IN-SITU ESTIMATION FOR FATIGUE LIFE OF BRIDGE DECK SLAB BY WIM METHOD

HIROSHI MITAMURA
Independent Administrative Institution, Civil Engineering Research Institute of Hokkaido

HIROYUKI ISHIKAWA
Independent Administrative Institution, Civil Engineering Research Institute of Hokkaido

SHIGEYUKI MATSUI
Professor of Civil Engineering, Graduate School of Engineering, Osaka University

Abstract

In recent yeas, life-cycle management of infrastructure has been gaining in importance. Accurate prediction of deterioration for structures is a basic task of life-cycle management. Deck slabs of highway bridges are members that experience fatigue deterioration, and various experiments and analyses have been done for slabs. This is because the loading data of vehicles passing over bridges have not been studied. This study attempted to obtain accurate axle loads for vehicles passing over two bridges by measuring the strain of cracks on the deck slabs of the bridges. The weight measurement method we developed is a weigh-in-motion (WIM) method that enables measurement of each axle of a tandem-axle truck or other tandem-axle vehicle whose rear axles are no more than 1.3 m apart.

1. Introduction

In recent years, many cases of crack damage in RC slabs of highway bridges have been reported. The mechanism of fatigue deterioration of a deck slab has been elucidated using a wheel load simulation machine[1),2), 3)]. The major factor of fatigue deterioration is repeated wheel loading by heavy vehicles, a mechanism that has been clarified through experiments using the wheel running machines. However, loading data for vehicles passing over deck slabs have not been obtained.

In this study, we installed strain gauges on the underside of the slabs of two bridges in service. The gauges were attached to cracks that had developed from drying shrinkage and that were roughly perpendicular to the bridge axis. After verification of the axle weight of a test vehicle by measuring the strain, we researched measuring calculating the axle weight and elucidating the loading characteristics of heavy vehicle traffic on the two bridges.

2. Selected Bridge

The selected bridge is Azuma Bridge on National Highway 12 (Fig 2.1). The bridge length is 133.0 m and the traffic volume is 36,361 vehicles per day. Of these, 12.8% are large vehicles.

The bridge is actually two bridges that are adjacent to each other. One was constructed in 1969 and has RC slab with three-span continuous steel girder. This is called the new bridge. The other was constructed in 1949 and has RC slab with steel cantilever girder. The bottom surface of this slab is reinforced with steel plate attaching and increased stringers. This is called the old bridge.

Fig. 2.1 Location of Azuma Bridge

3. Measurement Method

3.1 Measurement theory

Based on past studies[4)], axle weight was calculated using the dynamic opening response measured by strain gauges attached to a crack running in the transverse direction on the bottom surface of the slab. The principle of calculating axle load from the response is explained here.

The amount of opening and closing of cracks running in the transverse direction depends on the axle weight and running position of the vehicle. This relationship is expressed as Equation 3.1. The axle weight and running position are independent functions. Therefore, Equation 3.1 can be expressed as Equation 3.2.

$$Y_i = f_i(W, X) \quad (3.1)$$

$$Y_i = k_i \cdot W \cdot g_i(X) \quad (3.2)$$

where, Y_n: response from π gauge of i-th

n: number of a π gauge

W: axle weight

X: distance from the lane mark to the transverse location of the vehicle's left wheel

k_i: conversion coefficient of the π gauge used; in the case that the axle weight is calculated based on the calibration of measured value, then k_n is considered to be included in $g_n(X)$

g_i: influence line of bending strain

$k_i \cdot g_i(X)$ can be expressed as Equation 3.3, and it is known that in the case of RC deck slabs, the order of polynomial (n) is 3 or 4.

$$k_i \cdot g_i(X) = a_0 + a_1 \cdot X + a_2 \cdot X^2 + a_3 \cdot X^3 + \cdots + a_n \cdot X^n \quad (3.3)$$

To determine the unknown constant a_n in Equation 3.3, it was necessary to conduct a dynamic loading test by varying the transverse locations of a vehicle whose axle weight was already known. Once the influence line function is determined, the influence value can be obtained from the transverse location X and the axle weight W for any of the n gauges, where the response value calculated from Equation 2.2 agrees with the measured response value. However, estimating the axle weight from the measured value of one π gauge should be avoided because the measured values of each π gauge have errors. To minimize the estimation errors, use of the least-squares method is advisable. The transverse location and axle weight of a vehicle when the value of the expression in 3.4 is the smallest is considered to be the most probable value. It is also necessary to obtain the most probable values when the transverse location obtained for two or three wheels of the same vehicle are in agreement.

$$\sum_{i=1}^{j}\left(Y_{mi}-Y_{ei}\right)^{2} \tag{3.4}$$

where, i: gauge number

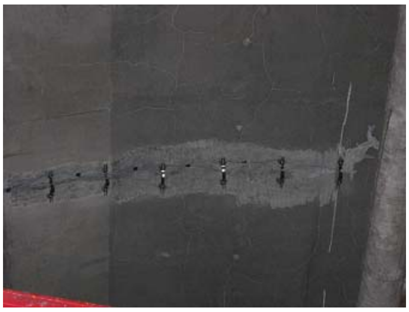
j: number of gauges

Y_{mi}: measured response

Y_{ei}: estimated response

3.2 Dynamic loading test

Six gauges were attached on each bottom surface of the slab as shown in Fig. 3.2.1. In the old bridge, cracks on the bottom surface were covered with steel plate. Therefore the authors focused on the joint of the steel plate.



(a) New bridge

(b) Old bridge

Fig. 3.2.1 Gauges on the bottom surface of the slab

A dynamic loading test using a dump truck with three axles whose weights are known was conducted to obtain the influence line function $g_n(X)$. The details of the test vehicle are shown in Table 3.2.1.

Table 3.2.1 Axle weight of the test vehicle

		Results of weighing
Axle weight	Front axle	49.932 kN (5.04 t)
	Rear two axles	164.052 kN (16.74 t)
Total weight		218.736 kN (22.32 t)

On the test lanes, white lane markings near the wheel guards were used as the base lines for location measurement. On the new bridge the base line was 920 mm from the wheel guard, and on the old bridge the base line was 850 mm from the wheel guard. On the test lanes, lines parallel to the base line were drawn at transverse intervals of 10 cm. The transverse passing locations were changed for each test run and the location was observed using the lines. The running position of the test vehicle, determined as the location of the outer edge of the rear left wheel, was recorded to the nearest 5-cm interval. Measurements were done for the traffic lanes on both bridges.

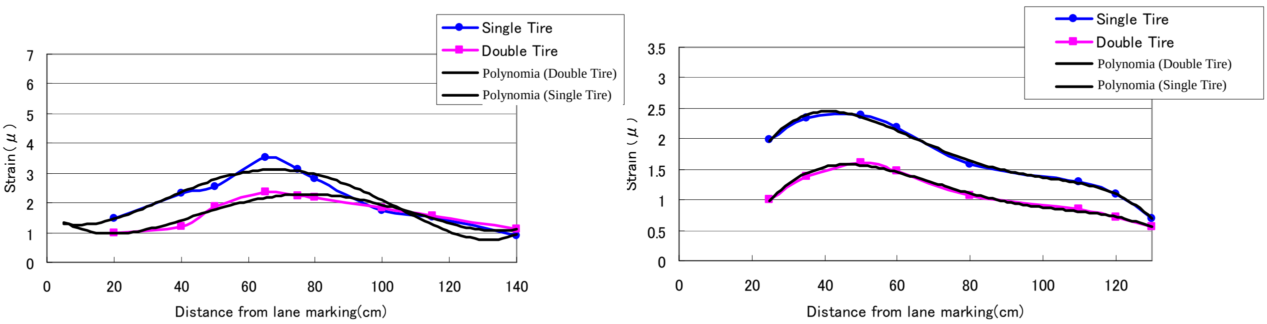
After dynamic loading test, the authors conducted 48-hour continuous observation of heavy-vehicles and running position on the test lanes.

4. Results

4.1. Results of calibration test

Fig. 4.1.1 shows the influence line obtained by one gauge. The large vehicles have a single tire on the front axle and double tires on the rear axle. Therefore, the influence line should be determined separately depending on the type of tire. The influence line function $g_n(X)$ was obtained by drawing the influence line for each gauge in the dynamic loading test and providing the approximated curve of strain vs. wheel location.

This function was approximated by a 4^{th}-order polynomial for both front and rear axles. For the rear axle response values, the two axles of the tandem were averaged. As shown in this figure, in the old bridge, the influence line is well approximated by the polynomial. Therefore, the authors were able to use the response value of the steel plate joint instead of the response value of the crack occurring in the transverse direction on the bottom of the slab.



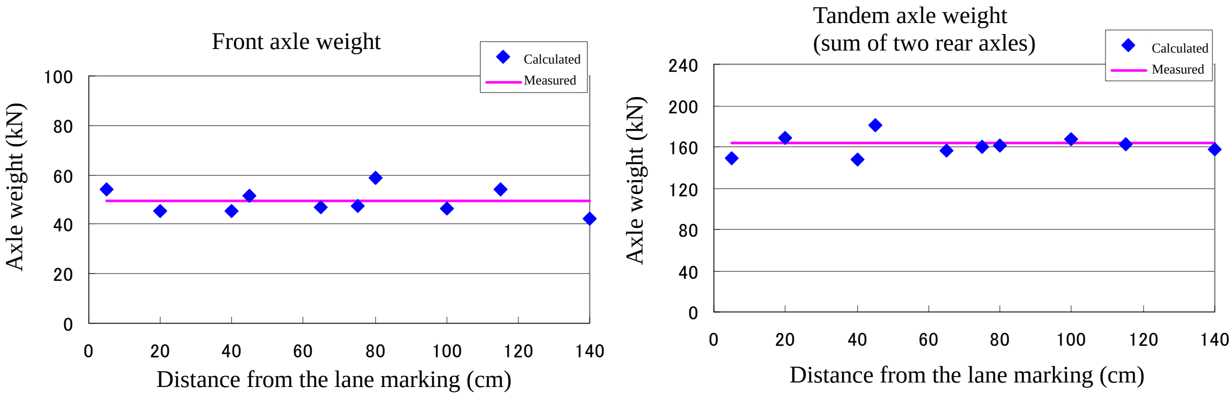
(a) New bridge (b) Old bridge

Fig.4.1.1 The influence line

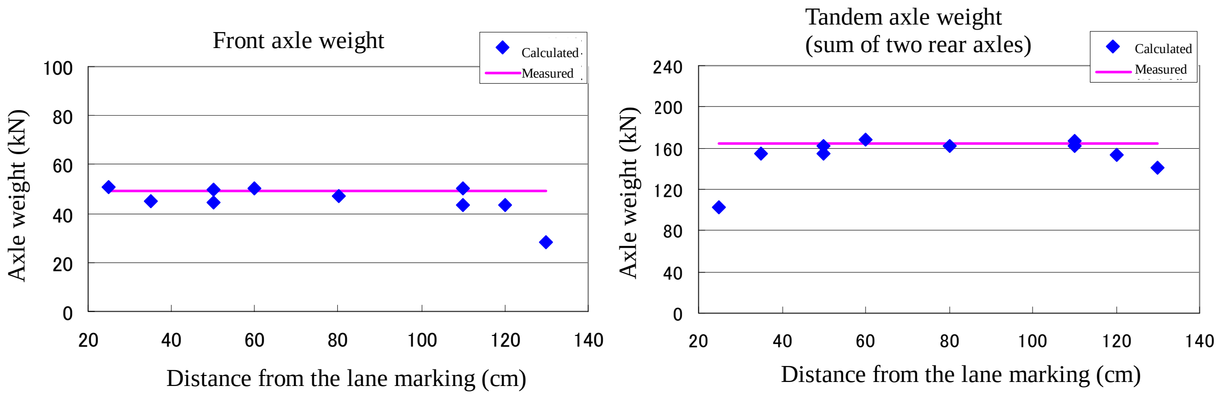
4.2 Accuracy of the influence line function

To determine the accuracy of the influence line function $g_n(X)$ obtained through the dynamic loading test, the axle weight calculated from the theory presented in Section 3.1 was compared with the measured weight of the test vehicle.

Fig. 4.2.1 compares the calculated weight and measured weight of the front axle and the tandem axle.



(a) New Bridge



(b) Old Bridge

Fig. 4.2.1 Comparison between calculated weight and measured weight

4.3 Determining the sensitivity limit

Comparison of the measured and calculated axle weights found the errors to be within roughly 10%. However, on the old bridge considerable error was observed at 25 cm and 130 cm from the lane marking.

The gauges showed the maximum strain response when the wheel passed directly above them. Near the point directly above the gauge, these response values changed considerably with even slight changes in the transverse location of wheel. But when the transverse location of wheel was far from the point directly above the gauge, the response value became low and the changes in response value caused by the changes of wheel location became small. This suggests that it is possible for the estimation accuracy to be low when the wheel location differs greatly from the point directly above the gauge.

On the new bridge the gauge attached at the farthest point downstream was near the point directly under the lane marking, but on the old bridge, because of the underside structure of the deck slab, the gauge attached at the farthest point upstream was far from the lane marking. This distance of the gauges from the lane marking can be considered the major reason for the errors in calculated axle weights of the test vehicle that passed at 25 cm from the lane marking on the old bridge.

It is assumed that vehicles will tend to travel in a certain area of the lane. When the location of a passing vehicle deviates greatly from that assumed area, it is possible that the data obtained from gauges for that vehicle will contain a large degree of error and that the problematic data will need to be discarded. To eliminate erroneous data, it is necessary to determine a sensitivity limit for locations of passing vehicles.

It is often impossible to pass locations 120 cm or more from the lane marking, because when the outer edge of the left tire is passing that location the right tire of a truck 2.4 m in width or so is at or over the center line. Therefore, the likelihood of a vehicle passing such a location can be considered to be low.

Based on considerations of limits of passing locations and of accuracy, we needed to determine an appropriate range of vehicle passing location and eliminate data of vehicles that deviated from that range.

Figure 4.3.1 shows the estimated locations of passing vehicles observed during the 48-hour continuous measurement.

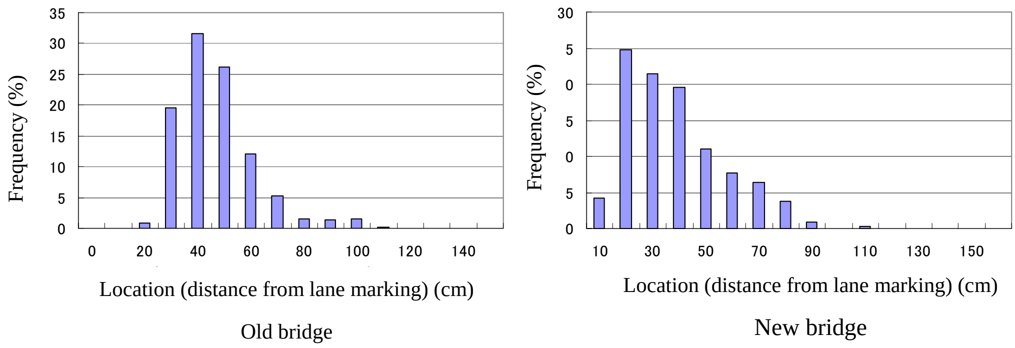


Fig. 4.3.1 Running position of vehicles from lane marking

By considering the average width of heavy vehicles, the limit for passing location was found to be about 110 cm from the lane marking on the old bridge, and about 90 cm on the new bridge. Judging from the recorded frequency of passing location in Figure 4.3.1 and the measurement accuracy understood from Figures 5.2.1 and 5.2.2, the sensitivity limit for passing location was set at 30 – 100 cm for the old bridge and 10 – 90 cm for the new bridge.

5. Results of 48-hour continuous observation

Large commercial vehicles observed during the 48-hour continuous measurement numbered 892 on the new bridge and 696 on the old bridge. Table 5.1 details the vehicles observed. Fig. 5.1 shows the distribution frequencies of axle load and Fig. 5.2 shows the distribution frequencies of total weight.

From Figure 5.1 it was found that the frequency distribution of axle weight has a lognormal distribution whose peak is around 4 tons, and from Figure 5.2 that the frequency distribution of the total weight has a lognormal distribution whose peak is around 10 tons. The share of vehicles heavier than the legal axle weight of 10 t was 11.2 %, and the share of vehicles whose design load exceeded 25 t was 4.4 %.

The frequency distribution of each axle weight and the frequency distribution of total weight are shown in Figure 5.3 for two-axle vehicles and Figure 5.4 for three-axle vehicles. From the frequency distribution for each axle it is found that the distribution pattern is bimodal for either of the vehicle types. This bimodality can be considered the result of the distribution of loaded and empty vehicles.

Table 5.1 Types and numbers of vehicle observed

Type	Number observed			Occupancy ratio
	New bridge	Old bridge	Subtotal	(%)
2-axle vehicle	762	536	1298	81.74
3-axle vehicle	84	118	202	12.72
4-axle vehicle	41	39	80	5.04
5-axle vehicle	4	2	6	0.38
6-axle vehicle	1	1	2	0.13
Total	892	696	1588	100.00

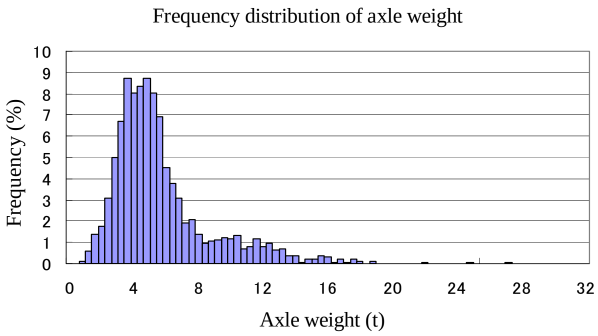


Fig. 5.1 Distribution frequencies of axle load

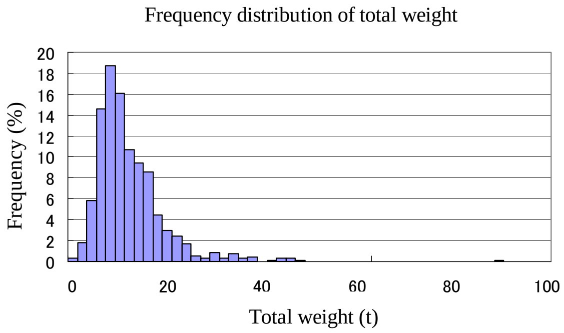


Fig. 5.2 Distribution frequencies of total weight

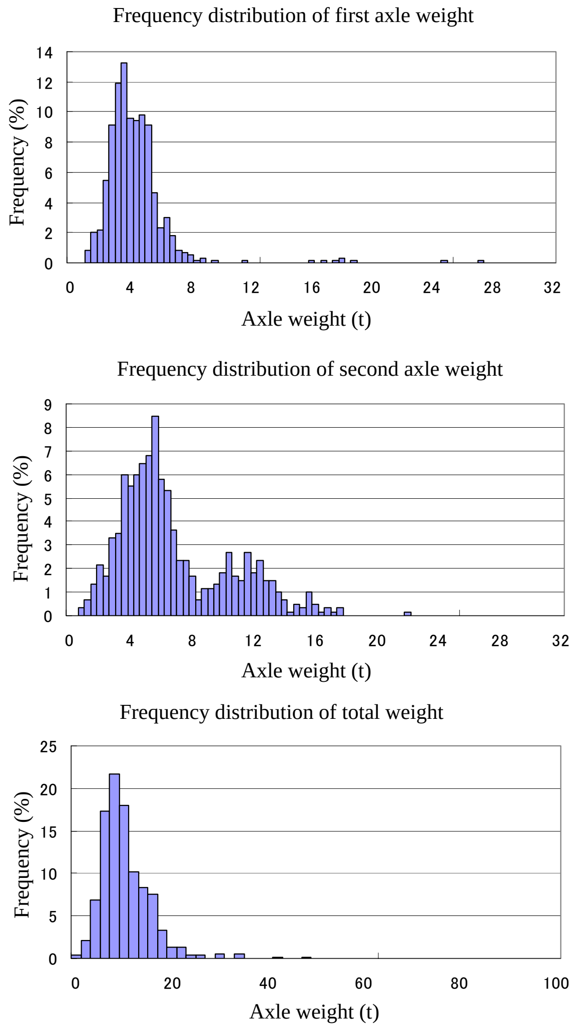


Figure 5.3 Frequency distribution of each axle weight (two-axle vehicles)

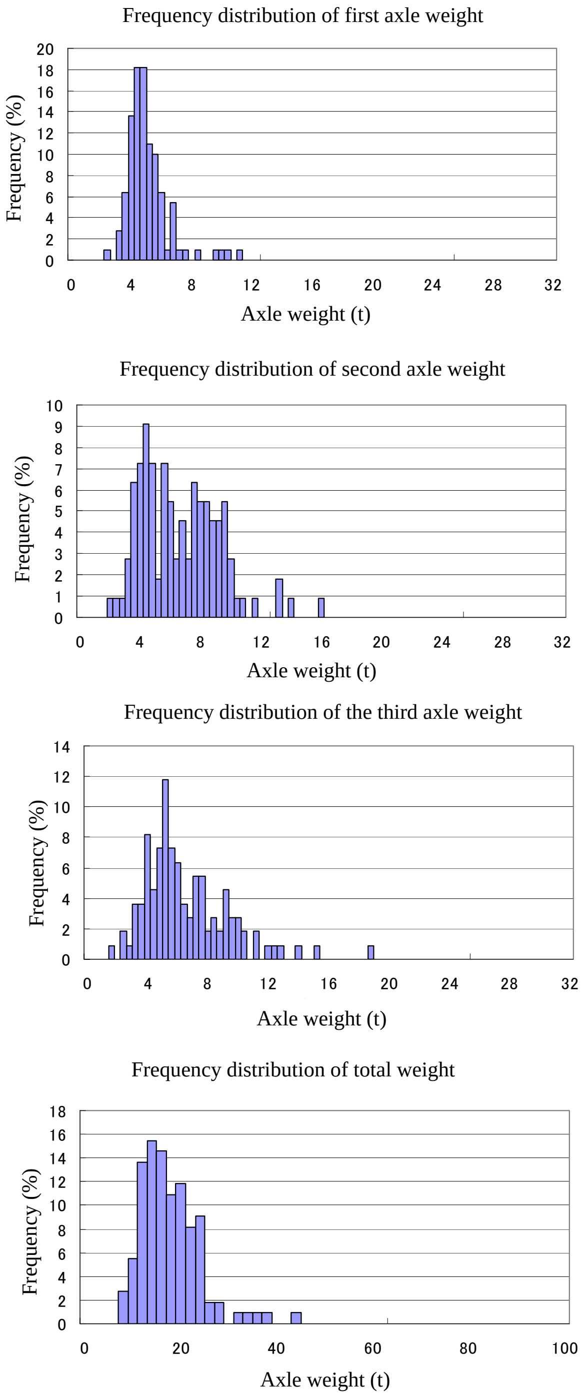


Figure 5.4 Frequency distribution of each axle weight (three-axle vehicles)

6. Summary

We conducted a dynamic loading test on Azuma Bridge on National Highway 12 and obtained the influence line function. We conducted 48-hour continuous observation using the measurement method explained in Section 3.2, and estimated the axle weights, total weights and locations of passing vehicles. We determined the range for vehicle passing locations and eliminated data for vehicles that passed outside that range.

Approximately 80% of vehicles that passed over the bridges in this study were two-axle vehicles, which shows that the route has a small volume of heavy commercial vehicle traffic. This is attributable to the fact that Hokkaido, which lacks the many industrial areas found in metropolitan Osaka and other parts of Japan, does not have a large volume of heavy commercial vehicle traffic. Although vehicles whose design load exceeded TL-25 accounted for only 4.4% of all vehicles, the influence of these vehicles on fatigue of bridges cannot be ignored. The characteristics of each axle weight for two-axle and three-axle vehicles were determined through graphs for frequency distribution of axle weight for each axle. For vehicles of four or more axles, we did not create frequency distribution graphs, because such vehicles were few.

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