Methodology of Studying Impact of Vehicle Overloading on Pavement Surface and Design of Overall Thickness

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Abstract - Overloading by commercial trucks in India is a stern problem. The ever-loaded trucks stress the road structure beyond permissible bearing capacity. One of the major factors affecting pavement life is the extent and frequency of the wheel load repetitions imposed on the pavement structure. In order to maintain the heavy gross vehicle weight and still stay within the legal axle load limits, the trucking and freight industry has devised multiple axle configurations, which include rear tandem axle trucks. This report aims to study the methodology to analyse the Vehicle Damage Factor (VDF) in overloading for different types of loading and mentioned multiple axle configurations and hence, establishing the connection between overloaded commercial vehicles and pavement failure. The study incorporates methodology of conducting Axle Load Survey on the project site that would give the details of different types of axles, axle load spectrum, repetitions of each load group expected during the design life period. The Axle load Survey data will further be used to calculate the Equivalent Axle Load Factor (EALF) & Vehicle Damage Factors (VDF) were calculated. Using the traffic and other engineering data, the methodology to analyse pavement performance has been evaluated for designed Flexible Pavement in this study. The required pavement thickness to is then calculated using design norms stated in IRC 37-2012.

Key Words: Axle Load Survey, Vehicle Damage Factor, Equivalent Axle Load Factor, Flexible Pavement, Pavement Thickness

1. Introduction

Road-network is vitally important to a nation’s economic development. The construction of a high-quality road network directly increases a nation’s economy by reducing journey time, vehicle operating costs and easing the mobility of people and goods making a region more attractive [1]. India, like most developing countries is facing the dilemma of vehicle overloading. The vehicle loads plying on the highways are much substantial than the strength of the infrastructure actually designed. Nowadays, the situation has entirely changed and goods transportation by railways has been mostly shifted to road due to the last mile connectivity service offered by road. The local truck body makers are producing wider and elevated truck bodies which enable the truck owners to reduce haulage cost. The over loaded trucks stress the road structure beyond its safe bearing capacity. This causes a drastic reduction in the pavement service life and gets destroyed before its design life. IRC-3-1983 clearly specifies the maximum amount of load that a truck’s axle can carry based on the axle configuration. Due to lack of strict enforcement, these rules and regulations are getting violated most of the time. For getting more profit in less time, the truck owners overload their trucks exceeding their maximum carrying capacity thereby ignoring the rules.

A detailed methodology study on the analysis of overloading of trucks and its impact on pavement structure is incorporated in this paper. The study uses axle load survey as the main component to identify and calculate performance variables. The variables are then used to calculate the mean number of equivalent standard axles for a typical vehicle in each vehicle class. These variables are then combined with traffic flows and forecasts to determine the total predicted traffic loading that the road will carry over its design life in terms of millions of equivalent standard axles (MSA). Pavement design is performed by accounting various factors such as traffic data, growth rate, lane distribution of vehicles, and the vehicle damage factor. Vehicle Damage Factor (VDF) which is a representing parameter for traffic load is one of the predominant components on pavement design. The design curves relating characteristic pavement deflection to the cumulative number of standard axles to be carried over the design life are then used to design the required pavement thickness in order to cater to the overloading demands.

1.1 Scopes and Objectives

The research paper integrates the following objectives:

- To study the methodology to analyse the behavior of commercial overloading by conducting Axle Load Survey on the proposed project site
- To study the methodology to analyse Equivalent Axle Load Factor, Vehicle Damage Factors and other variables from the survey data, and
- To assess the effect of overloading on pavement performance and design the overall pavement thickness.
2. Axle Load Survey

The most effective way to compare the damaging effect of traffic on given roads is to measure the complete spectrum of axle loads and calculate the appropriate equivalence factors [2]. The main purpose of the axle load survey for trucks is to collect preliminary information regarding the range of heavy axle loads traversing the nation’s main highways. With axle load calculation for trucks, road authorities can make better decisions on which stretch to repair and which part of the road or pavement to prioritize, in order to optimize traffic flow. The data helps reduce the effects of overloading and prevents accelerated damage to pavement. With a comprehensive study of axle loads for trucks road planning departments can ensure that existing roads are appropriately maintained so that they provide appropriate level of service for road users across a longer duration. These surveys also assist to improve existing road conditions to meet the necessary standards in order to enable them to carry prevailing levels of traffic with the desired level of safety.

The total weight of the vehicle is carried by its axles. To keep wheel load induced stresses on pavement within allowable limit the total vehicle load is distributed onto wider areas of pavement by using more axles and wheels. This is the reason why a greater number of axles and wheels are fitted to heavy load carrying trucks. The VDF varies with the vehicle axle configuration and axle loading. There are following types of axles:

1. Single Axle
2. Tandem Axle
3. Tridem Axle

For the analytic purposes, each tandem axle repetition may be considered as two repetitions of a single axle carrying 50% of the tandem axle weight as axles separated by a distance of 1.30 m or more do not have a significant overlapping of stresses. Similarly, one application of a tridem axle may be considered as three single axles, each weighing one third the weight of the tridem axle. For example, if a tridem axle carries a load of 45 tonnes, it may be taken to be equivalent to three passes of a 15-tonne single axle.

When conducting an axle load survey, the validity of the two following assumptions are made:

1. The load on the wheels of an axle remains constant at all times, i.e. it remains the same as it was when the vehicle was originally loaded.

2. The load exerted on the road by any wheel of any vehicle, whether at rest or in motion, is constant and determined by the initial load distribution of the vehicle.

These assumptions disregard the fact that the load concentration on a wheel or an axle changes continuously when the vehicle is in motion. Table – 3 & Table – 5 should be used while conducting Axle Load Surveys.

2.1 Vehicle Classification

Since, the flows of such vehicles are too high, a sample should be selected for weighing. However, not all types of vehicle need to be weighed. This is because almost all of the structural damage to a road pavement is caused by the heavy goods vehicles, medium goods vehicles, and large buses. Thus, it is not necessary to weigh vehicles of less than 1.5 tonnes weight, for example; motorcycles, cars, small buses or small trucks with single rear tyres [3]. Large buses often have quite high axle loads and should be weighed in the survey. However, since many buses will pass the survey station repeatedly during the day with fairly similar payloads, to avoid unnecessary inconvenience it is often sufficient to weigh a smaller sample of buses than the sampling rate chosen for other vehicle types.

According to IRC, the variables are calculated at by carrying out axle load surveys on the existing roads for a minimum period of 24 hours in each direction. Frequency of each class interval was computed. Midpoint values of each weight class have been considered for obtaining the equivalency factors for respective weight class. The minimum sample size of commercial vehicles to be considered for the axle load survey is given in table below. Care should be taken to ensure that there is no bias in the selection of the vehicles for the survey. The vehicles to be surveyed should be selected randomly irrespective of whether they are loaded or empty. On some sections of roads, there may be a significant difference between the axle loads of commercial vehicles plying in the two directions of traffic. In such situations, the VDF should be evaluated separately for each direction.

<table>
<thead>
<tr>
<th>Commercial Volume (CPVD)</th>
<th>Traffic Traffic to be Surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3000</td>
<td>20%</td>
</tr>
<tr>
<td>3000-6000</td>
<td>15 per cent (subject to a minimum of 600 cvpd)</td>
</tr>
<tr>
<td>&gt;6000</td>
<td>10 per cent (subject to a minimum of 900 cvpd)</td>
</tr>
</tbody>
</table>

Table - 1: Sample Survey Data
For simple purposes, classifications are defined in such a way that vehicles can be assigned to them from a quick and purely visual inspection; in other words, irrespective of knowledge of a vehicle's unloaded weight or payload capacity.

<table>
<thead>
<tr>
<th>Heavy vehicle Category</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>Seating capacity of 40 or more</td>
</tr>
<tr>
<td>Medium goods vehicle (MGV)</td>
<td>- 2 Axles incl. steering axle</td>
</tr>
<tr>
<td></td>
<td>- 3 tonnes empty weight or more</td>
</tr>
<tr>
<td>Heavy goods vehicle (HGV)</td>
<td>- 3 Axles incl. steering axle</td>
</tr>
<tr>
<td></td>
<td>- 3 tonnes empty weight or more</td>
</tr>
<tr>
<td>Very heavy goods vehicle (VHGV)</td>
<td>- 3 tonnes empty weight or more</td>
</tr>
<tr>
<td></td>
<td>- 4 or more axles incl. steering axle</td>
</tr>
</tbody>
</table>

Table - 2: Vehicle Classification and Definitions

2.2 Weighing Method: Primary Data Collection

The actual weight of a car is known as the gross vehicle mass or weight (GVW). It refers to the current weight of a vehicle will all of its parts and everything inside it including cargo and passengers. It also counts the bulk of all the fluids and payload inside the car.

The portable wheel weight measuring equipment should be used for the measurement of wheel loads \[4\]. Each vehicle to be weighed is to be aligned on to the unit and stopped with the wheel being weighed at the centre of the top plate. The vehicle should be stopped just long enough for the reading on the display unit to get stabilized. Assuming the load on each axle as evenly distributed, the axle load was taken in proportion to the wheel load. While the vehicles are being weighed, information about the axle-type should also be recorded.

3. Axle Load Survey Variable

The following variables are calculated in order to judge the pavement performance and further design the overall pavement thickness.

3.1 Equivalent Axle Load Factor

An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the \(i\) th type of axle relative to the damage per pass of a standard axle load. A standard load is defined as a single axle load carrying 80 KN load on which the pavement design is based. An equivalency is simply a convenient means for indexing the wide spectrum of actual loads to one selected value. One of the most important and useful products of the AASHO Road test was the development of a relationship characterizing the relative damaging effect of varying axle loads on pavements in terms of the equivalent 8.2 tonnes single axle load. The relationship sometimes referred to as 'fourth power' rule has subsequently been verified by the studies reported by several agencies in different countries. The rule states that the damage power of an axle load increases roughly as a fourth power with the weight of an axle i.e. any single axle load less than 8200 kg is some fractional EAL, whereas any greater single load is some multiple of EAL. According to IRC 37-2012, for converting one repetition of a particular type of 18 axle carrying a specific axle load into equivalent repetitions of 80 kN single axle with dual wheel, the following equations may be used.

1. Single axle with single wheel on either side = \[
\frac{\text{(Axle Load in KN)}}{65}\]
2. Single axle with dual wheel on either side = \[
\frac{\text{(Axle Load in KN)}}{80}\]
3. Tandem axle with dual wheel on either side = \[
\frac{\text{(Axle Load in KN)}}{148}\]
4. Tridem axle with dual wheel on either side = \[
\frac{\text{(Axle Load in KN)}}{224}\]

Since the axle load equivalence factors reported from the AASHO Road Test for flexible as well as rigid pavements are not significantly different for heavy duty pavements, it is assumed that the VDF values estimated for checking subgrade rutting and bituminous layer fatigue cracking can be used for checking the fatigue damage of cemented bases also.

From the above suitable calculations, the Equivalent Single Axle Load is calculated. The Equivalent Single Axle Load is the number of repetitions of the 80 KN standard axle load that causes the same damage caused by one pass of the same standard load.

\[
\text{Equivalent Single Axle Load (ESAL)} = \sum F_i \times N_i
\]

Where,

\(F_i = \text{EALF of the } i^{th} \text{ axle group}\)

\(N_i = \text{number of passes of the } i^{th} \text{ axle load during the design period}\)

For simplification, Single Wheel with Single Axle is considered as Cat. A, Single Wheel with Dual Axle is considered as Cat. B, Tandem axle is considered as Cat. C and Tridem Axle is considered as Cat. D.
Table – 3: Axle Load Survey Data

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Buses</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>2.</td>
<td>MGV</td>
<td></td>
<td></td>
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<tr>
<td>3.</td>
<td>HGV</td>
<td></td>
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<tr>
<td>4.</td>
<td>VHGV</td>
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</tbody>
</table>

Here,

MGV: Medium Good Vehicles
HGV: Heavy Good Vehicles
VHGV: Very Heavy Good Vehicle

It should be noted that the Average ELAF is calculated using the following formula:

\[
\text{Average ELAF} = \frac{\sum_{i=1}^{n} EALF_i \cdot V_i}{N}
\]

It should be noted that Average E.L.A.F. calculated here is to be taken as the value of Vehicle Damage Factor.

Table – 4: Additional Truck Info.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Vehicle Category</th>
<th>Total no. of Vehicles Surveyed</th>
<th>Total Load Exceeding Legal Load Limit</th>
<th>Additional Truck Required to Transport Overload Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Buses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>MGV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>HGV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>VHGV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where,

\[V_i = \text{Traffic volume of i}^{th}\text{vehicle load class}\]
\[EALF_i = \text{Equivalent Axle Load Factor of i}^{th}\text{vehicle load class}\]
\[N = \text{Total number of vehicles weighed}\]

With the standard axle of 80 kN resting on dual tyres on axle configuration, it can be assumed that the axle on single tyres is 6.5 kN. Using the data from the above Table, the percentage proportion of overloaded trucks is found out. The overloaded goods weight is then assumed to be transported by the use of additional trucks [1]. The modified value of VDF is then calculated which would be definitely less than the value of VDF calculated before.
Table – 4: Modified Axle Load Survey Table

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Buses</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>MGV</td>
<td></td>
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</tr>
<tr>
<td>3.</td>
<td>HGV</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>VHGV</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It should be noted that the Modified Average ELAF is calculated using the following formula:

\[
\text{Modified Average ELAF} = \frac{\sum_{i=1}^{N} V_i \times EALF_i}{N}
\]

Where,

- \( V_i \) = Modified Traffic volume of \( i^{th} \) vehicle load class after inclusion of additional trucks to cater to the overloaded weigh
- \( EALF_i \) = Modified Equivalent Axle Load Factor of \( i^{th} \) vehicle load class
- \( N \) = Modified total number of vehicles weigh

### 3.2 Vehicle Damage Factor

The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions [5]. It is defined as equivalent number of standard axles per commercial vehicle. The VDF varies with the axle configuration, axle loading, terrain, type of road, and from region to region. The axle load equivalency factors are used to convert different axle load repetitions into equivalent standard axle load repetitions.

The VDF is calculated according to the following formula:

\[
\text{Vehicle Damage Factor (VDF)} = \frac{\sum_{i=1}^{N} V_i \times EALF_i}{N}
\]

Where,

- \( V_i \) = Traffic volume of \( i^{th} \) vehicle load class
- \( EALF_i \) = Equivalent Axle Load Factor of \( i^{th} \) vehicle load class
- \( N \) = Total number of vehicles weighed

Vehicle Damage Factor is now to be equated with the Average E.L.A.F. and the Modified Average E.L.A.F. calculated before

### 4. Pavement Design

In order to avoid failure, the pavement must be designed such that it caters to the overloaded vehicles too. The design of the overall thickness should be done according to IRC:37-2012. According to the IRC, the flexible pavements have been modelled as a three-layer structure and stresses and strains at critical locations have been computed using the linear elastic model.

The following variables are to be calculated to design the pavement thickness.
4.1 Initial Traffic

Initial traffic is determined in terms of commercial vehicles per day (CVPD) [5]. For the structural design of the pavement only commercial vehicles are considered assuming laden weight of three tonnes or more and their axle loading will be considered. Estimate of the initial daily average traffic flow for any road is based on 7-day 24-hour classified traffic counts (ADT). In case of new roads, traffic estimates can be made on the basis of potential land use and traffic on existing routes in the area.

The following survey table is to be incorporated in order to calculate AADT as well as CPVD.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Vehicle Category</th>
<th>No. of Axles</th>
<th>Vehicle Count</th>
<th>PCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bus</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>M.G.V.</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>H.G.V.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>V.H.G.V.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2 Traffic Growth Rate

For estimating the cumulative traffic expected to use the pavement over the design period, it is necessary to estimate the rate(s) at which the commercial traffic will grow over the design period. The growth rates may be estimated as per IRC 108. Typical data required for estimation [5] of the growth rates (s) are:

- Past trends of traffic growth and
- Demand elasticity of traffic with respect to macroeconomic parameters like the gross domestic product and state domestic product and the demand expected due to specific developments and land use changes likely to take place during the design life period.

If adequate data is not available, it is recommended that an average annual growth rate of 7.5 percent may be adopted.

4.3 Pavement Design Period

The design period to be adopted for pavement design is the time span considered appropriate for the road pavement to function without major rehabilitation. It is recommended by the IRC that a design period of 20 years may be adopted for the structural design of pavements for National Highways, State Highways and Urban Roads. For other categories of roads, a design period of 15 years is recommended. Pavements for very high-density corridors (more than 300 msa) and expressways shall preferably be designed as long-life pavements. Otherwise, for such corridors, the pavement shall be designed for a minimum period of 30 years. The commercial traffic, converted into equivalent repetitions of the standard axle, and adjusted for directional distribution, lateral distribution over the carriageway width, etc., is the design traffic.

4.4 Vehicle Damage Factor

The VDF to be used for overlay design is calculated after conducting Axle Load Survey on the Project Site. The average Equivalent Axle Load Factor (EALF) is to be used for the same purpose. Both, the Average and the Modified Average E.L.A.F. values should be used for designing according to project’s cost flexibility.

4.4 Lane Distribution Factor

A realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design. Until reliable data is available, the following distribution may be assumed. [5]

- Single lane roads: Traffic tends to be more channelized on single roads than two lane roads and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both directions.
- Two-lane single carriageway roads: The design should be based on 75 % of the commercial vehicles in both directions.
- Four-lane single carriageway roads: The design should be based on 40 % of the total number of commercial vehicles in both directions.
- Dual carriageway roads: For the design of dual two-lane carriageway roads should be based on 75 % of the number of commercial vehicles in each direction. For dual three-lane carriageway and dual four-lane carriageway the distribution factor will be 60 % and 45 % respectively.

4.4 Subgrade CBR Value

California Bearing Ratio (CBR) is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. For determining the CBR value of the subgrade, the standard procedure described in IS 2720 (Part 16) should be strictly adhered to. According to the recommendations, the test must always be performed on remolded samples of soil in the laboratory. Also, the samples must be soaked in water four days prior to testing.
After calculation of above required parameters, the computation of Design Traffic in terms of Million Standard Axles (MSA) [5] is done by the following formula [6]:

\[ N_{des} = \frac{265 \times (1 + R)^{n - \frac{1}{2}} \times A \times D \times F}{n} \]

Where,

\( N_{des} \) = cumulative number of standard axles to be catered for during the design period of ‘n’ years

\( A \) = initial traffic (commercial vehicles per day) in the year of completion of construction (directional traffic volume to be considered for divided carriageways where as for other categories of the carriageway, two-way traffic volume may be considered for applying the lateral distribution factors)

\( D \) = lateral distribution factor

\( F \) = Vehicle Damage Factor (VDF)

\( n \) = design period, in years

\( R \) = annual growth rate of commercial vehicles in decimal

The traffic in the year of completion (A) of construction may be estimated using the following equation:

\[ A = P \times (1 + R)^{x} \]

Where,

\( P \) = number of commercial vehicles per day as per last count.

\( x \) = number of years between the last count and the year of completion of construction.

Corresponding to the CBR value of subgrade and the total computed traffic (MSA), the total thickness should be worked out using Pavement Thickness charts in the IRC Pavement Design Catalogue in IRC 37:2012. Using the total thickness, individual thickness and composition of Wearing Course (WC), Binder Course (BC), Granular Base (GB) and Granular Sub Base (GSB) is then worked out.

5. Conclusions

The paper discusses the methodology to be used to study the impact of overloaded vehicles on pavement surface. It also focuses on pavement design that should be followed to cater the demands of the overloaded vehicles. The conclusions derived from the study are highlighted below:

- The study when incorporated in a project will provide an analysis of the proportion of overloaded commercial vehicles operating on the project site. This proportion can further be used for future designs as well as to analyse the defaulting vehicles which do not abide by the legal limit.
- The methodology discussed will provide a conclusive statistical output on the Axle Load Variables in terms of Vehicle Damage Factor and Equivalent Axle Load Factor.
- The procedure will give a comparative analysis of the Specified v/s Observed VDF. Further the analysis will provide an insight into the effect of increased VDF due to overloading on pavement surface.
- Based on the observed VDF analysis, the pavements can be studied for thickness design.

REFERENCES


