Dynamic Effect Of Truck Loads On Girder Bridges

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ABSTRACT

The effect of truck loads on bridges is important in the effort of upgrading the transportation infrastructure. The determination of the Dynamic Load Factor (DLF), defined as the ratio of dynamic and static responses, is essential for the development of a new generation of reliability-based bridge design codes. Field measurements are performed to determine the actual variation of the DLF with various truck as well as bridge parameters. The objective of this paper is to present the effects of various parameters, such as truck gross weight, truck speed, truck type, girder static stress, and girder position, on the DLF.

The field tests are carried out on four steel girder bridges. Measurements are taken using a weigh-in-motion (WIM) system with strain transducers. For each truck passage, the truck weight, speed, axle configuration, and lane occupancy are determined and recorded. A numerical procedure is developed to filter and process collected data. The DLF is determined under normal truck traffic of various load ranges and axle configurations.

In absolute terms, the response due to dynamic load is practically constant and it does not depend on truck weight. However, for exterior girders the static stress is very small which results in large DLF. Therefore, the DLF should be considered based on girders of maximum stress values.

INTRODUCTION

The major load components include dead load, live load and dynamic load. This paper deals with truck induced dynamic loads in girder bridges. The dynamic load is time-variant, random in nature and it depends on the vehicle type, vehicle weight, axle configuration, bridge span length, road roughness and transverse position of truck on the bridge. An example of the actual bridge response due to an actual vehicle, a 5 axle truck traveling at a highway speed is shown in Fig. 1. For comparison, also shown is an equivalent static response, which represents the same vehicle traveling at crawling speed.

The dynamic load is usually considered as an equivalent static live load and it is expressed in terms of a dynamic load factor (DLF). There are different definitions for DLF as summarized by Bakht [1] in their state-of-the-art report on dynamic testing of bridges. In this study, DLF is taken as the ratio of dynamic and static responses [2],

$$DLF = \frac{D_{dyn}}{D_{stat}} \quad (1)$$

where: D_{dyn} = the absolute maximum dynamic response at any point (e.g. stress, strain or deflection) measured from the test data and D_{stat} = the maximum static response obtained from the filtered dynamic response.
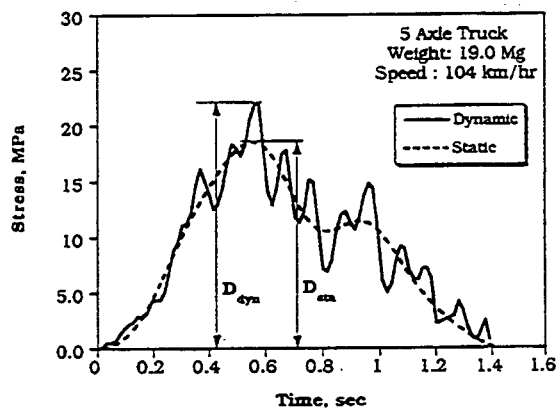

Fig. 1. Dynamic and Static Response for Girder 3, Bridge 1, Under a Five Axle Truck

The measurement of static load spectra is described by Nowak et. al [3]. An accurate dynamic load model is required for the development of rational criteria for the design and evaluation of bridges. Yet, the available data is insufficient and unclear. Analytical simulation procedures provided a basis for calculation of design provisions [4]. However, there is a need for field verification of the results. Therefore, the objective of this study is to determine the bridge response due to truck loads interms of dynamic load factor based on the field measurement data. The work is carried out on selected steel girder bridges. The obtained

results are compared with DLF's calculated on the basis of the analytically simulated model [4].

CODE PROVISIONS

The majority of bridge codes specify the dynamic load as an additional static live load. The actual values vary from one document to another. In the current AASHTO (1992), DLF or (1+I), is specified as function of span length only,

$$I = \frac{50}{125 + L} \qquad (2)$$

where L = span length in feet (1 ft = 0.305 m). However, the maximum value of DLF is 0.30. This empirical equation has been in effect since 1944.

In the new LRFD AASHTO Code [5], live load is specified as a combination of HS20 truck (AASHTO 1992) [6] and uniformly distributed load of 640 lb/ft (9.3 kN/m). DLF is equal to 0.33 of the truck effect, with no dynamic load applied to the uniform loading.

PREVIOUS STUDIES

The available data on dynamic load in bridges is rather limited [7]. Some measurements were taken by the Ontario Ministry of Transportation [2]. A total of 27 bridges were tested. The structural types included prestressed concrete (girders and slabs), steel girders (rolled sections, plate girders and box girders), steel trusses and rigid frames. Data were recorded for test vehicles and actual traffic. The mean values are about 0.05 to 0.10 for prestressed concrete AASHTO type girders and 0.08-0.20 for steel girders. The maximum observed values exceed 0.5 and some of the coefficients of variation are over 1.0. However, the correlation between DLF and truck weight is not available. On the other hand, it is expected that the largest DLF's correspond to lighter trucks. Considerable differences in DLF are observed for otherwise very similar structures which indicates the importance of factors such as surface condition.

Cantieni [8] tested 226 bridges in Switzerland, mostly prestressed concrete. With the exception of 11 bridges, all were loaded with the same vehicle, under the same load, and with the same tire pressure, thus minimizing the variability due to truck dynamics. The effect of local unevenness in the

pavement on the dynamic load was also investigated. The study showed that the dynamic fraction of the load was as high as 0.7 for bridges with fundamental natural frequency between 2 and 4 Hz. However, as in the Ontario data [2], the static and dynamic loads were recorded separately, so that it is not possible now to determine the degree of correlation. It is also expected that the high values of DLF are associated with lighter vehicles.

O'Connor and Pritchard [9] found that the dynamic load is vehicle dependent and it varies with the suspension geometry. They carried their tests on a short span composite steel and concrete bridge in Australia. The results indicate that as the weight of the vehicle increases, the dynamic load decreases. Also, O'Connor and Chan [10] collected strain data and, as in the previous studies, the extreme values are associated with light trucks.

FIELD MEASUREMENTS

The purpose of the testing program is to measure the amplification in dynamic response in simple span steel girder bridges due to truck loads. Corresponding truck weights, in particular axle loads and axle spacings, are also recorded. The measurements are taken simultaneously by a WIM System (truck information and girder strains) [11]. The WIM System was developed by the Bridge Weigh Systems. Its purpose is to measure and record all relevant truck information in addition to the strain response in each girder. The strain gages are placed on lower flanges close to the position of the maximum moment. The system is triggered by special tape switches, pasted to the pavement. The same tape switches are used to determine the truck speed, number of axles and axle spacings.

Four bridges are selected for the field tests. All of them are located in South-Eastern Michigan. The span lengths vary from 9 to 24 m (30-80 ft). The same procedure is used for all bridges, however, with a different equipment setup. All selected structures are multi-simple-span bridges with steel girders and concrete slabs. The basic design parameters include span length, girder spacing, slab thickness, and skewness. The basic parameters of the selected bridges are given in Table 1.

The strain gages are attached to bottom flanges of girders. The location of the strain gage was 2-3 ft from midspan, depending on span length and access to the point of installation.

Table 1. - Parameters of tested bridges

Bridge No.	Bridge Location	Girder Spacing (m)	No. of Girders	Span (m)	Slab Thickness (mm)	Bridge Width (m)	Skew Angle
1	US-23/ Huron River	1.9	6	24.5	190	11.0	14°
2	M-14/ N.Y.C. Rail Road	1.85	8	16.0	200	12.8	25°
3	I-94/ Jackson Road	1.70	9	16.0	190	14.5	25°
4	I-94/ Pierce Road	1.70	10	10.5	175	13.7	29°

The equipment is calibrated using trucks with known axle weights and spacings. The accuracy of calculation for axle loads is within 20 percent and for gross vehicle weight (GVW) within 10 percent (within 5 percent for 3 and 5 axle trucks). The measurements are carried out for several days at each location.

A computer program is developed for the automated data processing. Each data file contained data from 6 or 8 channels. Each record represents the passage of a truck over the bridge, in either right or left lane. The data capturing starts when the truck crosses over the first tape switch, which is about 6 m (20 ft) from the bridge support, in either lane. The tape switch signal is used to trigger the system, and start collecting data from the accelerometers and strain transducers. The data collection is automatically stopped after the departure of the last truck axle from the bridge. However, this synchronization works for bridges with traffic intensity not higher than normal. On bridges with trucks of certain characteristics (e.g. heavy, 11 axles), the manual trigger permits a better control of the data acquisition system.

The strain records are smoothed and filtered using the widely used Fast Fourier Transform (FFT) technique [12]. The FFT procedure is utilized assuming that the measured strain-time (or acceleration-time data) can be represented as the sum of all contributions from all mode shapes. FFT is also used to determine the dominant frequencies as well as the cutoff frequency in the frequency domain. The cutoff frequency is best estimated, for each individual bridge, by minimizing the error in estimating the total energy under the power spectrum plot in the frequency domain. After eliminating the contribution of all modes (or frequencies) above the cutoff frequency in the frequency domain, inverse FFT is then performed to obtain the time-domain equivalent static response (referred to as static response). This process is performed on various truck strain records using a computer program that was developed based on available numerical routines [11]. The dynamic and static response are then plotted and compared to determine the DLF.

The WIM measurements provided data on truck weights, axle loads, axle configurations and vehicle speeds. Most of the trucks traveled at about 90 km/h (60 mph). The truck traffic was a mixture of mostly 5 axle vehicles with few very heavy 11 axle trucks. The GVW ranges were above the legal limits.

MEASURED DYNAMIC LOAD

The measurements are carried out on four bridges listed in Table 1. Static and dynamic stress is determined for each girder. The resulting dynamic load factors (DLF) for 3, 5 and 11 axle trucks, are plotted versus the static stress in the most loaded girder in Fig. 2-5. The results show that DLF for 11 axle trucks (heavy trucks) is lower than that of 3 and 5 axles.
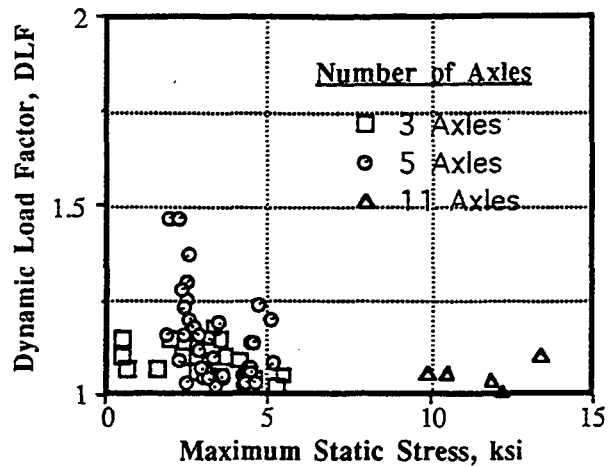

Fig. 2. Dynamic Load Factor (DLF) vs. Maximum Static Stress for Girder 3, Bridge 1.
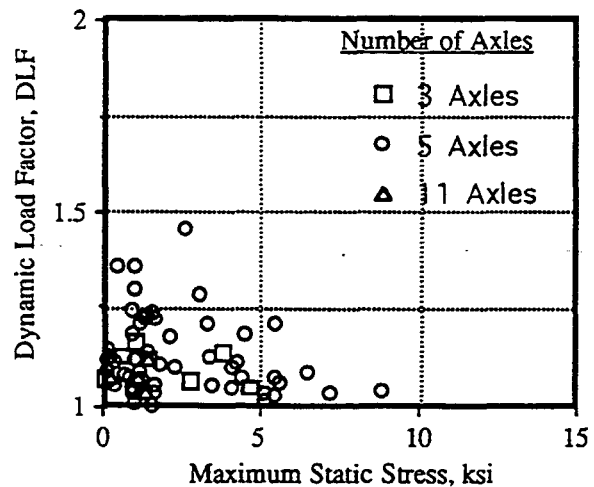

Fig. 3. Dynamic Load Factor (DLF) vs. Maximum Static Stress for Girder 4, Bridge 2.
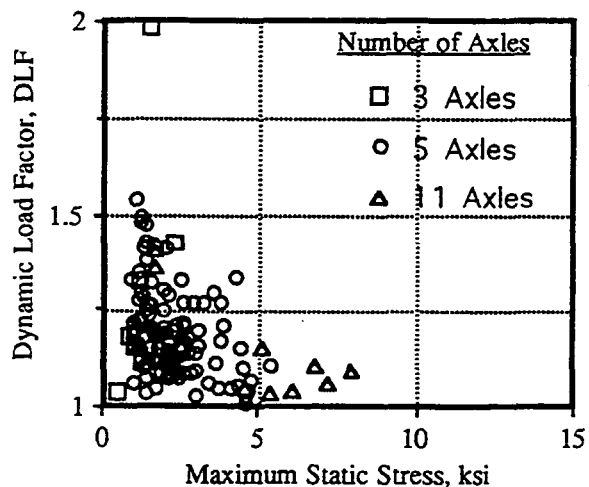

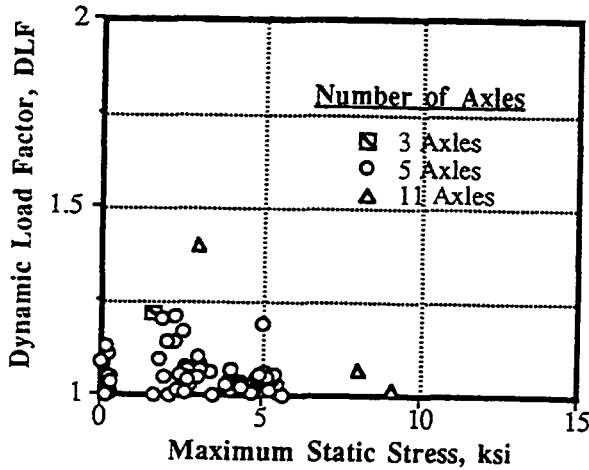Fig. 4. Dynamic Load Factor (DLF) vs. Maximum Static Stress for Girder 4, Bridge 3.

Fig. 5. Dynamic Load Factor (DLF) vs. Maximum Static Stress for Girder 4, Bridge 4.

In general, DLF decreases as the static stress in each girder increases. However, the DLF is the ratio of dynamic and static stress, and static response varies from girder to girder, depending on the positions of the girder and truck. The variation of DLF with truck weight for three types of trucks is shown in Fig. 6-9 . Results for each bridge are shown corresponding to the most loaded interior girder.
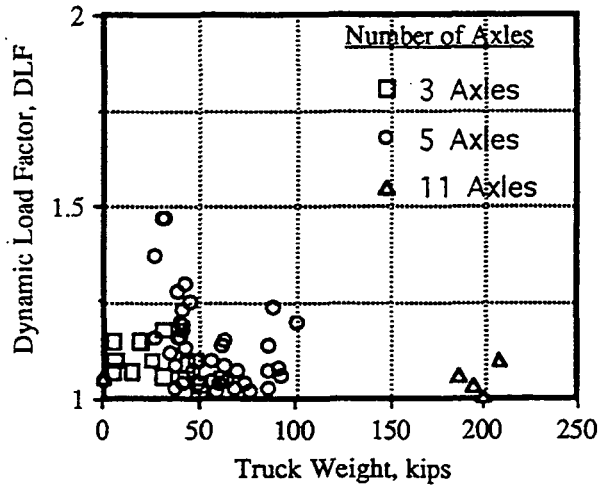
Fig. 6. Dynamic Load Factor (DLF) vs. Truck Weight, for Girder 3, Bridge 1.
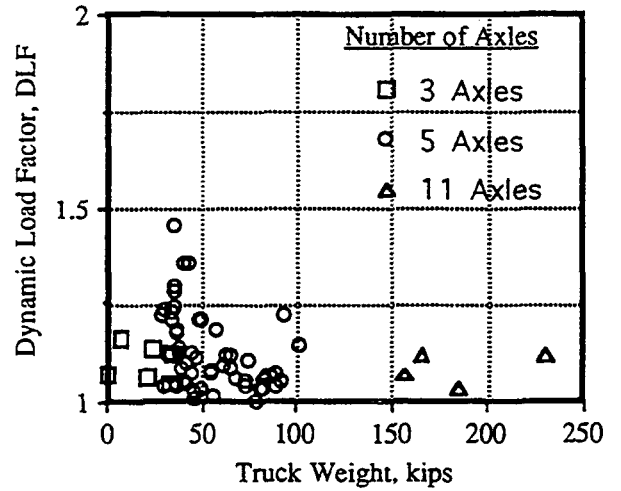
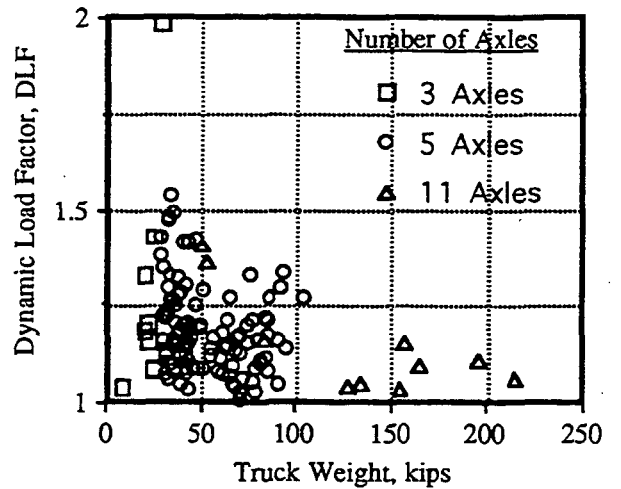Fig. 7. Dynamic Load Factor (DLF) vs. Truck Weight, for Girder 4, Bridge 2.

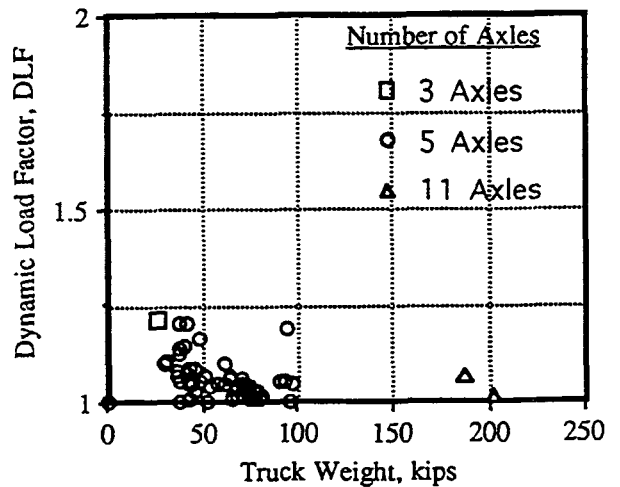Fig. 8. Dynamic Load Factor (DLF) vs. Truck Weight, for Girder 4, Bridge 3.

Fig. 9. Dynamic Load Factor (DLF) vs. Truck Weight, for Girder 4, Bridge 4.

It is observed that the DLF decreases as the GVW increases for all bridges. It is also observed that among all types of vehicles (excluding light weight 2 axle vehicles), 4 and 5 axle trucks cause the largest DLF values. Additionally, the DLF decreases with an increase in truck speed as shown in Fig. 10. It is noted that , on average, the most loaded girders (girder 3 and 4) will have values of DLF below 1.20.
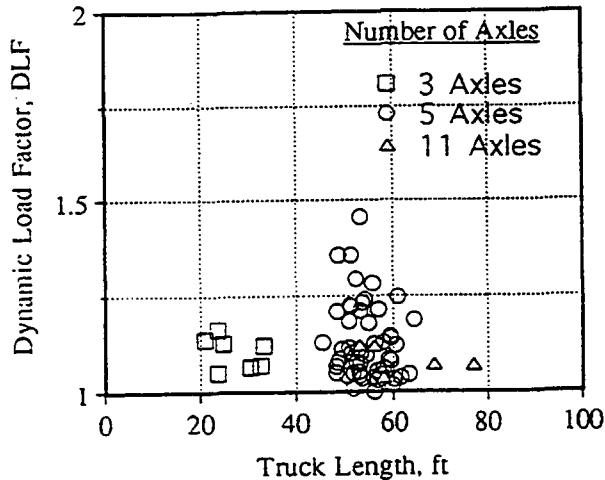

Fig. 10. Dynamic Load Factor (DLF) vs. Truck Length

CONCLUSIONS

The dynamic loads under a normal highway traffic are measured for selected steel girder bridges. For each truck, the measured parameters include: axle loads, axle spacings, speed, strain record and acceleration record. A numerical procedure is developed for data processing, filtering and smoothing. The dynamic load factor (DLF) is calculated using strain records.

It is observed that the dynamic component of stress (i.e. dynamic increment) is practically independent on static component. Therefore, DLF decreases with increased static stress. For very heavy trucks, DLF does not exceed the theoretical results [4].

Larger values of DLF are observed in exterior girders, however, this is due to relatively smaller static load effect. Values of DLF should be based on those obtained from the most loaded interior girders.

It is also observed that 5 axle trucks cause the largest amplification in bridge response (stress or deflections).

ACKNOWLEDGMENTS

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NOMENCLATURE

I = Impact Factor
DLF = dynamic load factor;
L = span length;
D_{dyn} = maximum dynamic component of deflection or stress;