Effect Of Vehicle Axle Loads On Pavement Performance

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ABSTRACT

The ever increasing vehicle population and heavy axle loads has caused substantial damage to Indian roads. Trucks carry loads much in excess of legal limits and are largely responsible for poor road conditions in addition to the inadequate structural capacity of pavements and diminishing allocation of funds year after year for maintenance and rehabilitation. Very huge capital investments are now needed to upgrade and rehabilitate the existing road network to make it capable to withstand high stresses and tyre pressures caused by heavy wheel loads. In view of very remote possibility of such large magnitude of funds ever becoming available in the near future, one of the best course to remedy the situation would be to strictly enforce the legal axle limits. Pavement performance data base generated and pavement deterioration models developed from the Pavement Performance Study, recently completed in the country, has been used/applied for the present analyses. An attempt has been made in this paper to evaluate the effects of heavy axle loads on pavement performance in terms of increase in service life if overloading is restricted through strict enforcement. Further detailed analyses is planned to be done for obtaining reliable and accurate results.

INTRODUCTION

Transportation is a vital sector to the economy of a nation. India is a fast developing country and has got one of the largest rail and road transportation network in the world. The share of road transport to rail transport has increased to 80 % and 60 % in 1993 from 26% and 11% in 1951 for passenger and goods transport respectively. The road length has correspondingly increased from about 0.4 milliom km. to 2 million km. during the last four decades. Due to industrialisation and increased economy, the vehicle population has increased from 0.3 million in 1951 to about 21 million during the same period, thus registering a 70 fold increase. The growth of passenger and frieght traffic is also phenominal and it is about 10% per annum at present. The passenger traffic has risen to 1200 billion passenger km. (bp km) in 1991 from 31 bp km in 1951 and the freight traffic has gone to 295 billion tonne km (bt km) in 1991 from 5.5 bt km in 1951. It is expected that passenger and freight traffic would be about 3 times and 4 times respectively than the present traffic in the next 15 years, calling for heavy demand for additional vehicles and better roads etc. Not only the traffic volume has increased but also the tendency of most of the heavy vehicle drivers is to overload their vehicles in order to save operation cost. Most of the goods vehicles in India are two-axle rigid chassis and constitute about 98.5 % of the total fleet. Overloading of trucks is a common scene on Indian roads and it is not surprising to find heavy vehicles with high tyre pressures than normal values and carrying as high as 18 to 20 tonnes axle loads against the legally permissible axle load of 10.2 tonnes. The arterial road system comprising National Highways (NH) and State Highways (SH) is just about 2% and 6% of the total road length respectively but is responsible of carrying as high as two-third of the total road traffic. The funds allocated for road development purposes is about 30-40% short for NH system and is short by about 50-60% for SH system than the actual needs.

Several research studies have been completed and some are in progress for the purpose of understanding pavement behaviour (performance) under different conditions of traffic volume and loading, climate, subgrade, structural composition etc. One such study recently completed is the Pavement Performance Study. The data base and models available through this study has been made use of in conducting analyses presented herein, to evaluate the vehicle loading effects (overloading) on pavement performance.

The paper presented describes an overview of the present status and road developmental policies and practices in India; importance and implication of vehicle loads; studies conducted towards modernisation of vehicle fleet and development of efficient road infrastructure. The paper discusses in detail the analyses/procedures adopted to evaluate the effects of vehicle loads on pavement performance and the results obtained therefrom. Further work in this direction is also suggested towards achieving reliable results.

AN OVERVIEW OF PRESENT STATUS AND ROAD DEVELOPMENTAL POLICIES/PRACTICES IN INDIA

The unanticipated increase in vehicle population and heavy axle loads has brought the road network to a crumbling stage. The network is grossly short of its structural capacity, highly distressed and has started showing signs of premature failure. The road network is unable and incapable to sustain high stresses caused due to heavy wheel loads and increased tyre pressures. It has been indicated that the condition of NH system is not very satisfactory and encouraging and that 3 Km. out of every 5 km. of state highways are in bad shape needing immediate attention.

The assets built at huge capital costs are ageing due to continuous shortfall in investments on road maintenance in addition to excessive utilization of roads. It has been estimated that the country is loosing about Rs. 150,000 million ($ US 5,000 million) on account of excess vehicle operation cost due to poor road conditions. The public investment on road sector need to be stepped up by 2.7 times the present level of funds allocation for road maintenance and upgradation. Huge investments are needed for removal of deficiencies which have built up because of the reason that timely preventive maintenance treatments could not be undertaken due to paucity of funds. A broad estimate about the requirement of funds for the horizon year 2001 for building expressways and upgradation, improvement and rehabilitation of the NH system is about Rs. 600,000 million ($ US 20,000 million).

Pavement design in India is empirical and based on subgrade strength CBR (4 days soaking) and cumulative standard axles over a design life. The design stipulates the materials and specifications alongwith their thicknesses in different pavement layers. very recently, design guidelines have been brought out based on mechanistic (analytical) design methods. As regards maintenance of roads, norms and guidelines available are tentative and not based on the results of any scientific study. The decisions taken for implementation of various maintenance tasks are subjective in nature and depend largely on Engineer's judgement and personal experience. Rehabilitation / strengthening requirements are based on the Benkelman beam rebound deflection data. Pavement Management studies are now finding great applications in India towards efficient, effective and coordinated management of road network, within the funds constraints. The Government of India is now encouraging private enterpreneures to invest in road sector so as to provide good roads for comfortable, speedy and fuel-efficient road transport in the country.

VEHICLE LOADING - ITS IMPORTANCE AND IMPLICATION

As emphasied earlier in the paper, trucks in India carry loads in excess of their capacity. There are standards available in India of size, weights and dimensions of the truck body but these are, in general, not largely followed. The vehicle owners make changes and have wider and higher bodies so that a truck can carry more goods than permissible, thus producing a considerable reduction in haulage charges. It is not very strange that newly constructed flexible pavements, particularly those with unbound bases, frequently show signs of distress shortly after they are opened to traffic. The immediate effects of overloading are less obvious on pavements with bound bases but their service lives are significantly reduced than normally expected. Heavy traffic loading produce rapid differential compaction in the upper layers of pavement in addition to fracture of the asphalt surfacing. Implications of overloading on overall transport costs have been examined worldwide and it is evident that vehicle overloading seriously affects the improvements of road network in many developing countries including India largely because of increased demands for maintenance and rehabilitation due to pavement's damage caused by heavy axles.

The dimension of the overloading problem is such that specific precautions need to be adopted to minimise its affects. One way is to make sure that pavements are designed using a realistic assessment of the expected traffic loading because incorrect estimates of vehicle loading would seriously affect its behaviour. The other option is to strictly enforce the legal axle limits and thus obtain increased pavement's service life and performance.

It has been established that structural damage to road pavements is caused largely by commercial traffic and that the pavement damage increases very steeply with the axle loadings. The damage which a heavy commercial vehicle does is a function of the degree to which the various axles are loaded. The damaging effect of traffic is expressed as the number of standard axles per 100 commercial vehicles and is termed as Vehicle Damage Factor (VDF).

To design pavements, it is necessary to know the distribution of axle loads to which the pavement will be subjected during the design life. The distribution is generally referred to as the axle load spectrum. The axle load surveys have been conducted in India from time to time on various roads and the VDF_S, which is a multiplier for converting of axle-load repetition, have been determined. The indicative VDF values recommended by Indian Roads Congress (IRC), for different range of traffic volume (commercial vehicles per day) and the terrain, are given in Table-1. These are the VDF values used for design of pavements in India, if specific VDF is not available/assessed for a given road. The results of axle load surveys conducted in India in the recent past have brought out the following;

i) Damaging effects of heavy commercial vehicles have increased alarmingly particularly on more heavily trafficked corridors and highways.

ii) Overloading beyond the legal axle limits is very frequent and is of very large magnitude which, as a matter of fact, has led to the belief/conclusion that overloaded vehicles are responsible for pavement damage and thus poor road conditions.

Table. 1 Indicative VDF Values

Initial traffic intensity in terms of number of commercial vehicles/day	Terrain	VDF values (Standard axles of 8.16 tonnes per commercial vehicle)		
		Unsurfaced	Thin Bituminous Surfacing	Thick Bituminous Surfacing
Less then 150	Hilly	0.50	0.75	--
	Rolling	1.50	1.75	--
	Plain	2.00	2.25	--
150-1500	Hilly	--	1.00	1.25
	Rolling	--	2.00	2.25
	Plain	--	2.50	2.75
More then 1500	Hilly	--	1.25	1.50
	Rolling	--	2.25	2.50
	Plain	--	2.75	3.00

The legal limit for axle loads in India has increased from 8.16 tonnes to 10.2 tonnes in the last decade or so. The Motor Vehicle Act stipulates maximum axle and vehicle weights as under:

Single axle with two tyres	6.0 tonnes
Single axle with four tyres	10.2 tonnes
Tandem axle with eight tyres	19.0 tonnes

Very little attempt is generally made to enforce the law in this respect. The increase in axle limits has been effected but the economic justification for changes in these limits has not been examined very closely and accurately in India because of non-availability of data which would enable evaluation of vehicle operating costs and the estimation of additional pavement damage caused by the heavier axle loads. In developed countries, several major studies have been conducted which have identified factors influencing the cost of operating vehicles and it is now possible to conduct incremental analyses to show the economic effects of increases in axle loads. It has also been concluded through these studies that increases in legal axle load limits are justified under a wide variety of conditions.

The cost of operating a road transport system consists of two main components, namely the operating cost of vehicles fleet using the facility and the cost of constructing and maintaining the roads. It is now a well known fact that the transport cost of a particular freight tonnage decreases quite rapidly with increase in amount of freight carried by vehicles and also that the cost of providing and maintaining the roads increases as the vehicle axle load increases. The magnitude of these component costs varies with extent of axle loads carried by vehicles. India spends a large proportion of her scare resources on road transportation and it is therefore desirable that the road transport system should operate under conditions which minimises the total cost.

The most widely used relationship between vehicle loading and pavement performance was derived from the AASHO Road Test in early sixties. An axle load carrying a load of 8.16 ton was defined as a standard axle, with a damaging effect of unity. The damaging effects of lighter and heavier axles were expressed as equivalency factors. The structural damage to a pavement caused by wheel loads is given by an empirical equation of the following form:

Pavement damage (Axle load)^n

The results have revealed that value of exponent, **n**, can vary from 2.4 to 6.6 under extreme conditions. It was concluded that for heavy wheel loads on roads of medium or high strength, as measured by structural number, the value of **n** is in the range of 3.2 to 5.6. The conclusion emerged from the AASHO Road Test was that the relative damage to both flexible and rigid pavements varied approximately as the fourth power of the applied wheel loads. It is this relationship that provides the basis for assessing the effects of vehicle loading in most current methods of pavement design globally. The relationship enables converting the estimated spectrum of axle loadings into an equivalent number of repetitions of a standard axle load of 8.16 tonnes. The factors for this conversion to Equivalent Standard Axles ($ESAL_s$) were derived based on this relationship. In India, the value of exponent **n** is taken as 4 and the traffic is defined by the Equivalent Standard Axles ($ESAL_s$) which is calculated by multiplying the number of commercial vehicles and Vehicle Damage Factor (VDF) derived from axle load spectrum using standard "Fourth Power Law".

STUDIES CONDUCTED IN INDIA TOWARDS DEVELOPMENT, IMPROVEMENT AND MODERNISATION OF ROAD INFRASTRUCTURE AND VEHICLE FLEET

PAVEMENT PERFORMANCE STUDY

This is a long term research study of national importance, sponsored by the Ministry of Surface Transport , Govt. of India, and was commenced in the year 1986. The study is a sequal to the already completed **Road User Cost Study in India**, which had, earlier in 1982, successfully brought out road user cost models for different roadway and traffic situations. The Pavement Performance Study is planned to evolve road cost models, comprising initial construction cost and subsequent maintenance cost during the design / service life, and which in conjunction with road user costs, would develop information/data for total transportation cost models under Indian conditions. The study objectives are proposed to be achieved through the following:

i) Development of pavement performance data for pavement materials normally used in the country

ii) Based on the performance data, to attempt development of layer equivalencies, as feasible

iii) Limited studies on the effect of maintenance level on pavement performance

iv) Generation of data on the construction and maintenance inputs of different pavements

The study consists of two parts:

a) Study on Existing Pavement Sections

b) Study on New Pavement Sections

Study On Existing Pavement Sections

This part of study has recently been completed on in-service road sections. A total of 113 road sections on arterial road network, each 500 meter length, in the states of Haryana, Uttar Pradesh, Rajasthan and Gujarat were monitered for their performance, at every half year interval, over a period of 3 to 5 years. The various observations/ measurements taken on these test sections included the following:

i) Pavement structural details (materials/specifications and their thicknesses in different layers)

ii) Surface defects (cracking , patching, potholes, ravelling, shoving, depression etc.)

iii) Roughness by Fifth wheel bump integrator

iv) Rebound deflection by Benkelman beam

v) Subgrade moisture content

vi) Traffic volume surveys (on representative sites)

vii) Axle load surveys (on representative sites, annually)

viii) Lateral placement of vehicles (during sixth and tenth series of observations)

ix) Transverse profile

Modified Structural Number (MSN) is an indicator of pavement's structural strength and has been used for this study. It is calculated using the following equation developed during Kenya study

$$MSN = SN + SN_{SG}$$

where

SN = Structural Number

$$= a_i \quad t_i$$

a_1, a_2, a_3, ... a_n are the strength coefficients of different materials in various pavement courses and

t_1, t_2, t_3,........t_n are the thicknesses of various pavement layers in inches.

SN_{SG}=Structural support due to subgrade

$$=3.51(\log_{10} CBR)-0.85(\log_{10} CBR)^2 -1.43$$

where

CBR =California Bearing Ratio at Field moisture content and Field dry density

The voluminous time-series pavement performance and traffic - related data was analysed and incremental models developed for prediction of various modes of distress for pavements with surfacings of Premix Carpet (PC), Semi-Dense Bituminous Concrete (SDBC) and Bituminous Concrete (BC) . The various models developed (available) are :

a) Initiation of Cracking
b) Progression of Cracking
c) Initiation of Ravelling (for premix carpet surface only)
d) Progression of Ravelling (for premix carpet surface only)
e) Initiation of Potholes
f) Progression of Potholes
g) Progression of Roughness

These models are capable of predicting the state of health (various defects) of the pavements, over a passage of time and traffic applications, which would assist and enable highway planners, professionals and policy makers in deciding upon optimal and rational maintenance and rehabilitation strategies for road network. These models may also be used for the following :

i) To evaluate the effect of structural strength on pavement performance(pavement deterioration)

ii) To evaluate the effect of traffic loading on pavement performance

iii) To evaluate the existing pavement design

iv) To support the analytical pavement design methods

v) Pavement maintenance management system development

For the work reported in this paper, the pavement deterioration models discussed above have been applied to evaluate the effects of increased axle loads (overloading) on pavement performance.

Study On New Pavement Sections

This part of study has recently been launched and is in progress. The study is to be conducted on specially designed and constructed experimental road sections, for detailed and comprehensive coverage of various parameters, in order to obtain reliable and refined pavement deterioration models for a variety of applications.

VEHICLE FLEET MODERNISATION AND ROAD USE CHARGES STUDY

This study undertaken with the World Bank assistance has been completed and was taken up to determine the optimal future composition of the motor vehicle fleet and appropriate levels of road use charges. The study estimated future demand for road transport and the analyses of the changing scenario of the freight market. It involved assesment of the appropriateness of the present state of the road infrastructure and transport industry. The study established the need for modernising India's truck fleet and road infrastructure, along with identification of areas and level of modernisation required and the policy framework desired to achieve them.

The following major rcommendations concerning to the part of vehicle fleet modernisation study emerged from the results of this study are:

i) In order to meet the future transport demand and to reduce the total transportation cost, it is necessary to improve the existing road network and modernise the vehicle fleet.

ii) Old and obsolete vehicles should be phased out and economically more efficient multi-axle vehicles should be introduced.

iii) There is an urgent need to undertake various measures such as promotion of technological progress in vehicle design to improve safety, fuel efficiency and to reduce road damage.

iv) Two- axle rigid vehicles are not paying their fair share in proportion to the road cost inflicted by them by way of road use and road damage.

EVALUATION OF EFFECT OF VEHICLE AXLE LOADS ON PAVEMENT PERFORMANCE

The pavement performance data base generated under the **Pavement Performance Study-Study on Existing Pavement Sections (PPS-EPS)**, was utilised for evaluating the effects of increased axle loads (overloading) on pavement performance. The road sections (sites) selected for the present analyses were selected in a manner that they represent the most prevailing practices of constructing and maintaining the National highways and would largely cover the varying operating conditions of traffic volume and loading, pavement's structural strength, different materials and specifications in constituent layers and surface types etc. The test sections included in the analyses can be regarded as window representation of National highway system of the country. The analyses is carried out in the following two steps.

DETERMINATION OF DAMAGE DUE TO OVERLOADING

As stated earlier, the majority of commercial vehicles (trucks) in India are two-axle rigid body. From the large axle load data available for these vehicles, it is observed that

i) The Gross Vehicle Weight (GVW) is normally about 16 tonnes

ii) The unladen weight (empty weight) of such trucks is normally about 5.5 tonnes

Based on the earlier results available from different studies and as per the general loading norms on the two axles of a truck in the ratio of 1:2 (front axle versus rear axle), it is assumed that front axle weight should be limited to 5.5 tonnes and the rear axle weight to 10.5 tonnes which would lead to the presumption that a vehicle having GVW in excess of 16 tonnes (5.5 tonnes front axle and 10.5 tonnes rear axle) is a vehicle carrying loads beyond legal axle limits and is referred to as overloaded vehicle for the purpose of present analyses. The axle load data for different sites is analysed to obtain VDF at the actual loads and the same is denoted by VDF_A. The same data is reanalysed to obtain the restricted VDF by limiting the individual axle loads to the ones discussed above. The VDF so derived is expressed as VDF_R. $ESAL_S$ based on VDF_A is represented by $ESAL_A$ and are the ones for actual traffic repetitions. $ESAL_S$ based on VDF_R represent the load repetitions if strict enforcement of axle limits is employed and no overloading is allowed on pavements. The results obtained from the analyses carried out indicate that there is a substantial reduction in vehicle damage factor when the load in excess of legal axle limits is removed.

EVALUATION OF DAMAGING (OVERLOADING) EFFECTS ON PAVEMENT PERFORMANCE

Having established the reduction in vehicle damaging effects due to exclusion of excess loads carried by the vehicles in comparision to legal axle load limits, the subsequent analyses was conducted to quantify/evaluate the effect of vehicle overloading on pavement performance. Various deterioration relationships developed for pavements with surfacing of PC, SDBC and BC towards prediction of initiation and progression of various distress modes were applied to the different road sections included in the present analyses. In view of any threshold / intervention levels not being available for Indian conditions, it is considered that resurfacing should be needed in the following two cases.

a) The cracking level of a pavement has reached 25 % of the total surface area and / or

b) The roughness level has reached 5000, 4500 and 4000 mm/km when surface type is PC, SDBC and BC respectively

The above levels have been fixed based on past experience and existing maintenance standards for providing resurfacing / renewal coat etc. These levels are regarded as critical / terminal level and it is at this time that the resurfacing is assumed to be applied on a pavement if otherwise the road is structurally adequate. Extensive measurements of roughness conducted in India on newly constructed/ rehabilitated pavements have indicated that initial roughness for pavements with surfacing of PC, SDBC and BC are normally of the order of 2500, 2000 and 1500 mm/Km respectively when the construction quality is good. These values of initial roughness have been used for the present analyses. With these assumptions and considerations in mind, the time to reach the above defined critical levels (based on cracking and roughness separately) is determined through application of various pavement deterioration models, for the two situations viz. i) when the actual loads are plying and ii) when the overloading has been excluded and the vehicles are carrying legal axle loads. The time so obtained is the service life for that particular surfacing because another resurfacing would be needed after the pavement has reached pre-defined intervention levels as above. Such treatments are applied primarily for the purpose of providing better rideability and retarding further deterioration of pavement structure. Based on the comparision of service lives obtained for actual loads and restricted loads, the percent increase in service life is calculated for the two criterias separately viz. cracking and roughness levels. The results obtained from the analyses discussed above are presented in Table-2. It is seen that there is an increase of about 30 - 40 % in service life for surfacings of PC and BC and upto about 20 % for SDBC when cracking level is considered as the critical criteria. The increase in service life is about 10 - 20 % for PC, upto about 20% for BC and upto about 10 % for SDBC when roughness level is regarded as critical criteria. The low

Table. 2 Increase in service life due to removal of excess axle loads (overloading) on different pavements subjected to varying degree of traffic volume and loadings

Site No.	Surface Type	Modified Structural Number (MSN)	Commercial vehicles per day (CVPD)	VDF at actual loads (VDF_A)	VDF at restricted loads (VDF_R)	ESALs ($x 10^6$) per year at actual loads ($ESAL_A$)	ESALs ($x 10^6$) per year at restricted loads ($ESAL_R$)	Percent increase in service life due to removal of excess axle loads	
								Cracking level	Roughness level
1	PC	3.72	920	6.18	2.75	2.08	0.92	40	10
2	PC	3.06	587	5.61	3.00	1.20	0.64	30	9
3	PC	3.81	4449	4.49	3.00	7.29	4.87	33	10
4	PC	4.35	889	5.53	2.75	1.79	0.89	31	6
5	PC	3.67	2484	5.53	3.00	5.01	2.72	38	20
6	BC	4.08	3623	6.01	3.00	7.94	3.97	40	21
7	BC	4.20	4886	6.18	3.00	11.02	5.35	44	21
8	BC	4.14	6101	4.92	3.00	10.95	6.68	29	20
9	BC	5.02	5832	6.29	3.00	13.38	6.39	42	16
10	SDBC	4.48	1552	4.17	2.75	2.36	1.56	13	6
11	SDBC	5.01	2316	5.13	3.00	4.23	2.54	18	10

increase in service life at roughness level as compared to high increase in service life at cracking level can be said to be probably due to differences in pavement's surface texture, other(associated) surface defects influencing roughness, variability in construction quality and seasonal/ climatic changes etc.The increase in service life for different pavements would depend on the traffic repetitions ($ESAL_S$ / year), structural strength of the pavement (MSN), materials/ specifications in pavement structure, construction and maintenance standards and environmental conditions etc. In the ultimate analyses, it can rightly be concluded that there would be considerable improvement in service life when strict compliance of legal axle limits are enforced.

CONCLUDING REMARKS

Based on the analyses conducted and the results obtained, it can be concluded that there is a significant improvement in service life when strict enforcement of legal axle limits is done. The various benefits arising from strict enforcement of legal limits are as given below:

i) Reduction in maintenance and rehabilitation cost of roads

ii) More funds would be available for upkeep of pavements

iii) The road pavements can be maintained at desired/ minimum serviciability levels

Based on the limited work done and results available, it will be too early and premature to quantify and estimate the saving in maintenance cost on account of load restrictions. It is, however, expected and believed that the savings in maintenance cost on rough basis should at least be of the order of 20-25% of what is presently spent if legal axle limits are enforced and no vehicle is allowed to carry loads beyond the permissible one. Savings of such magnitude would certainly help road organisations in providing better roads to its users.

The work presented here in this paper is preliminary and is based on a small sampling of traffic volume and loading characteristics on few road pavements. It is, therefore, recommended that large sampling of data would need to be included before arriving at definite, realistic, reliable and accurate results. The work reported is planned to be continued/ extended by involving varying operating situations of pavements and traffic loading, different category of roads and other influencing parameters affecting pavement performance.

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