SITE-SPECIFIC PROBABALISTIC BRIDGE LOAD ASSESSMENT

E.J. O'Brien[1], C.C. Caprani[1], A. Žnidarič[2], M. Quilligan[3]

[1] Department of Civil Engineering, University College Dublin, Ireland.
[2] Slovenian National Building and Civil Engineering Institute, ZAG, Ljubljana, Slovenia.
[3] Royal Institute of Technology, Stockholm, Sweden.

ABSTRACT

The assessment of loading is identified as a great source of uncertainty in any bridge assessment. Notional loading models, used for assessment in some countries, are necessarily conservative as they are valid for a wide range of loading conditions. This paper focuses on the calculation of site-specific characteristic load effects. Loading simulations, using traffic weight and volume statistics collected on site, are checked using direct measurement of strain on a bridge. The simulations are shown to be effective but sensitive to the period simulated.

KEYWORDS: Bridge, assessment, traffic, load, loading, site-specific, WIM, weigh-in-motion, simulation, Gumbel.

1. INTRODUCTION

In recent years, increasingly sophisticated approaches to the assessment of bridges have emerged in an effort to minimise unnecessary repair or replacement. Considerable attention has been given to the assessment of the load carrying capacity of existing bridges and it is possible to assess carrying capacity reasonably accurately. However, particularly in less heavily trafficked bridges, there is often greater potential for savings in an accurate assessment of the actual traffic loading at the bridge site. In some countries such as the United Kingdom, a notional assessment traffic load model is specified. However, such models are necessarily conservative as they are deemed to represent a wide range of traffic conditions. Bridges can often be shown to be safe for the traffic loading to which they are subject, even if they do not have the capacity to resist the notional assessment load.

Traffic loading can be determined from statistics of traffic weights, frequencies and mix and numerical modelling of truck crossing and meeting events. Recent advances in the accuracy and durability of WIM technology has greatly improved the accuracy of truck and axle weight statistics (Jacob et al. 2002). O'Connor et al. (2002) have looked at the sensitivity of bridge loading to the accuracy of the original weight measurements and have stated that Class C accuracy, as determined from the COST 323 specification (Jacob & OBrien, 1998), is sufficient for bridges of up to 50 m span. To aid the original loading studies that were performed for Eurocode 1, Part 3, Eymard & Jacob calculated the effects induced in a bridge by the passage of traffic loads and performed a statistical analysis of these effects. More recently Bailey (1996), Grave et al. (2000) and Caprani et al. (2001) have developed alternative methods of simulating traffic loading.

The statistical theories utilised in extrapolating data representing relatively short periods of time (normally around two weeks) to the return period required (1000 to 3500 years), are well established (Fisher & Tippett 1928, Gumbell 1958). However it was not until recently that these theories were applied to the modelling of traffic loading on bridges.

For this paper, statistical data was collected using SiWIM, a Bridge weigh-in-motion system developed in Slovenia (Žnidarič et al. 1999, Žnidarič et al. 2002). This data was collected as part of a safety assessment of a two-lane bridge structure in the city of Vienna. The SiWIM system provided site-specific, continuously recorded data on truck weights, speeds, time of arrival and axle configuration as well as strains directly measured on the main beams of the bridge.

In this paper, the authors present the results of a sensitivity study on the influence of the quantity of traffic modelling data available, on the characteristic 1000-year bridge beam strain. These results are compared to results obtained by directly extrapolating from the measured strains.

2. FIELD MEASUREMENTS

The SiWIM weigh-in-motion system was installed on a simply supported, reinforced concrete beam-and-slab bridge on National Road No. B224 in the 23rd district of Vienna, Austria. The crossing consists of two independent bridges, one built in 1953 and the other in 1961 (see Fig. 1). Each bridge has two lanes and the flow of the traffic is unidirectional. The traffic volume on each bridge is approximately 62 000 vehicles per day of which 2 500 are trucks. The measurements were performed on the bridge constructed in 1953 which has four main longitudinal beams and transverse diaphragm beams at mid-span and at the supports. The total length of the bridge is 14.32 m and the total width is 10.2 m (Fig. 2). The main beams are 1.13 m deep × 0.5 m wide. The beams carry the reinforced concrete bridge slab which is 200 mm deep.

(a) General view of bridge

(b) Main longitudinal beams and mid-span diaphragm

Fig. 1. Instrumented Bridge in Vienna

This SiWIM installation consisted of pneumatic axle detectors on the road surface and strain transducers on the beams underneath. The axle detection used in this installation consisted of parallel road hoses at two locations, separated by a distance of 4 m, plus a diagonal road hose to determine transverse truck location (Fig. 3). The road hoses are not durable but are suitable for a temporary installation such as this one.

Strain transducers were attached in pairs to the bottom flange of each longitudinal beam at 4 locations near the mid-span of the bridge. The mean strain from the two transducers was deemed to represent the strain for each beam. Transducers were fixed using 2 holes per sensor, by inserting steel anchors and using washers and bolts.

The axle detectors and transducers were connected to a data acquisition system which was linked to a personal computer. Installation of this equipment took about half a day with calibration of the system taking a further 2 hours in free flowing traffic conditions.

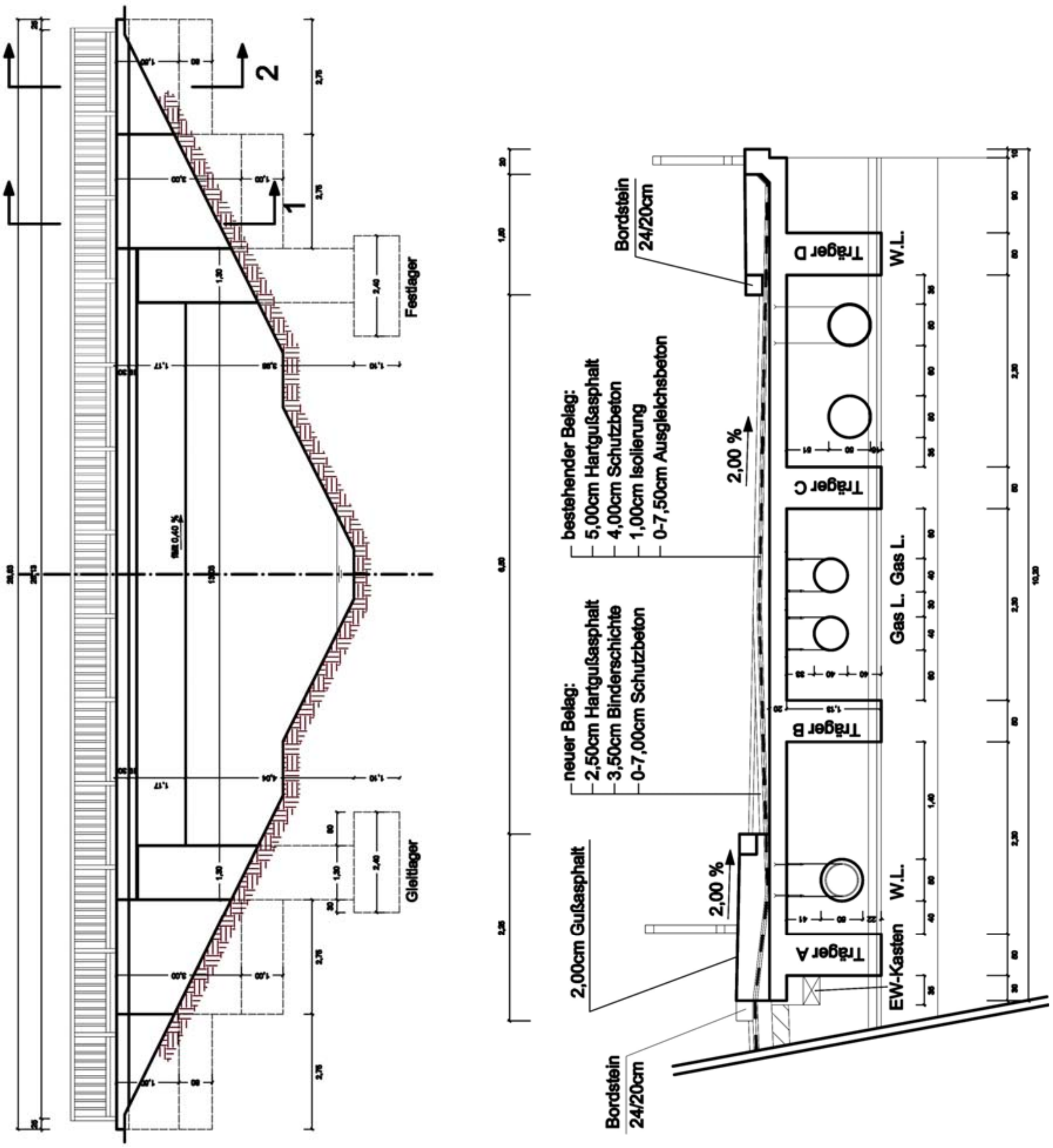

Fig. 2. Elevation and cross-section of the bridge (after Eichinger 2002)

This weigh-in-motion system has been compared to a range of other weigh-in-motion technologies and has been found to give similar levels of accuracy in a wide range of climatic conditions (OBrien et al. 2002).

A three-axle truck was used for the calibration with axle weights of 8.75 t, 8.05 t and 7.85 t for the first, second and third axles respectively and spacings of 3.85 m and 1.40 m. A significant bouncing effect was observed due to the roughness of the road surface which may have influenced the accuracy of the calculated static axle loads. Several calibration runs were made in the first and second lane with different speeds. After calibration, data was collected over a four day period. A total of 16 663 trucks were identified.

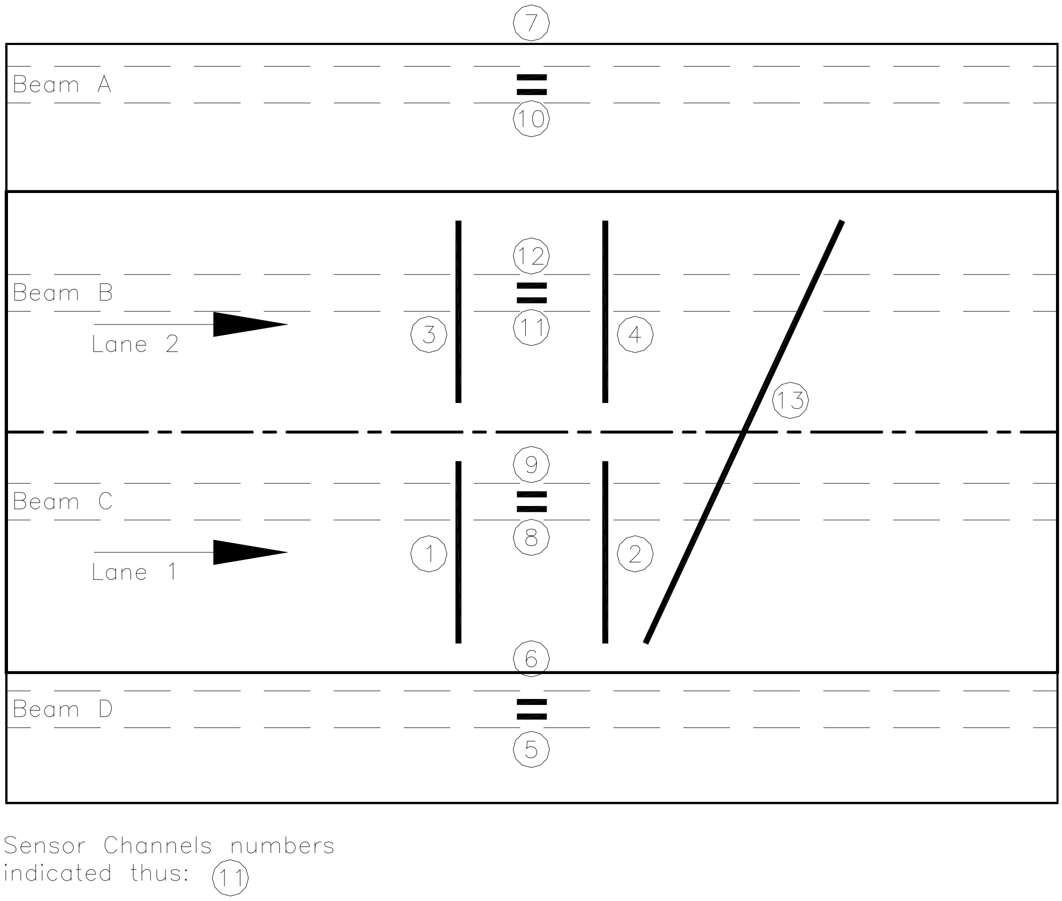

Fig. 3. Schematic layout of channels and beams

3. TRAFFIC SIMULATION

Traffic simulations were performed using computer programs developed in Dublin (Grave et al. 2000, Caprani et al. 2001) to determine the characteristic values of strain at three locations – the mid-spans of Beams A, B and C in Fig. 3. For such a structure it is known that the free flowing traffic in two lanes will govern the extreme (O'Connor 2001). No dynamic amplification was applied to the calculated strains. For bridge assessment purposes, a dynamic factor should be applied to the characteristic static strains to allow for dynamic interaction between the vehicle and the bridge.

The traffic data was analysed to determine the parameters of the statistical distributions that characterise that traffic flow (Grave et al. 2000). Monte-Carlo simulation was used to generate a traffic file whose statistical distributions closely matched those of the measured data.

Simulations were carried out using the generated traffic files. In order to minimise the processing requirements, events with combined gross vehicle weight (for all vehicles) in excess of 30 tonnes were identified and only in these situations were further calculations performed. The simulations used influence lines to calculate the value of the load effects for any position and arrangement of truck(s).

The load effect (strain) caused by the passage of trucks is a random variable and the results of the calculations of all the events noted above gives a parent population of an undetermined statistical distribution. The extrapolation from the sampling periods to the 1000 year return period is achieved using Extreme Value statistics. The maximum hourly load effect was taken as the basis for the Extreme Value distribution population. These hourly maxima are themselves random variables conforming to an Extreme Value distribution (Ang & Tang 1975, Castillo 1991, OBrien et al. 1995).

The maximum load effects per hour were assumed to comply with the Extreme Value Type I (Gumbel) distribution. Fig. 4 illustrates Gumbel plot for Beam B. In this case the number of data points is 211 and the distribution is fitted to the tail, taken to consist of the 29 greatest strains. The linearity of the plot in the tail region is evidence of a reasonable approximation to a Gumbel distribution.

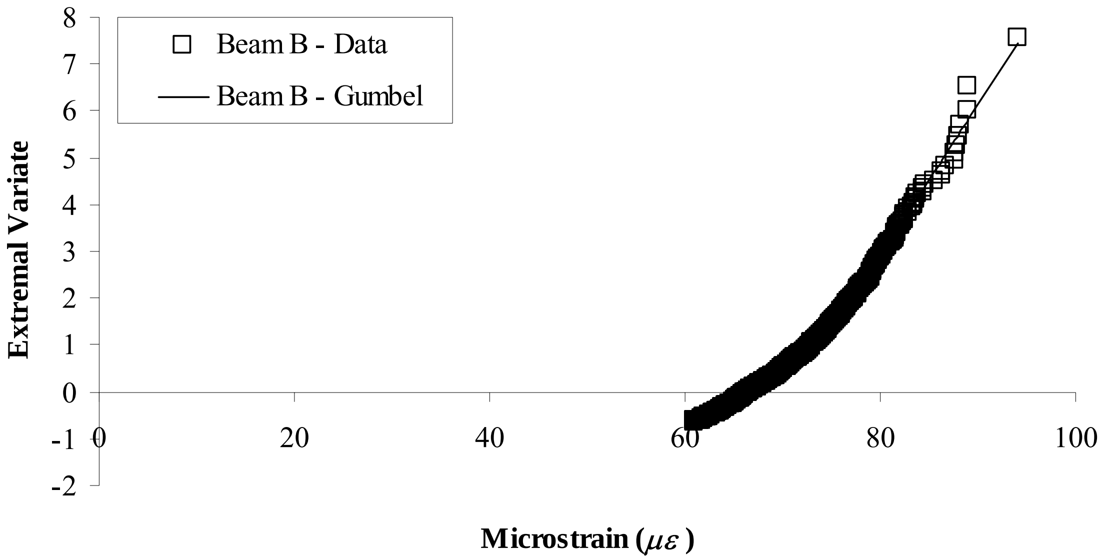

Fig. 4. Beam B, 60 day simulation period

5. RESULTS

Simulations were performed for various time periods. For each period 5 runs were made to investigate the variation in the extrapolated extremes from the different runs. All the simulation run results were then extrapolated using Extreme Value statistics to give the characteristic 1000 year return period strain value. It is expected that, due to the nature of the extrapolation process, the variation in the predicated extremes should reduce as the sampling period increases.

Each strain sensor on the bridge has two influence lines of interest, one for each lane in which a truck may be travelling. In this paper Beams A, B and C (refer to Fig. 3) are considered and thus six influence lines are required – named *bi*, where *b* is the beam letter and *i* is the lane number of the truck under consideration.

The direct strain measurements used to assess the accuracy of the simulation process were the maximum strains from the 20 most critical loading events. These recordings are statistically extrapolated using Extreme Value theory to generate the expected 1000 year return period strains. Some of the 20 maximum strains were induced by a truck overtaking another truck on the bridge. The Bridge weigh-in-motion system used was not calibrated to obtain the axle weights when more than one truck was present on the bridge. Therefore, in the case of 6 of the 20 critical loading events, the weights of trucks involved were not calculated and are missing from the truck weight statistics.

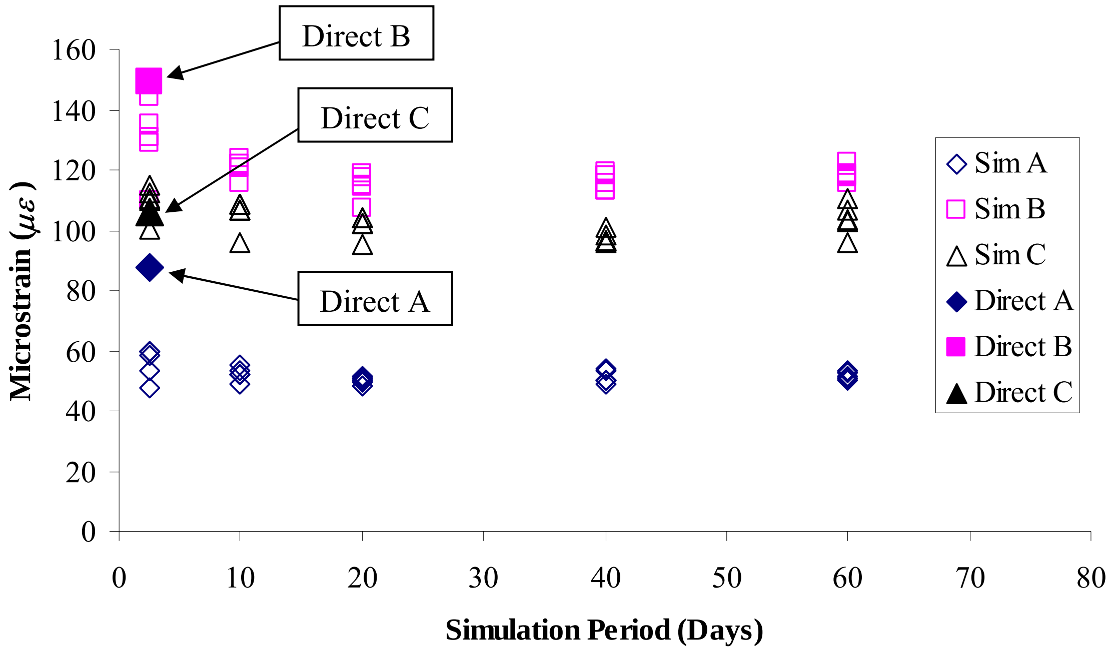

Fig. 5. Results of simulations and direct measurements

The 20 maximum loading events represent a period of measurement of 91 hours. As this period is relatively short, it is to be expected that the predicted extremes will have a large coefficient of variation. Fig. 5 gives characteristic strains for the simulations based on a range of time periods, together with the corresponding values determined from the direct measurements.

For Beam C, which is underneath the slow lane (Fig. 3), the simulations give reasonably consistent results, regardless of the period of time simulated. There is also good agreement with the results of the direct measurement. There is a deviation of up to about ±10% between runs. Surprisingly, this variation does not seem to diminish significantly with the period simulated.

For Beam B, under the fast lane, the results are more variable. However, the results do appear to converge with increasing time of simulation. The results are not in good agreement with the results from direct measurement but this is unsurprising given the short period of measurement. Strains in this beam are more sensitive to trucks travelling in the fast lane for which there was a limited amount of statistics.

The results for Beam A, in the shoulder outside the fast lane, are reasonably consistent and appear to converge with the period simulated. However, there is considerable variation from the results of direct measurement.

6. CONCLUSIONS

The process of collecting traffic weight and volume statistics and the simulation of loading events to determine the characteristic strain in a bridge beam is demonstrated and tested by direct measurement. Traffic load simulation is shown to be an effective technique. However, results were found to be sensitive to the period of time simulated.

Direct measurement of strains on the bridge are also used to obtain a calculation of the characteristic strain. Despite a short period of measurement, the results are reasonably consistent with the results of the simulations.

It can be concluded that traffic load simulation is a useful means of determining site-specific characteristic load effects which can be used for bridge assessment. However, results should be used with caution as they can be sensitive to the period of time simulated.

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