement, inspection, and penalty for overloading.

8 Conclusion

From the analysis and study of the traffic data, we concluded that:

1. The cumulative design ESALs for Topi-Swabi is 12,516,667, For KDA Road Kohat is 1,577,495, and that for Nasir-Bagh Road Peshawar is 330909. Whereas the depths for different layers of the road i.e., surface course, base course, and sub-base for Topi Road Sawabi are 4,6, and 10 inches, and that for KDA road Kohat and Nasir-Bagh Road Peshawar is 2,4 and 6 inches respectively.
2. The pavement structure is more damaged by heavy vehicles. The research shows that passenger automobiles account for 76.71 percent of the traffic on Topi Road Sawabi, while buses account for 2.61 percent as shown in Table-02. Buses have a lower ratio of passengers than passenger vehicles. However, the ESAL design for buses is 714259.2, whereas the design for passenger automobiles is 9833.03. As a result, large trucks are more likely to harm the pavement structure than passenger cars.
3. Traditionally, all rural roads in KP are designed using the thumb rule of 2 in, 6 in, and 6 in, although this is not always the case, as evidenced by the results.

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