Load Spectra for Girder Bridges

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Measurement results of static truck loads and the corresponding response of the girders under normal traffic on six girder bridges located on Interstate highways, state highways, U.S. highways, and surface streets are presented. Truck data are available from highway weigh station logs and citation files and also through the use of weigh-in-motion (WIM) technology. Stationary scales are biased and do not accurately reflect the distribution of truck axle weights and gross vehicle weight caused by avoidance of scales by illegally loaded trucks. Citation data are helpful in understanding the nature and extent of overloaded trucks but cannot present the entire spectra of normal traffic. WIM measurements of trucks can be taken discretely during normal traffic, resulting in unbiased data for a statistically accurate sample of truck traffic traveling a particular highway. The results show that truck loads are strongly site specific. There is a negative correlation between law enforcement effort and occurrence of overloaded trucks. Overloaded trucks are observed on roads not controlled by truck weigh stations. A comparison of the weigh station data, truck citation data, and WIM measurements obtained in this study confirms this observation. Additionally, load spectra for each girder are strongly component specific as demonstrated by this study. This information is useful to focus inspection efforts.

Presented are measurement results of truck loads on six bridges. A study of the bridge structures was performed at locations of different average daily truck traffic and proximity to stationary weigh stations. Measurements were conducted using two systems: a truck weighing system and a strain data acquisition system. The data include approximately 22,000 truck files including axle weight and spacing, speed, and multiple presence and 150 stress spectra records representing 1 week of normal traffic each. The recorded truck data were processed to develop cumulative distribution functions (CDFs) of gross vehicle weight (GVW) for each of six sites. The stress histories are collected at midspan of each girder bottom flange and processed using the rainflow algorithm. These data are then converted to an equivalent (root mean cube) stress as a convenient method of comparison between components.

Also presented are truck data provided by the Michigan State Police Motor Carrier division and the Michigan Department of Transportation (MDOT). These data include both weigh station and 1985 citation data, which serve as a point of reference for the weigh-in-motion (WIM) data.

Measurement Equipment and Bridges

Truck axle weights, gross vehicle weights, and axle spacing were obtained with a bridge WIM system from Bridge Weighing Systems, Inc. using prescribed procedures for setup and calibration. Strain data (stress spectra) were collected using the rainflow algorithm with a data acquisition system from the SoMat Corporation. During 1991, 1992, and 1993 WIM and strain measurements were conducted at six bridge sites (*1*). These sites are located in southeast Michigan on U.S. Interstate, Michigan, and city roadways. The location and description of the bridges are as follows:

1. The bridge on US-23 over the Huron River (US-23/Huron River) is constructed as a two-lane, five simple span, six steel composite girder structure that carries northbound (NB) traffic.
2. The bridge on US-23 over the Saline River (US-23/Saline River) is constructed as a two-lane, three simple span, ten steel composite girder structure that carries southbound (SB) traffic between the metropolitan Detroit area and Toledo, Ohio. There is no weigh station on the route.
3. The bridge on I-94 over Pierce Road (I-94/Pierce Rd.) is constructed as a three simple span, ten steel composite girder bridge that carries eastbound (EB) traffic between Detroit and Chicago. The site is 6.5 km east of a weigh station.
4. The bridge on I-94 over Jackson Road (I-94/Jackson Rd.) is constructed as a three simple span, nine steel composite girder bridge and carries westbound (WB) traffic between Detroit and Chicago. The weigh station for this route is 40 km west.
5. The bridge on US-23/M-14 over the New York Central Railroad (M14/New York RR) is constructed as a two-lane, three simple span, eight steel composite girder structure and carries EB traffic.
6. The bridge on Wyoming Road over I-94 (Wyoming Rd./I-94) in Detroit is constructed as a four simple span, ten steel composite girder bridge and carries SB surface street traffic in Detroit. The area is heavily industrialized with more truck traffic than is typical for a city street.

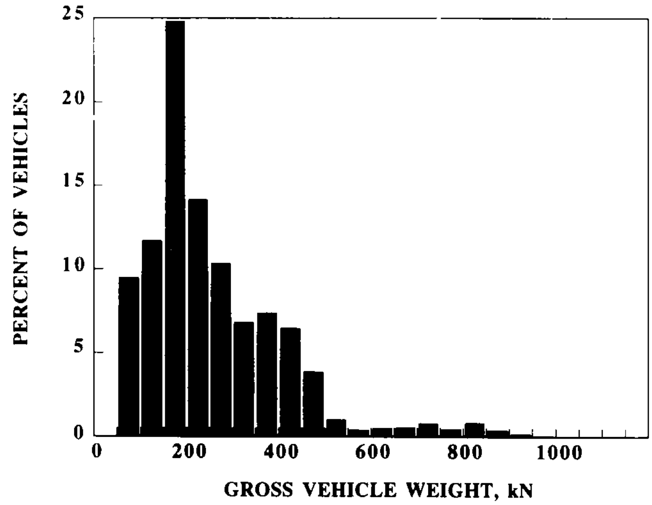

FIGURE 2 Histogram of GVW, US-23/Saline River, 1992.

Truck Weight Measurements

Statistical data are presented in the form of histograms and cumulative distribution functions. CDFs are used to present and compare the critical extreme vaues of the data and are plotted on normal probability paper (*2*).

Most states allow a maximum GVW of 355 kN; however, Michigan legal limit allows for an 11-axle truck of over 710 kN, depending on axle configuration. From the tables and graphs it can be seen that there were a number of illegally loaded trucks measured during data collection at several of the sites.

Measurement results of GVW taken at US-23/Huron River NB in 1992 (Figure 1) indicate that the extreme values are dominated by 11-axle vehicles. This bridge

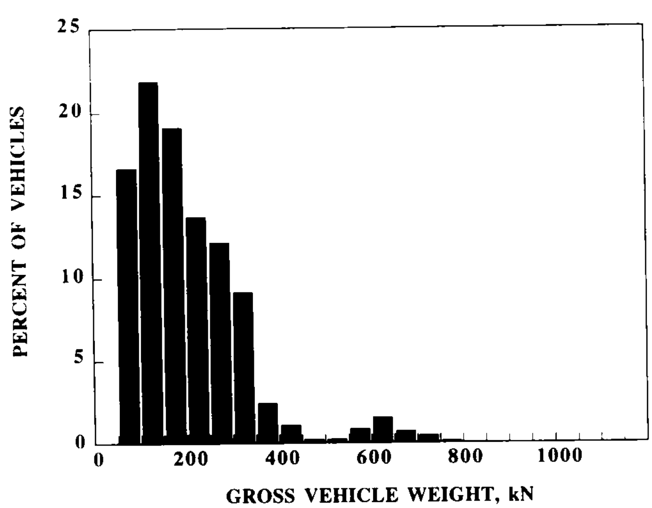

FIGURE 1 Histogram of GVW, US-23/Huron River, 1992.

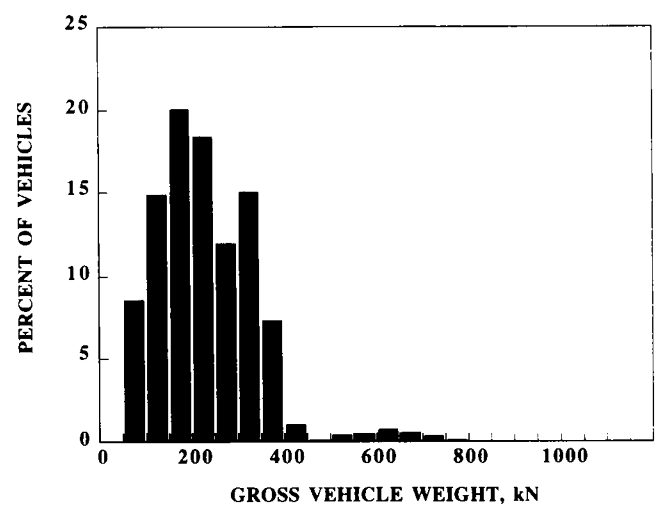

FIGURE 3 Histogram of GVW, I-94/Pierce Rd., EB, 1993.

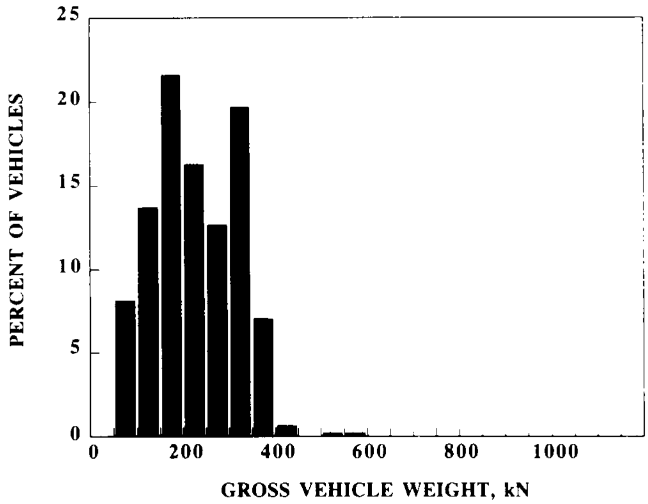

FIGURE 4 Histogram of GVW, I-94/Pierce Rd., EB, 1991.

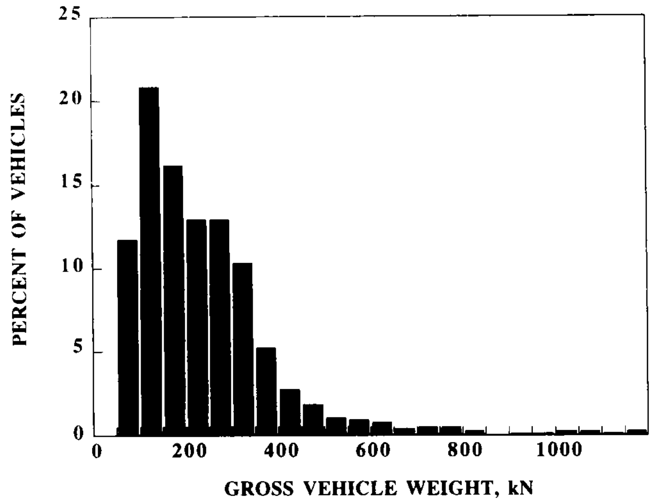

FIGURE 6 Histogram of GVW, M-14/New York Central RR, EB.

is not on a route near or between major industrial areas and the data reflect this because there are almost entirely legally loaded vehicles, despite the absence of a weigh station in the vicinity.

The US-23/Saline River SB bridge site is along a north-south route between the major industrial areas of metropolitan Detroit and Toledo, Ohio, as well as a heavily used route between Chicago and other Ohio cities. A critical factor affecting the use of this route is the absence of a weigh station. It can be expected, as the GVW (Figure 2) data reveal, that heavily and illegally loaded trucks are motivated to travel this route. The heaviest vehicle weighed was a 1100-kN, 11-axle truck. Several vehicles weighed over 900 kN and many exceeded legal limits.

Measurements taken at I-94/Pierce Rd. in 1993 (Figure 3) were conducted when the nearby stationary weigh station was closed for repairs. I-94/Pierce Road is 7 km east of the stationary weigh station on I-94 EB. As a comparison, WIM data were collected in 1991 (Figure 4) with the stationary weigh station in operation. It is suspected that illegally loaded trucks avoid stationary weigh scales causing the data to be biased. The data presented support this as seen from comparing both the GVW and lane moment. A total of 1,031 trucks were weighed in 1991 and a total of 2,951 trucks were weighed in 1993. Trucks weighed in 1991 while the stationary weigh scales were open had much lower GVWs than the trucks weighed in 1993 when the stationary weigh scales were closed, as seen in Figures 3

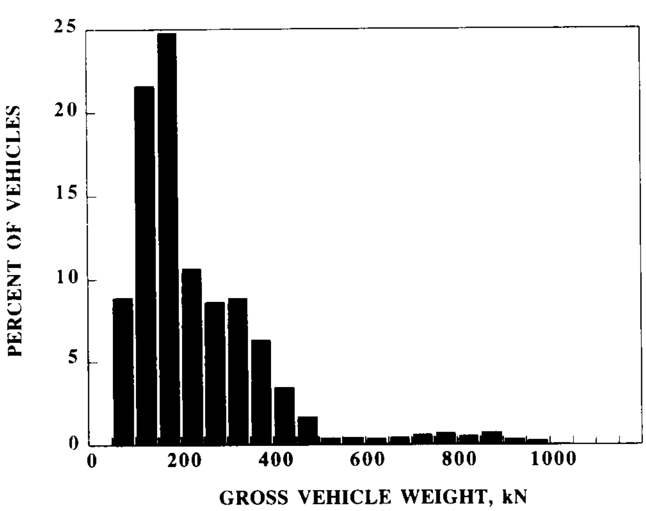

FIGURE 5 Histogram of GVW, I-94/Jackson Rd., WB.

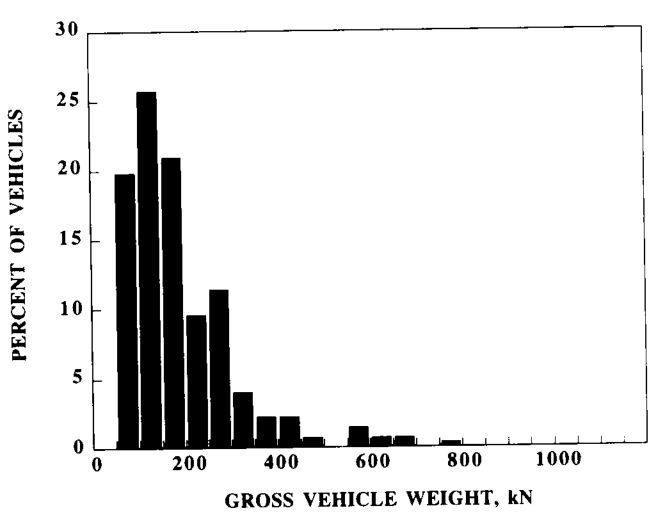

FIGURE 7 Histogram of GVW, Wyoming Rd./I-94, SB.

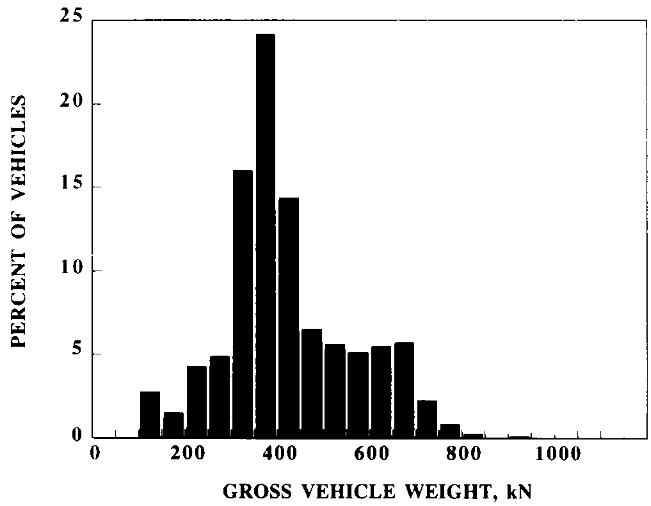

FIGURE 8 Histogram of GVW of Michigan citation data, 1985.

through 9. The 1993 maximum GVW of 807 kN is considerably larger than the 1991 maximum GVW of 593 kN.

GVW measurements collected at I-94/Jackson Rd. WB (Figure 5) indicate very heavy vehicles with the extreme values dominated by 11-axle vehicles. This bridge is on the major route between Detroit and Chicago, which accounts for the very heavy vehicles. The nearest weigh station is approximately 40 km west of the site, also contributing to higher GVWs and illegally loaded vehicles.

GVW measurements collected at M-14/New York RR EB (Figure 6) indicate very heavy vehicles with the extreme values dominated by the 11-axle vehicles. This bridge, although not in an industrial area, is a route used between northern Detroit suburbs and the metropolitan Chicago area, accounting for the very heavy vehicles.

Extreme values of GVW (Figure 7) at Wyoming Rd./I-94 SB reflect very few vehicles exceeding that allowed by the state of Michigan. Although the vicinity of the bridge is heavily industrialized, trucks traveling the surface street may be engaged in shorter local deliveries, reducing the incentive to overload.

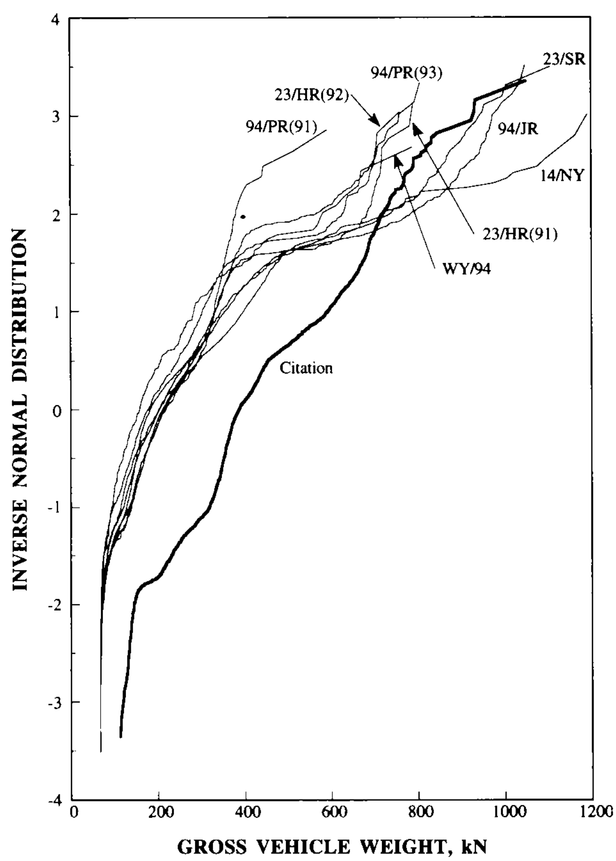

FIGURE 9 Comparison of GVW CDF for all bridges (all vehicles GVW > 67 kN).

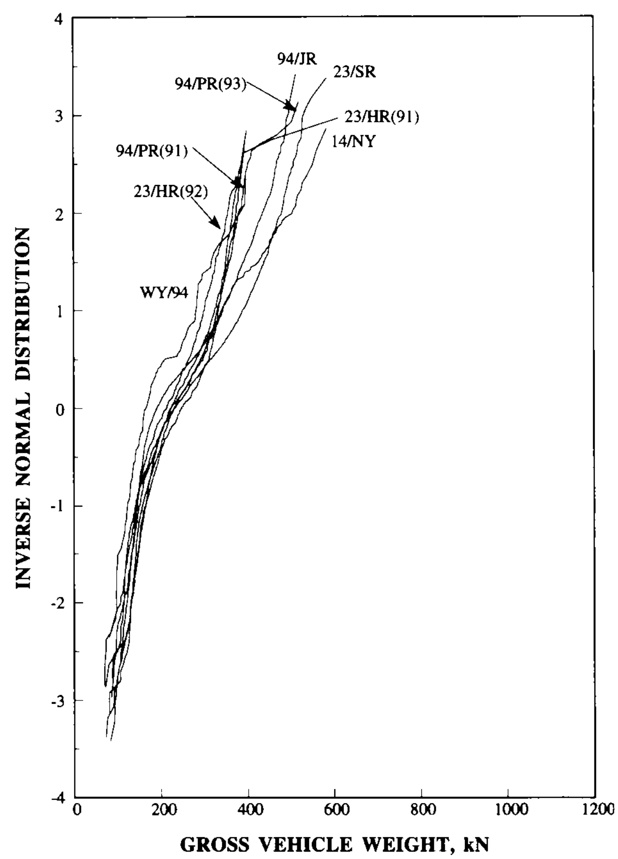

FIGURE 10 Comparison of GVW CDF for five-axle vehicles for all bridges.

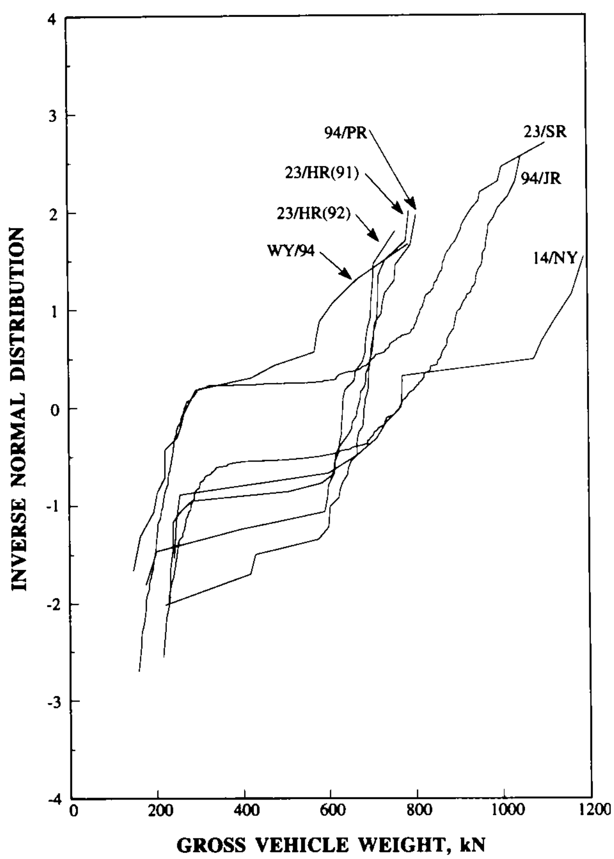

FIGURE 11 Comparison of GVW 11-axle vehicles for all bridges.

For comparison, Figure 8 presents data (approximately 2,500 trucks) obtained for overload citations issued in Michigan for 1985. The maximum GVW was approximately 1070 kN.

Figures 9–11 present the GVW CDF of trucks from each bridge file. Figure 9 indicates the distribution of all vehicles weighed for the particular site weighing greater than 67 kN plotted with the 1985 citation data. Figure 10 indicates the distribution of GVW for five-axle vehicles greater than 67 kN, and Figure 11 indicates that for 11-axle vehicles.

Lane Moment Distributions

Static lane moment CDFs are presented for simple spans of 9, 18, 27, and 36 m in Figures 12 through 15 for each bridge. The truck files of each bridge site were processed through influence lines to determine maximum lane moments, which are then divided by the HS20 lane moment for that span.

The 9-m lane moments in Figure 12 show a wide variation between bridges. Maximum values of lane moment to HS20 moment vary from 1.4 at I-94/Pierce Rd. (1991) to 3.05 at I-94/Jackson Rd. The CDF for US-23/Huron River for both 1991 and 1992 are somewhat similar, with maximum lane moment to HS20 moment ratios of 2.0 and 2.3, respectively. All sites have a median lane moment between 0.45 and 0.6 times HS20 moment, which corresponds to an inverse normal value of 0.

The 18-m lane moment CDFs in Figure 13 also show wide variation between bridge sites. Maximum values of

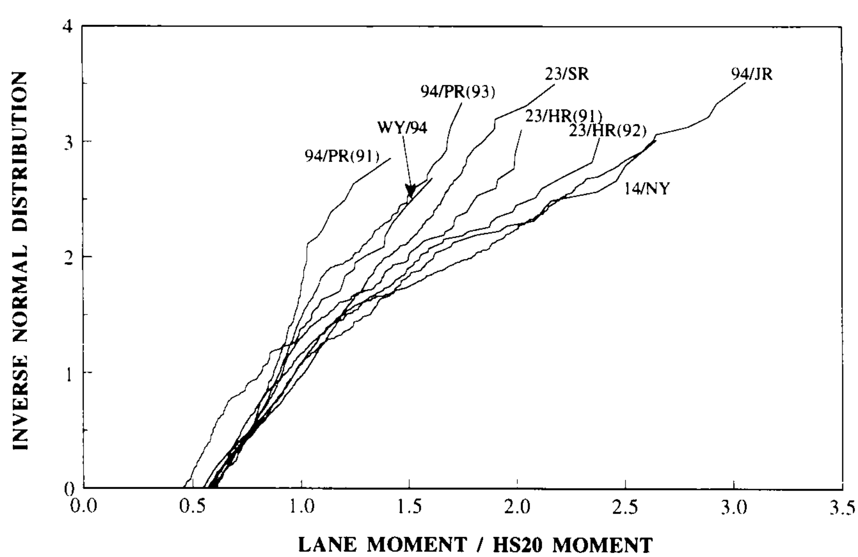

FIGURE 12 Comparison of 9-m static lane moments, all bridges (GVW > 67 kN).

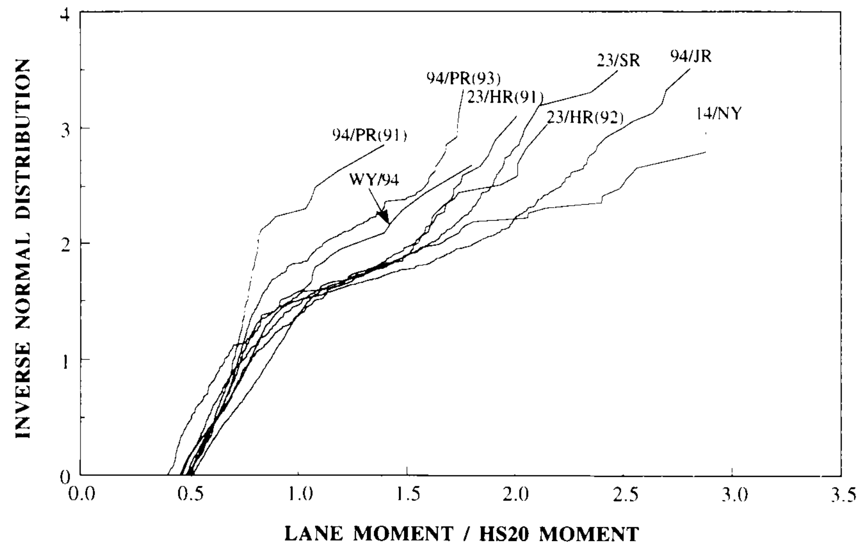

FIGURE 13 Comparison of 18-meter static lane moments, all bridges (GVW > 67 kN).

lane moment to HS20 moment vary from 1.4 at I-94/ Pierce Rd. (1991) to 2.9 at 14/NY. The extreme values of all distributions are dominated by US-23/Saline River, M-14/New York Central RR, and I-94/Jackson Rd. where there is little or no control by weigh stations. Again the CDFs for US-23/Huron River during 1991 and 1992 are similar with maximum lane moment to HS20 moment ratios of 2.0 and 2.2, indicating little change from year to year, whereas the 1991 and 1993 CDFs of I-94/Pierce Rd. are considerably different. All sites have a median lane moment between 0.40 and 0.50 times HS20 moment.

The 27- and 36-m lane moment CDFs in Figures 14 and 15 again demonstrate the wide variation between bridge sites of the load spectra. Observations for the 27- and 36-m span are similar to observations of the 18-meter span lane moment CDFs, although the trends are more pronounced. As the span increases, the lane moment is more closely a function of the GVW rather than axle weight, and similarities in the distributions can be observed.

Stationary weigh station scale data were provided by MDOT from stations located on I-75 at Monroe, Michigan, and I-94 at Grass Lake, Michigan (7 km east of

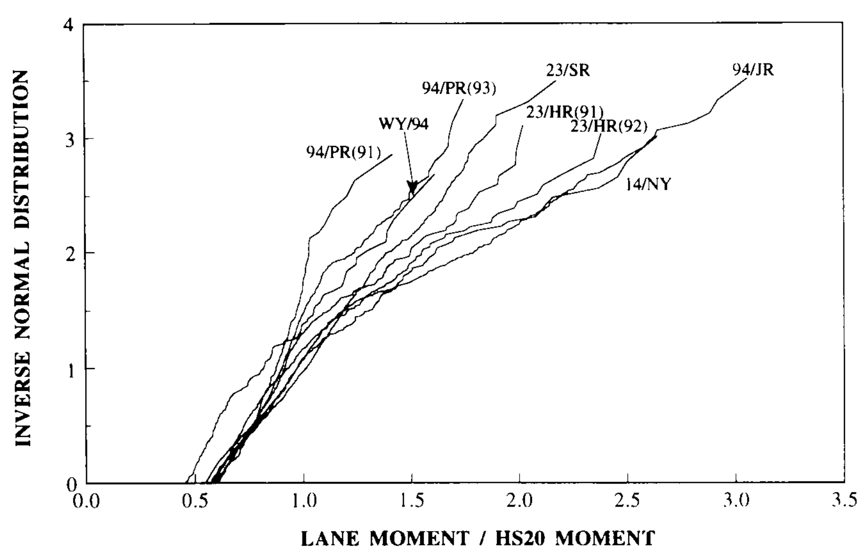

FIGURE 14 Comparison of 27-m static lane moments, all bridges (GVW > 67 kN).

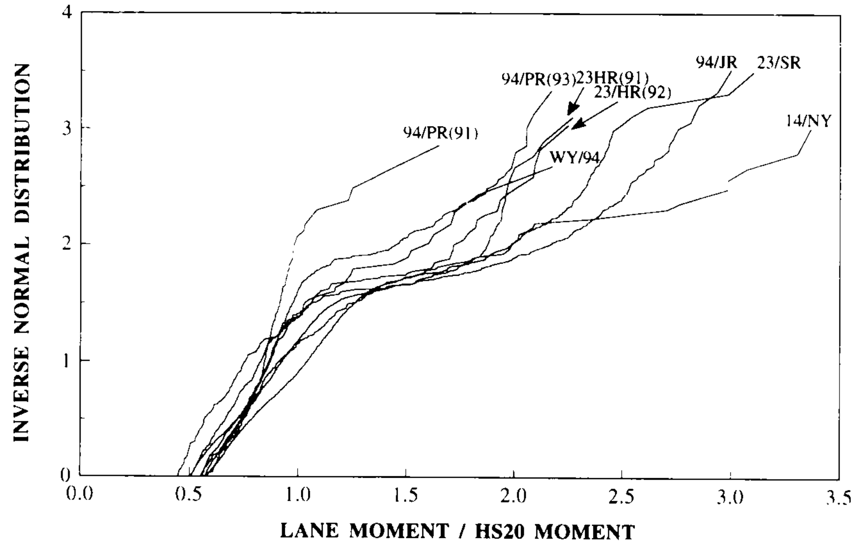

FIGURE 15 Comparison of 36-meter static lane moments, all bridges (GVW > 67 kN).

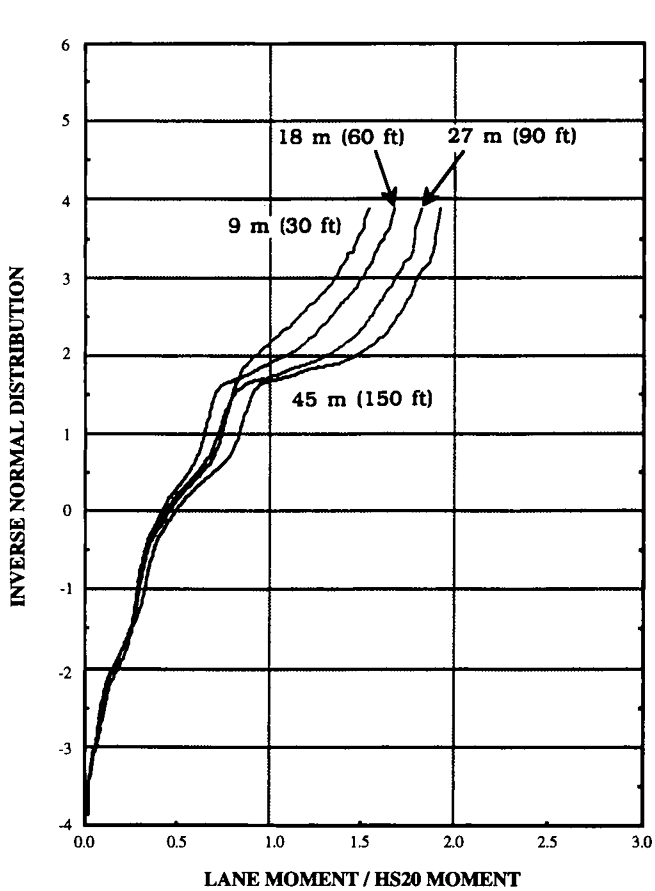

FIGURE 16 CDF of truck static lane moments from stationary weigh station data (*4*).

the tested bridge I-94/Pierce Rd.). The data presented here in Figure 16 are CDFs of lane moments caused by the trucks passing through the I-94 weigh station. Simple spans of 9, 18, 27, and 36 m were analyzed by Nowak et al. (*4*). The I-94 EB data are for October and November 1989 and include 19,874 trucks. Lane moment/HS20 moment values for I-94 Pierce Rd. (1993) ranged from 1.7 to 2.2 compared with 1.5 to 1.9 for the weigh station data. Lane moment/HS20 moment

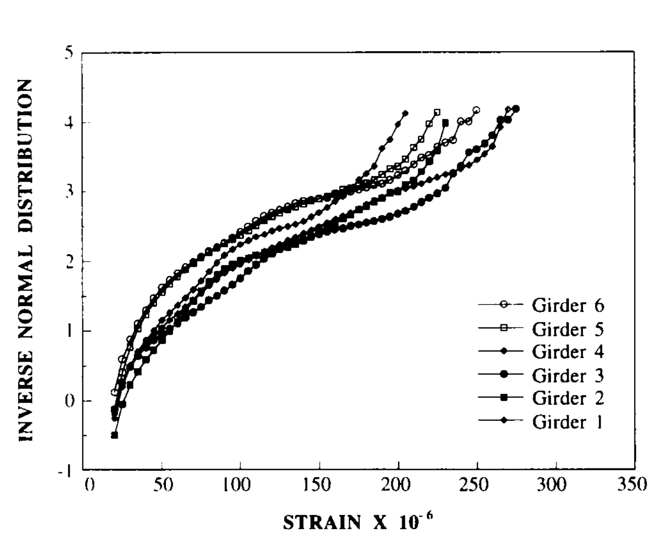

FIGURE 17 US-23/Huron River NB rainflow strain CDFs for G1–G6.

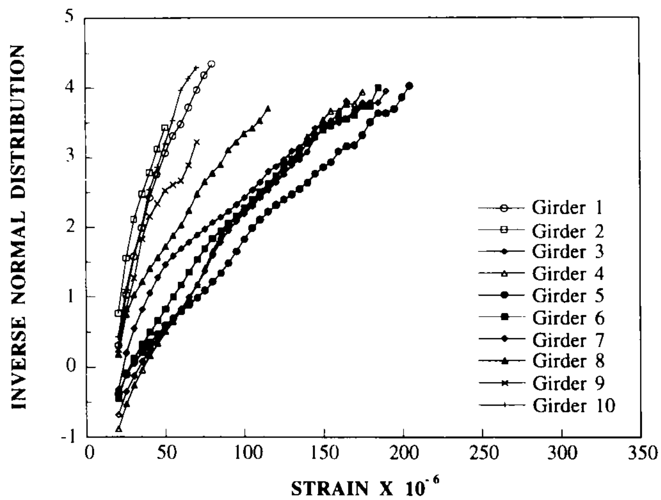

FIGURE 18 US-23/Saline River SB, rainflow strain CDFs for G1–G10.

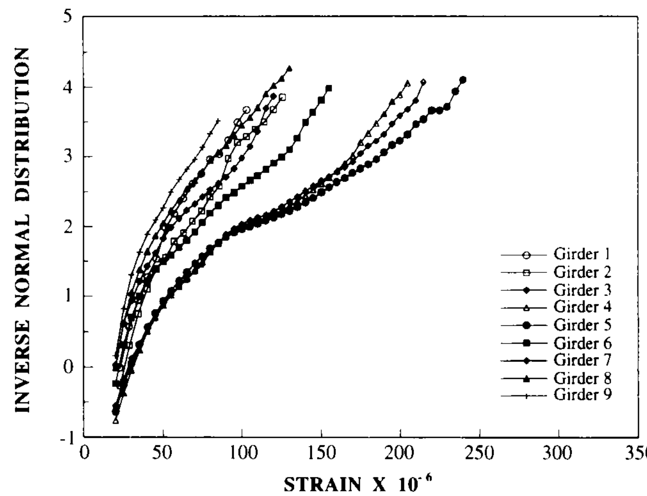

FIGURE 20 I-94/Jackson Rd. WB rainflow strain CDFs for G1–G9.

values for I-94 Pierce Rd. (1991) ranged from 1.4 to 1.7, demonstrating that although the weigh station was open in 1992 the load spectra of WIM and stationary scales were very much the same and increased when the station was closed in 1993.

Strain Measurements

All strain measurements were taken at the bridge girder bottom flange at midspan (*5*). The strain data were collected using the rainflow algorithm enabling long periods of data collection. The data presented in Figures 17 through 21 are the result of 1 week of continuous data collected at each bridge site. The bridge at Wyoming Rd./I-94 was not instrumented for strain data because of equipment security concerns. Equivalent stress (root mean cube) results of the strain data collection are presented in Figure 22. For orientation, Girder 1 is located at the extreme right of the right lane of the bridge.

The CDFs for US-23/Huron River in Figure 17 show considerable uniformity between girders, as may be expected as a result of the longer span and fewer girders. Girder 4 is the most highly stressed and Girder 6 experiences the lowest stresses, with a difference between the maximums at these girders equal to only 45 μstrain. The variation becomes more pronounced as the ratio of

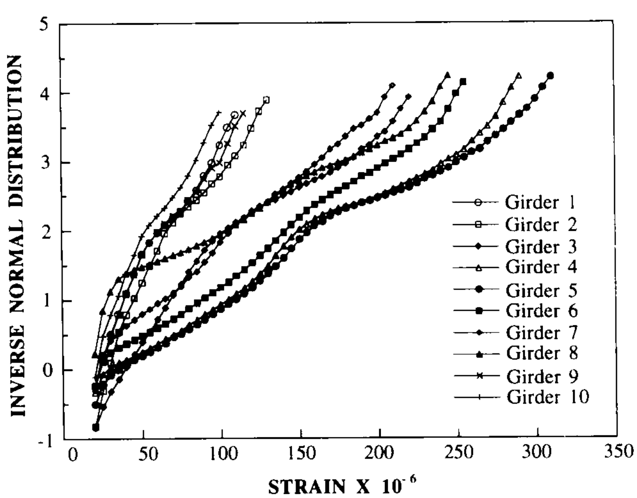

FIGURE 19 I-94/Pierce Rd. EB rainflow strain CDFs for G1–G10.

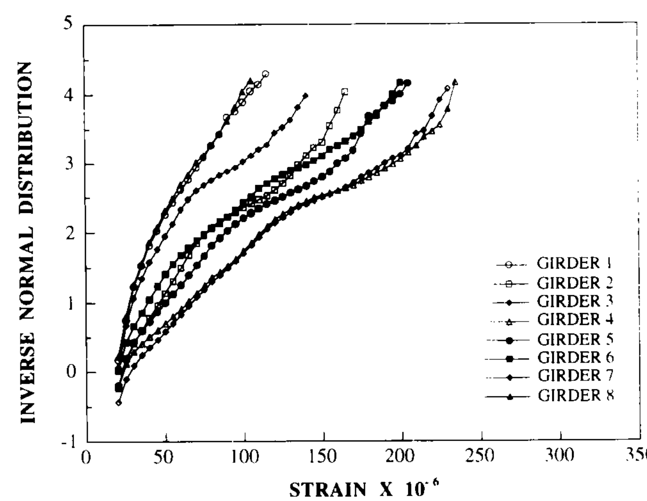

FIGURE 21 M-14/New York City RR EB, rainflow strain CDFs for G1–G8.

width to length of the bridge dimensions increases. Maximum strains measured in the girders of the bridge on US-23/Saline River vary from 50 μstrain in Girder 2 to 205 μstrain in Girder 5. Maximum strains measured in the girders of the bridge on I-94/Pierce Rd. vary from 100 μstrain in Girder 10 to 310 μstrain in Girder 5. The unusually high strain at this location was investigated and the design of the bridge was compared with others of similar span and girder spacing. The bridge at US-23/Saline River is a shorter span (9.9 m) than I-94/Pierce Rd. (10.5 m), and both bridges have girder spacing of 1.5 m; however the girder size at I-94/Pierce Rd. is substantially smaller (W24×68 versus W27×102). This size differential is likely the cause of the higher stresses.

I-94/Jackson Rd. and M-14/New York Central RR exhibit similar CDFs for girder stresses, as seen in Figures 20 and 21. This may be expected since the load spectra are somewhat similar and the bridge spans are approximately the same. Both bridges experienced a maximum strain of about 240 μstrain.

The plots of equivalent (root mean cube) stresses (Figure 22*a* through *e*) demonstrate that girders nearest the left wheel of vehicles traveling in the right lane experience the highest stresses. This observation is important for fatigue considerations and inspections.

Conclusions

From the presented data of GVW and lane moments, load spectrum is highly site specific and is dependent on a number of factors. These factors include proximity to stationary weigh stations, weigh station hours of operation, proximity to industrial areas, and desirability of the route for traffic between major metropolitan areas.

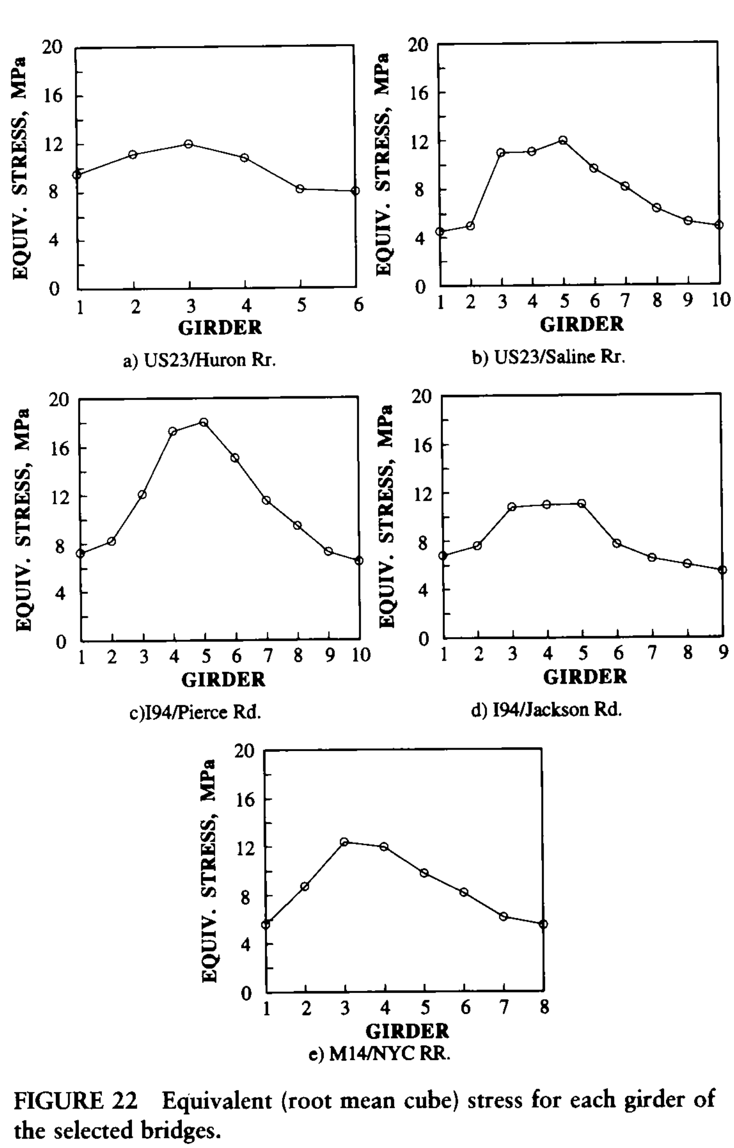

FIGURE 22 Equivalent (root mean cube) stress for each girder of the selected bridges.

The distribution of moments caused by the truck traffic is related to the same factors as GVW. In some locations the level of the lane moments may be exeedingly high.

Michigan State Police citation data confirm that very heavy trucks should be expected when data are collected without observation, which is possible with WIM equipment. Resources devoted to legal load limit enforcement activities can directly affect load levels within a given location and will prevent accelerated deterioration of the transportation systems.

Strain spectrum is component dependent and varies greatly from girder to girder. The tests consistently indicated that girders located nearest the right lane left wheel vehicle track experienced the highest strains, typically Girders 3 to 5. These girders are affected by side-by-side multiple presence of vehicles, in addition to the predominant traffic in the right lane. Girders supporting the left lane experienced moderate strains, and outer girders experienced low levels of strain. Truck traffic in the left lane is significantly lower in volume than that in the right lane, which results in different stress spectra. Exterior girders are a greater distance from the load location and may also benefit from stiffening effects of the concrete barriers.

ACKNOWLEDGMENTS

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