HOKKAIDO UNIVERSITY

Title	MONITORING OF TRAFFIC AXLE LOADS IN ORTHOTROPIC STEEL DECK STRUCTURES
Author(s)	SUZUKI, K.; YOSHIKAWA, S.
Citation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, A-2-6., A-2-6
Issue Date	2013-09-11
Doc URL	http://hdl.handle.net/2115/54203
Type	proceedings
Note	The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan.
File Information	easec13-A-2-6.pdf

Instructions for use

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

MONITORING OF TRAFFIC AXLE LOADS IN ORTHOTROPIC STEEL DECK STRUCTURES

K. SUZUKI[1*†] and S. YOSHIKAWA[2]

[1]*Graduate School of Engineering, Fukui University, Japan*
[2]*Department of Architecture and Civil Engineering, Fukui University, Japan*

ABSTRACT

The main cause of fatigue damage in orthotropic steel deck structures is local deformation due to tire loading. To grasp the actual axle weights and its frequency is very important regarding to design and maintenance. This study develops a calculation method of axle weights of running vehicles on the orthotropic steel deck. The calculation uses the dynamically recorded strain responses of longitudinal ribs. An advantage of the strain response is higher sensitivity to axle passing than that of transverse ribs. This advantage contributes more accurate calculation of axle weight by using the least square method. Although the strain response fluctuates as the vehicle running position changes, the fluctuation is corrected by bridge Weigh-In-Motion using strain responses of a transverse rib. Calculation results show an axle weight histogram for one-week monitoring. It is also shown that several vehicles have over 200kN axle loads.

Keywords: Bridge Weigh-in-Motion, Orthotropic steel deck, Axle load, Fatigue damage, Strain response

1. INTRODUCTION

Fatigue damage in orthotropic steel deck structures is caused by over loaded vehicles. Orthotropic steel deck components consist of thin steel plates; in addition, stresses are fluctuated by each tire passage; therefore, the structural components are in a very severe fatigue environment of high stress level and high stress frequency. Fatigue damage of orthotropic steel deck structures in Japan has been a serious issue due to the large number of heavy vehicles especially in urban expressways. Actually, over 7,000 fatigue cracks have been found in the Metropolitan expressway, the Hanshin expressway and so on (JSCE 2010).

For the perspective on maintenance and feedback to the new design of the orthotropic steel deck, to grasp the axle weight level and its frequency is of the essence. The Metropolitan expressways (Tokida et al. 2005) evaluated their fatigue environment using the Origin-Destination data and the

* Corresponding author: Email: suzuki-k@u-fukui.ac.jp

† Presenter: *ditto*

vehicular axle loads. The axle loads are acquired from the instruments placed under the pavement at tollgates. Since this instrumentation device is costly and requires highly sensitivity; also, is laid out by removing the pavement, laborious construction works and maintenance works are necessary.

Another method to obtain axle loads is Bridge Weigh-In-Motion (BWIM) (Moses 1979) . The source data are strain of the bridge components; that is, it does not require to construction works on the road surface; then, it does not prevent traffic flow from the instrumentation to the measurement. In addition, the speed of system development is high because the data processing is simple matrices operations. Hence, BWIM has an advantage on the short term traffic monitoring.

Kobayashi et al. developed an automatic BWIM system (Kobayashi et al. 2004). Strain data acquisition is 3 points per one lane. The system calculates a vehicle's gross weight with 5~10% accuracy. The system is applied to two girder bridges and an orthotropic steel deck bridge.

Ojio et al. developed a system to calculate axle loads in orthotropic steel deck (Ojio et al. 1998). The system uses strain data of the longitudinal ribs. Axle loads are calculated by using strain differences between the instrumented longitudinal ribs. Xiao et al. also proposed an axle weight calculation method that uses strain responses of longitudinal ribs (Xiao et al. 2006). These methods use 4 or more strain gauges per one lane.

In order to reduce costs for measuring devices, this study limits the data acquisition points to 3 strain gauges per one lane; then, develops an axle load calculation method. The method is applied to the one-week continuously monitored strain data, and the traffic axle loads are analyzed.

2. CALCULATION OF AXLE LOADS

The axle loads are calculated with the least minimum square method. This method was originally proposed by Moses(1979). Strain history was initially recorded in running tests. The test used a truck, axles weights of which are known. Then, strain influence lines are calculated by using FFT(Tateishi et al. 1995). The BWIM is implemented with the curve fitting of the least square method. The influence lines are used to reconstruct the strain history that approximately traces the originally acquired strain history.

Data employed for curve fitting are strain data of a longitudinal rib (L-rib) and that of a transverse rib (T-rib). The characteristics of strain data due to live loads are different between the L-rib's and T-rib's. The strain response of the L-rib is sensitive to the axle passage; that is, the characteristic of the axle load is reflected to the strain history. Hence, accurate axle weight can be calculated when curve fitting is done for the L-rib strain data. In the meanwhile, L-rib strain data is explicitly fluctuated by the vehicle's running position (**Figure.1**) because the L-rib has low stiffness for the transverse direction, and consequently the BWIM results are fluctuated although the ratio of axle

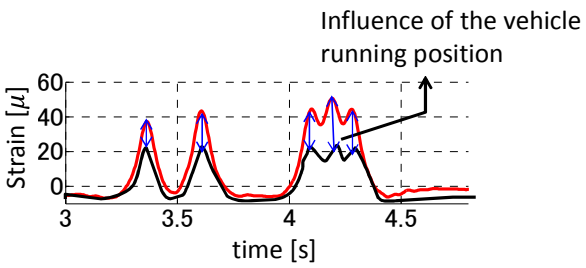

Figure 1 Strain fluctuation due to running position

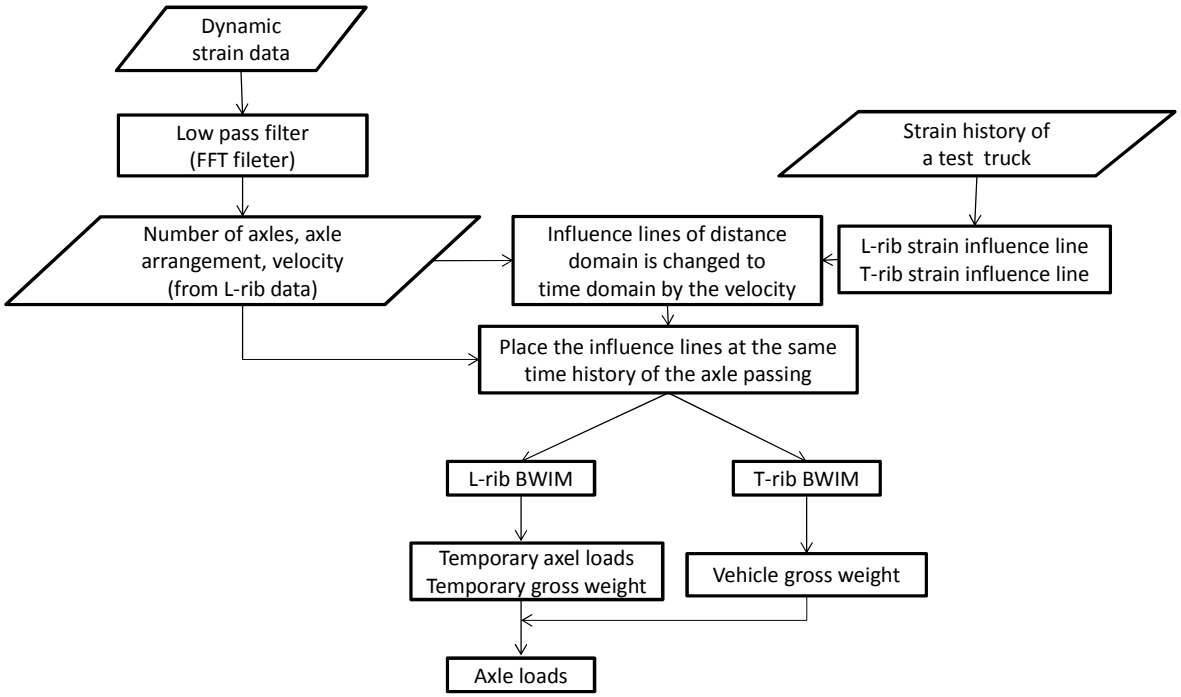

Figure.2 Data processing flow

weights in the vehicle ought to be accurate. On the contrary, T-ribs respond in less sensitive to the axle passage in its strain history but the strain response is stable to the vehicle running position.

The BWIM in this study takes both advantages of L-rib strain responses and T-rib ones. **Figure.2** shows the data processing flow. The calculation uses the accurate ratio among the axle's weights from the L-rib BWIM and accurate the vehicle gross weight from the T-rib BWIM. The axle weights from the L-rib BWIM are summed up to the temporary gross weight. The gross weight from the T-rib BWIM is divided by the temporary gross weight from the L-rib; then, the quotient is obtained as a correct value. The correct value is multiplied to the temporary axle's weight, and the axle weight is calculated.

3. ACCURACY OF THE CALCULATED AXLE LOADS

Three test trucks were used for running tests, the gross weights of those are 208kN with 3 axles, 310kN with 5 axles and 411kN with 6axles. The each axle load shown in **Table 1** is measured when they were standing. The target orthotropic steel deck structures and the instrumentation are shown in **Figure.3**. The strain data sampling rate was 250Hz. The orthotropic steel deck carries two lanes. The data acquisition was conducted through the 21 running tests, and the number of axle passing times was 85 in total. The tests included single truck tests, two trucks that are nose to tail tests and two trucks passing each other tests.

Figure.4 is a distribution of error (%). The standard deviation was 6.7%. It was one time that the error exceeded 20%.

Table 1 Axle loads measured at a stoppage condition

Weight	1st axle	2nd axle	3rd axle	4th axle	5th axle	6th axle	Gross Weight
3-axle truck	63.5	72	72.1				207.6
5-axle truck	58.4	67.4	61	55.6	67.7		310.1
6-axle truck	53	62.5	55.3	78.5	67.6	94.4	411.3

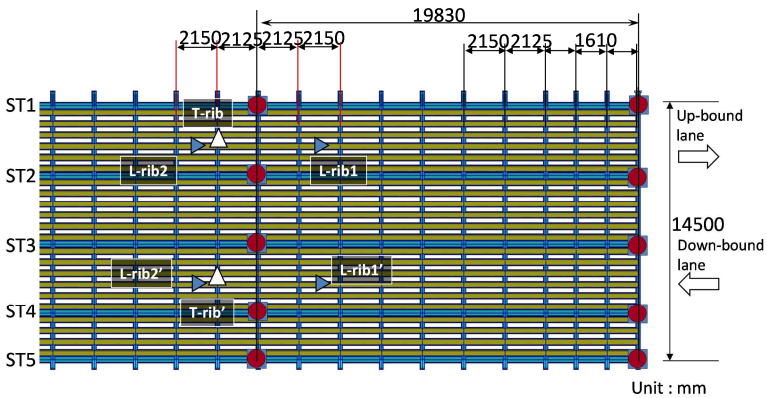

Figure.3 Instrumentation for dynamic strain data

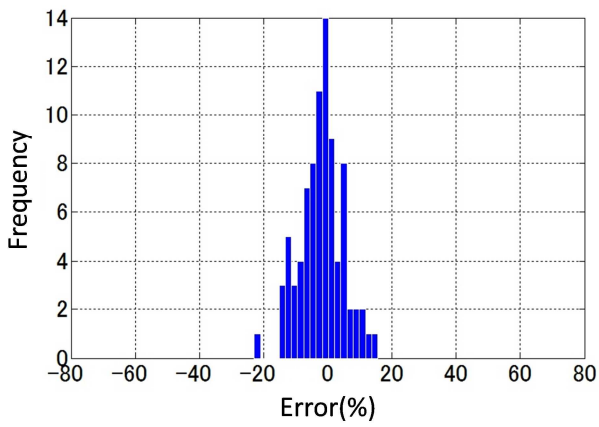

Figure.4 Distribution of errors from calculated axle loads

4. MONITORNG OF TRAFFIC AXLE LOADS

4.1 Distribution of axle loads

Figure 5 is a histogram of the axle loads monitored for one week. As axle load increases, the frequency decreases at the inverse proportion to the exponent of 10. Loads over 100kN counted 1,793 times. The loads over 100kN violate the Japanese Road Transportation Law. In addition, loads over 200kN, which is the design load for orthotropic steel deck, counted 31 times. The maximum axle load was 293kN, and the gross weight of the vehicle was 827kN.

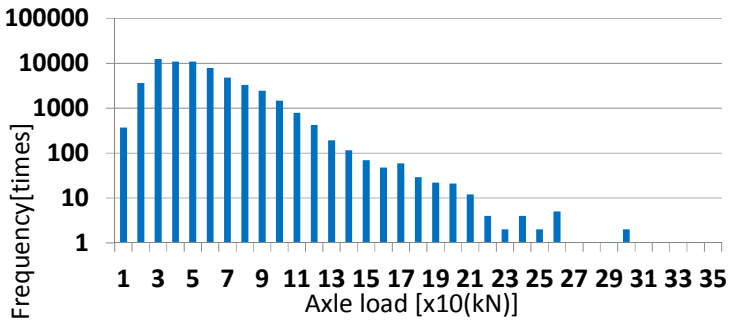

Figure 5 Histogram of axle loads

4.2 Equivalent axle load

The Metropolitan Expressways in Japan evaluated its fatigue environment (Tokida et al. 2005) using an equivalent axle load. The following equation calculates the equivalent axle load.

$$P_E = \sqrt[m]{\sum_k \frac{n_k \cdot P_k^m}{n}} \tag{1}$$

P_E : Equivalent axle load (kN)

P_k : Axle load (kN)

n_k : Frequency of P_k

n : The total number of axles over $50kN$

m : The slope of the fatigue design $\mathrm{S-N}$ curve $(= 3)$

Tokida used axle loads over 120kN to calculate the equivalent axle load because of the data saving function of axle load measuring devices at toll gates. This study uses axle load over 50kN, the number of which is 32,652 because the axle loads of heavy vehicles roughly consist of 50kN or over it as shown in **Table 1**. From the eq.(1), the equivalent axle load was calculated as 75.1(kN). The value can be one of the indicators for the fatigue environment. For the purpose of maintenance works, it is necessary to accumulate axle loads data and the equivalent axle loads of other orthotropic steel deck structures in the future.

5. CONCLUSIONS

This study developed an axle load calculation method using dynamic strain responses of longitudinal ribs and a transverse rib in the orthotropic steel deck structure. The proposed method was applied for dynamic strain data acquired for one week; then, the axle load distribution and the equivalent axle load were clarified. Followings are the concluding remarks.

1. The accuracy of the calculated axle load is mostly less than 20% error. In total 85 times of axle passages, error in 84 axle passages was less than 20%.
2. For the one week continuous monitoring, axle loads over 100kN were 1,793 times and those over 200kN were 31 times.
3. The equivalent axle load was calculated by using axle loads over 50kN in total 32,652 axles. The equivalent axle load was 72.5kN.

6. ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number 23760420. The author expresses sincere appreciation to the support.

REFERENCES

JSCE. Kosyoban no Hirou [Fatigue damage of orthotropic steel deck] (2010)

Kobayashi Y, Miki C and Tanabe A (2004). Long-Term Monitoring of Traffic Loads by Automatic Real-Time Weigh-In-Motion. JSCE Journal of Structural Mechanics and Earthquake Engineering. NO.773/I-69. pp.99-111.

Moses F (1979). Weigh-in-Motion System Using Instrumented Bridges. Transportation Engineering Journal. Proceedings of ASCE. Vol.105 No.TE3. pp.233-239.

Ojio T, Yamada K, Kainuma S, Obata T and Furuichi T (1998). Estimation of Traffic Loads using Strain Recording in Orthotropic Steel Deck. Journal of Structural Engineering. A. Vol.44A pp.1141-1151.

Tateishi K, Takenouchi H and Miki C (1995). Mechanism for Developing Local Stress at the Connection Details in Steel Bridge Structures. JSCE Journal of Structural Mechanics and Earthquake Engineering. NO.507/I-30 pp.109-119.

Tokida H, Nagai M and Miki C (2005). Evaluation of Fatigue Environment Based on Traffic Data for the Metropolitan Expressway. JSCE Journal of Structural Mechanics and Earthquake Engineering. No.794/I-72 pp.55-65.

Xiao ZG, Yamada K, Inoue J and Yamaguchi K (2006). Measurement of Truck Axle Weights by Instrumenting Longitudinal Ribs of Orthotropic Bridge. Journal of Bridge Engineering. Vol.11(5) pp.526-532.