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Authors(s)	O'Brien, Eugene J., Quilligan, Michael, Karoumi, Raid
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Eugene J. O'Brien
Professor of Civil
Engineering, University
College Dublin, Ireland

Michael J. Quilligan
Bridge Engineer,
Mott MacDonald,
Croydon, UK

Raid Karoumi
Associate Professor, Royal
Institute of Technology,
Stockholm, Sweden

Calculating an influence line from direct measurements

E. J. O'Brien MEngSc, PhD, CEng, FIEI, MStructE, M. J. Quilligan MEngSc, LicEng and R. Karoumi PhD

The response of a bridge to a pre-weighed truck can be measured on site. This paper describes a mathematical method for converting the measured response of a load effect into an influence line for that effect. One influence ordinate is calculated for each scan of the data acquisition system. The vector of ordinates is found by solving a large set of simultaneous equations expressed in matrix form. The general form of the matrices is described, and the particular matrices for a three-axle truck are given. The technique is demonstrated using measured strain on two bridges using pre-weighed trucks with different numbers of axles.

NOTATION

A	vehicle axle weights
L_k^M	measured load effect in k th scan
L_k^T	theoretical load effect in k th scan
C_i	number of scans
D_i	distance in metres between axle i and the 1st axle
ε_k	measure strain in k th scan
E	error function
f	scanning frequency of data acquisition unit
I_R	R th influence line ordinate
K	total number of scans
N	number of axles in vehicle
v	vehicle velocity
W	matrix dependent on vehicle axle weights
w_{ij}	component of matrix W

1. INTRODUCTION

The influence line (IL)—the load effect at a point due to unit load at different positions across a bridge—is a useful measure of the characteristic response of the bridge to load. Although ILs can readily be found by analysis, the results often do not correspond to measurements on site, and it is sometimes useful to derive the IL from direct measurements of the load effect in response to a vehicle of known weight. As vehicles invariably have more than one wheel, this paper describes a method to determine the IL from the measured multi-wheel response. In existing bridges such so-called ‘measured’ ILs can be used to determine and understand the real behaviour, to monitor changes over time, to accurately predict responses to various load patterns and to calibrate a bridge weigh-in-motion system.

Žnidarič *et al.*¹ propose revising a theoretical influence line by adjusting the support conditions and smoothing the peaks interactively to achieve better conformity with the real situation. This has been implemented in the proprietary SiWIM Bridge Weigh-in-Motion software. McNulty^{2,3} and O'Brien³ describe a ‘point-by-point’ graphical method of deriving the influence line from the bridge response to a calibration truck. However, this method is manual, and the accuracy is a function of the skill of the operator.

2. EXPRESSION FOR INFLUENCE ORDINATES

When a calibration truck with known axle weights, A_i , crosses a bridge, it results in a series of measurements of the load effect, L_k^M , one for each scan, k . The corresponding theoretical load effect caused by the calibration truck, is given by

$$1 \quad L_k^T = \sum_{i=1}^N A_i I_{(k-C_i)}$$

where N is the number of axles, I is an influence ordinate, and C_i is the number of scans corresponding to D_i , the distance between axle i and the first axle, given by

$$2 \quad C_i = \frac{D_i f}{v}$$

where f is the scanning frequency of data acquisition, and v is the vehicle velocity. Vehicle velocity is measured during calibration and should be as constant as possible. An error function equal to the sum of the squares of the differences between the measured, L_k^M , and theoretical, L_k^T , load effects has been defined by Moses⁴ as

$$3 \quad E = \sum_{k=1}^K (L_k^M - L_k^T)^2$$

where K is the total number of scans.

The starting-point for the influence line is usually taken as a fixed reference—for example, the instant the first axle reaches a specified point prior to the bridge. There is no need to know the exact position at which the applied load causes the bridge to start bending. Therefore the uncertainty surrounding the real boundary conditions and the very small strains generally induced near the supports is avoided.⁵

(a)

(b)

Fig. 1. Field trials: (a) Östermalms IP bridge; (b) Kramfors bridge with seven-axle calibration truck

In this case, there are small differences between measured and predicted results (Fig. 3(b)), probably due to the increased number of axles. Nevertheless, the match between measured and predicted strains is very good.

Fig. 2. Östermalms IP bridge: (a) response due to the crossing of a three-axle calibration truck with the calculated influence line (scaled for presentation purposes); (b) plot of measured against predicted response

Fig. 3. Kramfors bridge: (a) response due to the crossing of a seven-axle calibration truck with the calculated influence line (scaled for presentation purposes); (b) plot of measured against predicted response

4. CONCLUSIONS

A matrix equation is presented for the calculation of influence ordinates for a bridge from measured load effects. The method is shown to be very effective at finding the IL directly from strain measurements, particularly for two- and three-axle calibration trucks.

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