Analysis of Vehicle Damage Factor in Overloading for Different Types of Loading

Yogeshwar Kumar Singh¹, D. S. Ray²
PG Student¹, Professor²
Department of Civil Engineering
Babu Banarasi Das University, Lucknow, India

Abstract:
This paper aims to study the analysis of the vehicle damage factor in overloading for different types of loading. Overloading has been a problem because of permissible axle load limit is not followed. The idea is to use axle load survey data to evaluate Equivalent Single Axle Load (ESAL) and the Vehicle Damage Factor and then further analyze the pavement to determine the required overlay thickness. The axle load survey is carried put very carefully in order to get the correct vehicle damage factor value. There are many constraints regarding the steps to evaluate the vehicle damage factor, therefore it is carried out very carefully to avoid any wrong data. After the evaluation of the vehicle damage factor cost analysis is done for the dense bituminous layer of the flexible pavement. Overall this study can be used for the analysis of VDF (Vehicle Damage Factor), MSA (Million standard axles) and axle load survey data. The information obtained can be used in the final computation of pavement layers.

Key words: Axle load survey, permissible axle load limit.

I. INTRODUCTION

Vehicle damage factor is evaluated by using following formula:-

\[ VDF = \frac{\sum_{i=1}^{n} [W_i \times LEF_i]}{N} \]

where, \( W_i \) = Traffic volume of the \( i \)th vehicle load-class
\( LEF_i \) = Load equivalency factor of \( i \)th vehicle load-class
\( N \) = Total number of vehicles weighed

Every passage of a vehicle on a pavement will cause a certain amount of damage or distress in different forms. The degree of damage caused by a vehicle depends on its gross weight, number of axles as well as configuration of wheels. For example, if two vehicles have equal gross load, one with a single axle single wheel and the other with a tandem axle dual wheel assembly, the damage caused by the former vehicle will be greater. This is because the gross load is transferred onto the pavement surface over a wider area by more number of axles and wheels.

The damage caused by different vehicles is calculated using the vehicle damage factor which is used for performance modelling, design and maintenance of pavements.

The vehicle damage factor (VDF) is a numerical value which represents the equivalent number of standard axles per truck (IRC: 37-2001). It is a multiplication factor used to convert different commercial vehicles with varying axle load repetitions to standard axle load repetitions. From axle load survey data, VDF is calculated using the following equation.

The equations for computing equivalency factors for single, tandem and tridem axles given below should be used for converting different axle load repetitions into equivalent standard axle load repetitions. Since the VDF values in AASHO Road Test for flexible and rigid pavement are not much different, for heavy duty pavements, the computed VDF values are assumed to be same for bituminous pavements with cemented and granular bases. Factors affecting VDF numerous factors which are related to damage or distress caused to pavement affect VDF.

The factors may be related to traffic composition at the time of survey, load on axles, possible occasional (or seasonal) overloading, number of axles, wheels configuration, terrain, type of pavement, region, pavement condition, temperature, rainfall etc.

In pavement design, VDF obtained from axle load survey data should be used rather than an assumed value because the VDF value obtained from survey data represent a realistic value by considering actual traffic loading and other factors related to the region (or pavement considered.

II. KEYWORDS OF THE PROPOSED EXPERIMENT

A. Axle load survey

There are two methods to weigh truck or axle loads:-

- Static weighing
- Weighing In Motion (WIM)

In static weighing vehicles are stopped and weighed but WIM vehicles are weighed dynamically while in motion.

In the static method, the axle load of a vehicle is weighed using portable weights or load-pads (Figure 6.6) or a weighing platform.

Only axle loads having more than or equal to 3 tonnes are taken into account for analysis since the damage caused by axles weighing less than 3 tonnes is negligible. For traffic analysis, vehicles having axle weight = 3 tonnes are referred to as commercial vehicles.
Table 1. Comparison between Static weighing and Weighing in Motion (WIM)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Static weighing method</th>
<th>Weight in motion (WIM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vehicles are stopped and weighed</td>
<td>Vehicle is weighed automatically while in motion, without disturbing the driver.</td>
</tr>
<tr>
<td>2</td>
<td>Accurate weight measurement</td>
<td>Weight measurements may be influenced by parameters related to vehicle speed, suspension system of the vehicle, tyre pressure, acceleration and deceleration of the vehicle and dynamic forces produced due to pavement roughness, wind velocity etc.</td>
</tr>
<tr>
<td>3</td>
<td>Takes more time and interrupts free flow of traffic; may pose problems related to safety</td>
<td>There is no such interruption to flow traffic; can weigh high volumes of traffic.</td>
</tr>
<tr>
<td>4</td>
<td>Other information such as body type of vehicles, loading type etc. can be physically ascertained.</td>
<td>Collection of other information is not possibly by automated WIM equipment.</td>
</tr>
<tr>
<td>5</td>
<td>Less number of vehicles can be measured: selected vehicles are weighed; need more personnel, time and space, to weigh all vehicles.</td>
<td>More number of vehicles can be measured; better coverage of all vehicles since its automatic.</td>
</tr>
<tr>
<td>6</td>
<td>Less installation and maintenance cost.</td>
<td>High installation and maintenance cost.</td>
</tr>
<tr>
<td>7</td>
<td>The weigh pads can be installed at any location.</td>
<td>WIM equipment can be installed at a fixed location only.</td>
</tr>
</tbody>
</table>

B. Permissible axle load limit

The Ministry of Road Transport & Highways has issued a notification (18-July-2018) increasing permissible truck axle load. As per the amended rules, the maximum safe axle weight of each axle type in relation to the transport vehicles (other than motor cabs), with regard to the size, nature and number of tyres would be as follows:

Table 2. Permissible axle load limit in India

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Axle type</th>
<th>Maximum safe axle weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single axle</td>
<td>30 tonnes</td>
</tr>
<tr>
<td>1.1</td>
<td>Single axle with single tyre</td>
<td>7.5 tonnes</td>
</tr>
<tr>
<td>1.2</td>
<td>Single axle with two Tyres</td>
<td>11.3 tonnes*</td>
</tr>
<tr>
<td>1.3</td>
<td>Single Axle with four Tyres</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Tandem Axles (Two axles) (where the distance between two axles is less than 1.8 Mtr.)</td>
<td>21 tonnes*</td>
</tr>
<tr>
<td>2.1</td>
<td>Tandem axle for rigid vehicles, trailers and semi-trailers</td>
<td>28.5 tonnes</td>
</tr>
<tr>
<td>2.2</td>
<td>Tandem axle for Puller tractors for hydraulic and pneumatic trailers</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tri-axles (Three axles) (where the distance between outer axles is less than 3 Mtr.)</td>
<td>27 tonnes*</td>
</tr>
<tr>
<td>3.1</td>
<td>Tri-axle for rigid vehicles, trailers and semi-trailers</td>
<td>18 tonnes</td>
</tr>
<tr>
<td>4</td>
<td>Axle Row (two axles with four tyres each) in Modular Hydraulic trailers (5 tonnes load shall be permissible for single axle)</td>
<td></td>
</tr>
</tbody>
</table>

* Note: If the vehicle is fitted with pneumatic suspension, 1 tonne extra load is permitted for each axle. The amendment lays down that the gross vehicle weight (GVW) will not exceed the total permissible safe axle weight as above and in no case shall exceed:
- 49 tonnes in case of rigid vehicles
- 55 tonnes in case of semi-articulated trailers and truck-trailers except modular hydraulic trailers.

Number of days of survey will depend on project location, the type of project and the intensity and expected variation in traffic. This survey duration may vary between 24hours and 3 days, but should be carried out at least for one day at the traffic coundstations on a random basis for commercial vehicles. Buses may be omitted as their weight can be easily calculated and they do not result in excessive overloads. The period of conducting the survey should also be judiciously selected keeping in view the movement of commodity /destination oriented dedicated type of commercial vehicles. While finalising the design Equivalent Standard Axle load, the following should be considered:
- Past axle load spectrum in the region as well as on the road to the extent available.
- Annual variation in commercial vehicles.
- Optimistic and pessimistic considerations of future generation of traffic.
- Generation of changing VDF factor during the project period.
III. COST ANALYSIS

A. Introduction
From the present study it can be observed that the overloading of commercial vehicles on highway network is very high. It is known that increase in axle loads cause considerable damage to the pavement. It can be observed from the analysis and results that the damage caused by the vehicles with over loaded axles is very high when compared to the damage caused by the vehicles with allowable axle loads. It implies that the pavement is needed to be strengthened much earlier during the design life, if the same trend of axle loads and type continues. This increases the life cycle cost as the number of overlays to be provided is more. By enforcing the limitations on overloading of vehicles i.e. either by restricting the axle load limit for all vehicles or by introducing more no. of multi axle commercial trucks for higher loading capacity, the strengthening measures can be delayed / extended so that the number of overlays and thus the life cycle cost will reduce.

As we evaluated the vehicle damage factor, we observe that Dense Graded Bituminous Macadam which is below the Bituminous concrete can be compared and analysed because we see changes only in the DBM layer while all the layer remains the same i.e. base course and sub-base course.

The rate per cubic metre is Rs. 8570.11 for the Dense Graded Bituminous Macadam. Using the default values of vehicle damage factor Now the design of the pavement according to the suitable data. Data that we have:

- Initial Traffic = 1550 CVD
- Traffic growth per annum = 7.5
- Design life = 15 years
- Default Vehicle Damage Factor = 4.5
- Actual evaluated Vehicle damage factor using axle load survey = 12.22
- Design CBR = 8%
- Distribution factor = 0.75

Cumulative number of standard axle for default value of vehicle damage factor

\[ N = \frac{365 \times (1 + r)^n - 1}{r} \times A \times D \times F \]

where,
- \( A \) = Initial traffic = 1550
- \( D \) = Lane distribution factor = 0.75
- \( F \) = Vehicle damage factor = 4.5
- \( n \) = Design life in years = 15 years
- \( r \) = Annual growth rate of commercial vehicles (for 7.5 per cent annual growth rate, \( r = 0.075 \))

\[ N = \frac{365 \times (1 + 0.075)^{15} - 1}{0.075} \times 1550 \times 0.75 \times 4.5 \]

\[ N = 49.870568.81 \]

\[ N = 49.87 \text{ msa} \sim 50 \text{ msa} \]

At CBR 8%

Using the interpolation rule in pavement thickness design graph, the pavement design is 610mm for this evaluation. For further evaluation, the pavement

<table>
<thead>
<tr>
<th>CBR 8%</th>
<th>Cumulative Traffic (msa)</th>
<th>Total Pavement Thickness (mm)</th>
<th>PAVEMENT COMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bituminous Surfacing</td>
<td>Granular Base &amp; Sub-base (mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BC (mm)</td>
<td>DBM (mm)</td>
</tr>
<tr>
<td>10</td>
<td>550</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>20</td>
<td>573</td>
<td>40</td>
<td>85</td>
</tr>
<tr>
<td>30</td>
<td>590</td>
<td>40</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>610</td>
<td>40</td>
<td>120</td>
</tr>
<tr>
<td>100</td>
<td>640</td>
<td>50</td>
<td>140</td>
</tr>
<tr>
<td>150</td>
<td>660</td>
<td>50</td>
<td>160</td>
</tr>
</tbody>
</table>

Base = 250
Sub-base=200

Table.3. Pavement thickness CBR value

Table.4. Pavement thickness catalogue design catalogue is used to determine the dense bituminous macadam.
BC = 40 mm  
DBM = 120 mm  
Base = 250 mm  
Sub Base = 200mm

Cumulative number of standard axle for actual value of vehicle damage factor  
A = Initial traffic = 1550  
D =Lane distribution factor = 0.75  
F = Vehicle damage factor = 12.22  
n = Design life in years = 15 years  
r = Annual growth rate of commercial vehicles (for 7.5 per cent annual growth rate, r = 0.075)  
N = \frac{1365 * [(1 + 0.075)15 - 1] * 1550 * 0.75 * 12.22]}{0.075}  
N = 135426300.2  
N = 135.42 msa  

Using the interpolation method in pavement thickness design graph, the pavement design is 654 mm for this evaluation. For further evaluation, the pavement design catalogue is used to determine the dense bituminous macadam.  
BC = 50 mm  
DBM = 154 mm  
Base = 250 mm  
Sub Base = 200mm

IV. ANALYSIS OF RESULT

Now estimating the cost for 1km of road  
Taking the length of the road = 1 km  
Width of the road = 7.5 m  

Therefore, for default Vehicle Damage Factor is  
= 1000 * 7.5 * (120*0.001)  
= 900 cum  
Rate per cum = Rs 8570.11  
For 900 cum = 8570.11*900  
= Rs 77,13,099  

Therefore, for actual Vehicle Damage Factor is  
= 1000 * 7.5 * (154*0.001)  
= 1155 cum  
Rate per cum = Rs 8570.11  
For 1155 cum = 8570.11*1155  
= Rs 98,98,477  
Difference is  = Rs 98,98,477 - Rs 77,13,099  
= Rs 2185378

V. CONCLUSIONS

Due to overloading, pavement deteriorates at faster rate and the loss value due to overloading is estimated to be Rs 2185378 for our current surveyed site which is 28.33 percent of the road cost for DBM layer. Hence the overloading should be restricted to avoid further road damage and to provide more serviceability.  
- As overloading is increasing, it has to be controlled by rules and regulations.  
- Intensity of weight enforcement and the level of penalty only cannot control overloading activities. So fines must be associated with intensified enforcement when considered in further strategy. Enforcement has higher efficiency at the initial stage. However efficiency decreases rapidly when enforcement levels increase gradually. Thus, the balance between level of enforcement and efficiency of enforcement must be considered. Effective means of managing truck overloading is not unitary. It must combine monitoring, inspection, enforcement and punishment as a complete.  

Regular monitoring, inspection and enforcement are the effective ways to control overloading.  
- Use of technology (Automatic overloading information system) may be the effective way to control the overloading and Design should be done as per the actual traffic loading condition.  
- To construct or improve road built quality to withstand heavier loads.  
- To impose axle load limit and strict enforcement. This seems to be the only viable solution for saving our road infrastructure from the deterioration due to overloading and bringing it at par with international standards. Most of the highway engineers believe that unless a limit of axle load is imposed, no matter how strong pavements are built, would fail under the prevailing heavy loaded vehicles. The vehicle overloading is seriously handicapping the improvement of road network in many developing countries.  
- The deterioration rate of the pavement and the loss value due to overloading is estimated to be Rs 2185378 for our current surveyed site which is 28.33 percent of the road cost of DBM layer. Therefore, overloading should be restricted to avoid further road damage and to provide more serviceability.  
- There are many factors which results in overloading and heavier axle loads on the road, one of the reason is that the new introduction of the more spacious trucks which eventually alter the axle load distribution on the road. In order to compete and keep themselves in the market by keeping the haulage cost at minimum, the truck owner generally overload their vehicle much beyond their rated capacity. To carry extra load, the vehicle owner strengthens the vehicle body and adds extra suspension springs to increase the height of the vehicle’s body.  

VI. REFERENCES

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