Effect of Overweight Trucks on Fatigue Damage of a Bridge

Vasvi Aggarwal and Lakshmy Parameswaran

Abstract Overweight trucks affect the fatigue life of a highway bridge. The stress range increases substantially if trucks are overloaded. Despite of existing regulation of permissible limits of Gross Vehicle Weight (GVW), overloading of trucks is widespread in India. Fatigue is a great concern to bridge engineers especially with the use of high strength steel and concrete for the construction of bridges. In this paper, the effect of overloading on fatigue damage of a highway bridge is studied. The aim of this study is to observe the relationship between prevalent truck overloading and fatigue damage accumulation. The fatigue damage accumulation is calculated for the steel longitudinal girder of a four span continuous steel-concrete composite girder bridge of length 119 m subjected to cyclic loading due to actually weighed overloaded trucks and trucks loaded with permissible GVW as specified in IRC guidelines. From the fatigue damage analysis it is found that the increase in truck weight of 50 % would lead to an increase in fatigue damage accumulation of 80 % in the steel longitudinal girder of road bridges. The relationship between fatigue damage accumulation and overload factor is non-linear. The findings of the study will be useful for fatigue design of bridges especially which are on port connectivity or near to mines and heavy industrial area, where overloading of trucks is prevalent.

Keywords Overloading · Fatigue damage accumulation · Permissible load limits

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1 Introduction

Road bridges in India are generally designed for load effects due to live loads specified in IRC 6, such as Class AA, Class 70R, Class A or combination of these loads depending on the carriage way width of the bridge. However, the liberalization and globalization of Indian economy has brought unprecedented industrial, trade and commercial developments in our country during the last one decade which in turn has led to many fold increase in road traffic in terms of volume and axle load. The Motor Vehicles Act and Regulations 1988, specifies the revised limit of axle loads, Gross Vehicle Weight (GVW) and new limits on the dimensions of the actual vehicles. However, with the increasing cost of petrol and diesel, the truck operators have a tendency to carry excess weight above the legal limits, and this has been verified by the number of axle load surveys conducted on national highway (NH), state highway (SH) and major district roads (MDR) by Council for scientific and industrial research–Central road research institute (CSIR–CRRI) during the last four decades.

There has been a persistent upward trend all over the world, in permissible vehicle and axle weights, which is the combined result of improvements in vehicle and tyre technology and of the urge of transporters to achieve higher payloads in order to reduce the unit cost of transportation.

The two popular methods to collect the Gross Vehicle Weight (GVW) of trucks plying on the road are Stationary Weigh Scales (SWS) and Weigh-in-Motion (WIM) system. Conventional SWS measurements have several draw backs, such as driver's awareness and traffic congestion during peak hours. On the other hand, the use of WIM system can result in more accurate truck loading, because it can overcome the inherent shortcomings with the use of SWS.

Weigh-in-motion studies conducted in USA indicated a considerable variation in truckload effects on bridges [1]. The occurrence of illegally overloaded vehicles makes these uncertainties especially worrisome. Therefore, in order to refine the uncertainties regarding loads and resistance, there is a need to gather information about the actual traffic effects [2]. By monitoring heavy trucks, the uncertainties regarding loads plying over the roads and bridges can be quantified. Traffic and axle load surveys can provide information regarding traffic volume, truckloads, load on multi-lanes and extreme loads which can be effectively used to control the truckload effects and can provide a basis for a much more efficient operation of highway facilities.

Bridges are critical elements in a road network for the safe and efficient movement of people and freight. Over loaded truck traffic affects the service life of the bridge superstructure. Damages typically occur in the main superstructure elements like bridge deck, girders, diaphragms, joints and bearings. With the rapid growth of highway transportation, the increasing frequency of the over loaded trucks even leads to fatigue damage. Therefore, as with increase in truck loads the damage on highway infrastructure increases and additional funds are required for maintenance and repair, rehabilitation of these bridges.

In this paper an attempt has been made to understand the trend in safe legal limits of axle loads and maximum GVW legally permitted on roads in India and other countries. Subsequently, the axle load data collected using WIM on NH-7 near Bangalore has been analyzed to understand the prevalent over loading in truck traffic. Also, fatigue damage estimation of a longitudinal girder of a four span continuous steel concrete bridge is presented for this observed actual truck traffic plying during a day.

2 Background

The GVW for commercial vehicles are specified by the vehicle manufactures keeping in view vehicle dynamics of operation and design. As a result certain limits for axle loads are stipulated by the government/competent authorities and are referred as 'Safe Axle Load Limits'. However, it is found through axle load surveys that the actual loads carried by trucks seldom follow these specified limits, and always tend to be on higher side. This practice of carrying loads in excess of legally defined loads by a vehicle is known as 'Overloading'.

Every country has specified legal axle load limits and maximum permissible gross load and Fig. 1 shows these specified in some of the countries.

It can be seen from Fig. 1 that the maximum permissible gross load is specified in South Africa, i.e., 56 tons while the maximum permissible gross load for India is 80 % of this load. The minimum permissible gross load is specified in USA, i.e., 36 tons. The maximum load specified for single axle in India, i.e. 10.2 tons is 97 % of the maximum value of single axle load specified for UK which is 10.5 tons

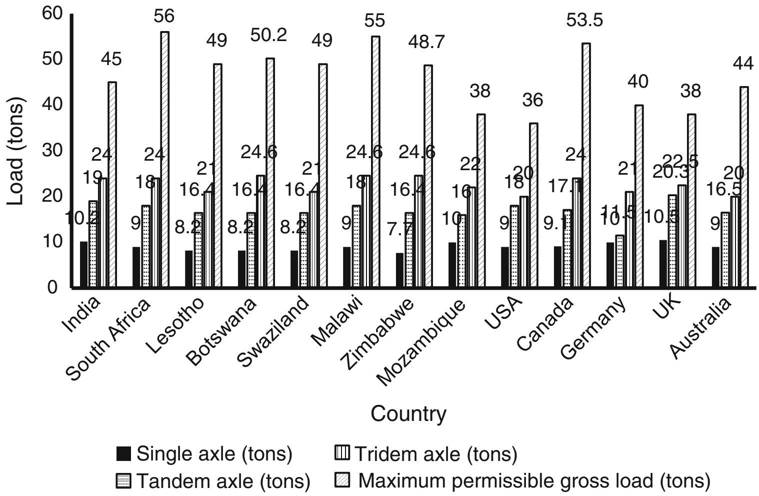
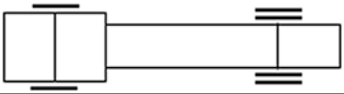
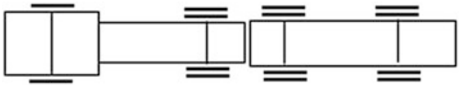
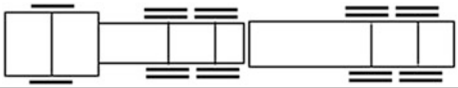


Fig. 1 Legal axle load limits in India and other countries

Table 1 Maximum permissible load for different types of trucks in India

Vehicle axle configuration	Vehicle type	Legal load limits (tons)
	Trucks—2 axle	16.2
	Truck—3 axle-semi trailer	25
	Truck—4 axle-trailer	35.2
	Truck—5 axle (both rear tandem)	45

However, the maximum load specified for tandem axle in India is 93 % of the maximum tandem axle load specified in UK. The maximum tandem axle load specified in India is 98 % of the maximum value specified in three countries, viz, Botswana, Malawi and Zimbabwe which is 24.6 tons.

In India IRC: SP: 37 [3] gives guidelines for evaluation of load carrying capacity of existing bridges based on working stress approach as the design of bridges are performed using allowable stress method. The maximum permissible load limits for different types of trucks or Heavy Commercial Vehicles (HCV) specified in IRC: SP: 37 [3] are given in Table 1.

3 Analysis of Truck Load Data Collected on National Highway (NH) 7

The main purpose of this study is to understand and study the extent of overloading and its effect on road bridges which further requires analysis truck axle load data. For the study purpose, the WIM (piezoelectric sensor type) system was installed on NH 7 at many locations by the CSIR. The WIM equipment in the test section consists of two sets of piezoelectric sensors (S1, S2) and (S3, S4) and two inductance loop detectors L1 and L2 in both the lanes. The installation of WIM system is shown in Fig. 2.

The loop detector installed on each lane at 4 m apart recognizes the presence of a heavy vehicle and then both the piezoelectric sensors weigh each wheel and the average is reported by the WIM system, which also counts the number of axles per vehicle.

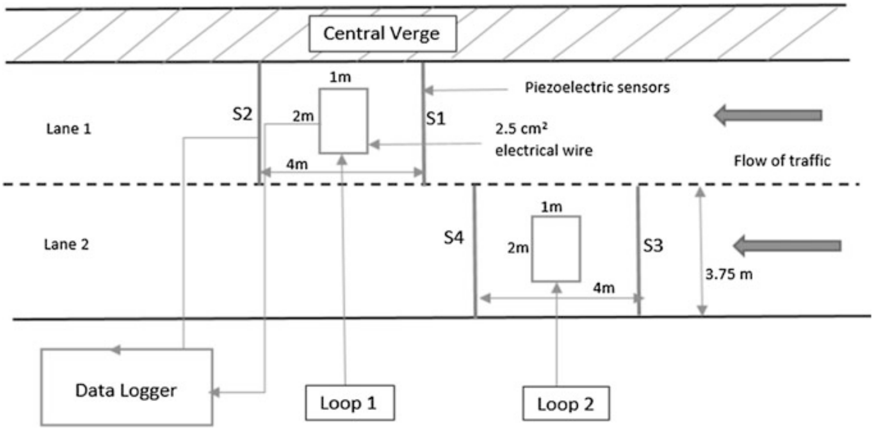


Fig. 2 Installation of WIM system

The truck load data considered for the study was collected on NH 7 during April 2013 near Bangalore and it consisted of 149 trucks collected during the period of 24 h. The average percentage of truck in overall traffic was 20 %. The truck load data collected using WIM was analyzed to estimate percentage distribution of truck by number of axles as shown in Fig. 3.

From Fig. 3 it can be seen that the 33 and 49 % of HCV consists of two and three axle trucks respectively. Also, it is to be noted that the trucks with more than three axles are less prevalent at the location of survey on this NH.

To study the extent of overloading, the percentage of number of trucks overloaded was studied and presented in Table 2 and it can also be seen that on an average 74 % trucks were overloaded.

Along with the high frequency of heavy trucks, over loading of trucks beyond permissible gross vehicle weight affects the bridge performance significantly. Therefore the overload factor was estimated and presented in Table 3.

Fig. 3 Truck percentage distributions by number of axles

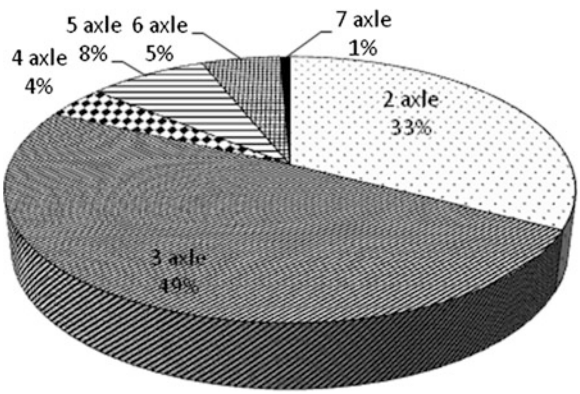


Table 2 Percent overloading in trucks studied on NH 7

Number of axle	Total number of trucks weighed	Number of overloaded trucks out of total trucks	Percentage of overloaded trucks (%)
2	49	33	67
3	74	59	80
4	6	6	100
5	12	6	50
6	8	6	75
		Average percentage of overloaded trucks	74

Table 3 Overload factor in trucks studied on NH 7

Number of axle	Safe GVW specified in IRC: SP: 37 [3]	Maximum GVW of trucks plying on NH 7	Overload factor
2	16.2	21.33	1.32
3	25	34.68	1.39
4	35.2	44.50	1.26
5	45.4	50.94	1.12
6	50.4	73.95	1.47
		Average overload factor	1.3

Thus the overload factor for trucks above safe GVW specified in IRC: SP: 37 [3] varies from 1.12 to 1.47. The average overload factor of GVW was found to be 1.3 times above the stipulated vehicle weight limit. Thus it is evident that overloading is prevalent in India and its effect on bridge needs to be studied.

4 Estimation of Fatigue Damage Accumulation

To study the effect of overloading on fatigue damage accumulation, a four span continuous steel-concrete bridge superstructure (21.25 m + 26 m + 42.25 m + 29.5 m) as shown in Figs. 4 and 5 was analyzed.

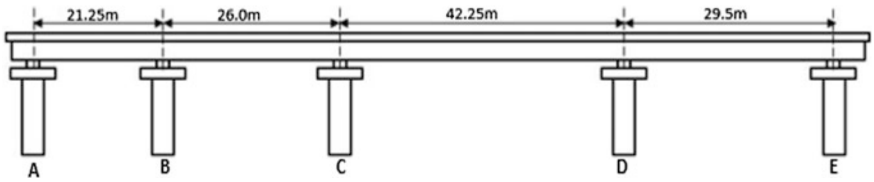


Fig. 4 Span arrangement of four span steel-concrete composite bridge

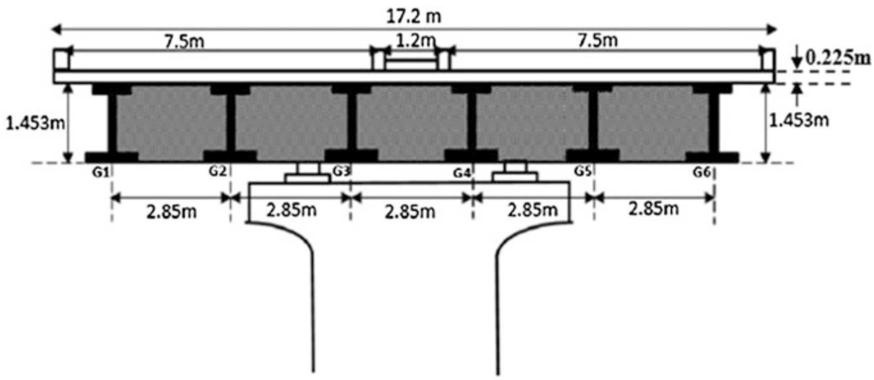


Fig. 5 Typical cross section of superstructure

The superstructure is supported on two POT/PTFE bearings spaced at 4 m apart. The grade of concrete used for deck slab is M40. The Fe 500 grade of reinforcement steel is used for the design of deck slab. The grades of structural steel used for steel plate girders and cross bracing are E350 and E250 respectively.

The road bridge considered was a two lane divided highway and the fatigue damage is calculated for the steel girder G2 (Fig. 5) at the centre of the bottom flange of third span CD (Fig. 4).

There are different approaches to analyze the fatigue damage of a bridge such as stress range concept, linear elastic fracture mechanics approach, continuum damage approach and advanced reliability approach. However, the stress range concept is widely used because of its simplicity and ease of application.

In this study, the methodology adopted to carry out fatigue damage analysis for road bridges is as follows: (1) Mathematical modeling of bridge superstructure, details shown in Figs. 4 and 5 is carried out. (2) Truck with permissible load limits and actual trucks plying on roads was applied as moving loads and stress history is generated. (3) Rainflow cycle counting method was used to decompose the stress history. (4) Stress histogram is prepared from decomposed stress history. (5) The fatigue damage accumulation was calculated using Miner's rule [4] which is given by Eq. 1.

$$D = \sum_i \frac{n_i}{N_i} \tag{1}$$

where, n_i = number of cycles applied at stress range S_i, N_i = total number of cycles to design limit/failure at stress range S_i. When D is greater than unity fatigue limit has been exceeded.

The fatigue damage is calculated due to the actually weighed 149 trucks including two axle, three axle, four axle, five axle and six axle trucks sampled using WIM and for the trucks with safe GVW as specified in IRC: SP: 37 [3] as shown in Table 1.

Table 4 Effect of overloading above permissible GVW of trucks on fatigue damage

Overload factor	Fatigue damage accumulation due to overloaded truck	Percent increase in fatigue damage accumulation (%)
1.05	7.0×10^{-7}	41
1.1	8.1×10^{-7}	49
1.15	9.2×10^{-7}	55
1.2	1.0×10^{-6}	60
1.25	1.2×10^{-6}	65
1.3	1.3×10^{-6}	69
1.35	1.48×10^{-6}	72
1.4	1.7×10^{-6}	75
1.45	1.83×10^{-6}	78
1.5	2.03×10^{-6}	80

The fatigue damage accumulation during a day produced by actually plying truck traffic with a composition as shown in Table 2 is 8.6×10^{-7}. The fatigue damage accumulation by replacing weight of all the overloaded trucks with safe load limits as specified in Table 3 is 4.1×10^{-7}. Thus it is seen that the overloading has increased the fatigue damage accumulation by 53 %.

A parametric study was also carried out to see the effect of overloading on fatigue damage accumulation produced by trucks beyond permissible load limit, by varying the overload factor from 1.05 to 1.5. The fatigue damage accumulation for overloaded truck is calculated by multiplying GVW with overload factors assumed for study and then generating corresponding stresses and calculating fatigue damage accumulation. Further, after multiplying each truck with overload factor the increase in fatigue damage was observed and is presented in Table 4.

From Table 4, it is seen that an increase in truck weight of 50 % would lead to an increase in fatigue damage accumulation of 80 % in the steel longitudinal girder of the road bridge included in the study.

By using the data presented in Table 4, relationship is developed between overload factor and percent increase in fatigue damage and is presented in Fig. 6.

Thus it is clear from this study that overloading of HCV exponentially increases the fatigue damage of the bridges.

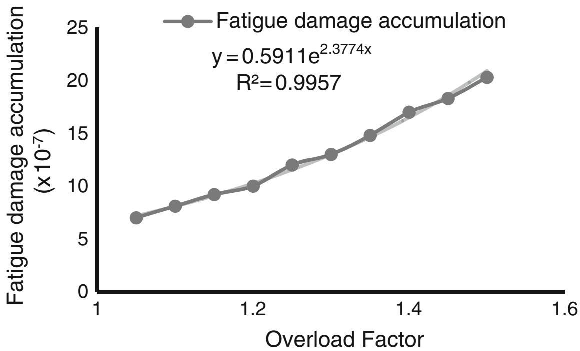


Fig. 6 Relationship between overload factor and percent increase in fatigue damage

5 Conclusions

This study has highlighted the effect of overweight vehicles on the load effects produced on road bridges. Based on the study, the following conclusions are drawn.

1. Significant violation of permissible limit of gross vehicle weight of trucks involving overweight commercial vehicles is observed, 80 % of the observed three axle trucks were overloaded. The three axle trucks are more prevalent on NH 7.
2. The frequency and degree of overloading of HCV is very significant. The overload factors for two axle trucks, three axle trucks, four axle trucks, five axle trucks and six axle trucks is estimated as 1.32, 1.39, 1.26, 1.12 and 1.47, respectively.
3. The overloading enhances the fatigue damage produced by actually weighed trucks plying on NH 7 by 53 % in comparison to that by the trucks carrying permissible GVW.
4. An increase in truck weight of 50 % for all trucks in the observed traffic composition lead to an increase in fatigue damage accumulation of 80 % at the mid span of steel longitudinal girder of the bridge.
5. The relationship between overload factor and fatigue damage accumulation is exponential.
6. Monitoring of HCV using WIM system would be a right step towards enforcement of legal axle load limits on a road network.

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