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DIRECT MEASUREMENT OF DYNAMICS IN ROAD BRIDGES USING A BRIDGE WEIGH-IN-MOTION SYSTEM

Eugene J. OBrien[1], Arturo González[2], Jason Dowling[3]✉, Aleš Žnidarič[4]

[1, 2]*School of Civil, Structural and Environmental Engineering, University College Dublin, Belfield, Dublin 4, Ireland*
[3]*Dept of Civil Engineering, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada*
[4]*Slovenian National Building and Civil Engineering Institute, ZAG, Dimičeva 12, 1000 Ljubljana, Slovenia*
E-mails: [1]*eugene.obrien@ucd.ie;* [2]*arturo.gonzalez@ucd.ie;* [3]*jadowlin@mail.ubc.ca;* [4]*ales.znidaric@zag.si*

Abstract. A method is presented of measuring a bridge's characteristic allowance for dynamic interaction in the form of Assessment Dynamic Ratio. Using a Bridge Weigh-in-Motion system, measurements were taken at a bridge in Slovenia over 58 days. From the total observed traffic population, 5-axle trucks were extracted and studied. The Bridge Weigh-in-Motion system inferred the static weights of the trucks, giving each measured event's dynamic increment of load. Theoretical simulations were carried out using a 3-dimensional vehicle model coupled with a bridge plate model, simulating a traffic population similar to the population measured at the site. These theoretical simulations varied those properties of the 5-axle fleet that influence the dynamic response; simulating multiple sets of total (dynamic + static) responses for a single measured static strain response. Extrapolating the results of these theoretical simulations to a 50-year Assessment Dynamic Ratio gives similar results to those obtained by extrapolating the data measured using the Bridge Weigh-in-Motion system. A study of the effect of Bridge Weigh-in-Motion system errors on the predictions of *Assessment Dynamic Ratio* is conducted, identifying a trend in the Bridge Weigh-in-Motion calculations of maximum static response. The result of this bias is in turn quantified in the context of predicting characteristic maximum total load effect.

Keywords: bridge, dynamics, Assessment Dynamic Ratio, soft load testing, Vehicle Bridge Interaction, Weigh-in-Motion (WIM).

1. Introduction

The allowance for dynamics in the design of short to medium span bridges is well documented and is appropriately conservative, as shown in the *Dynamic Interaction of Heavy Vehicles with Roads and Bridges*-(DIVINE) project of 1997, the AASHTO *LRFD Highway Bridge Design Specifications* and by Bhattacharya *et al.* (2005). This is in part due to the wide variety of considerations and circumstances that need to be considered in standards and codes of practice. There has been much effort devoted to the study of the dynamic response of bridges to the passage of moving vehicles (Kim *et al.* 2005; Law, Zhu 2005). Recent work in the *SAMARIS 2006: Guidance for the Optimal Assessment of Highway Structures* project and OBrien *et al.* (2009) has shown that a site-specific provision for dynamics in bridge assessment may be much less than, for example, that of the *EN 1991-2 Eurocode*: *Actions on Structures – Part 2: Traffic Loads on Bridges*, while achieving the prescribed levels of safety. This is particularly significant for the assessment of existing bridges which may be unnecessarily replaced because of an excessively conservative approach. This paper proposes the use of a Bridge Weigh-in-Motion (Bridge WIM) system to measure directly a site-specific dynamic factor. Bridge WIM is the technology of using sensors on an existing bridge to weigh the trucks that cross over it. Recording the weights of vehicles for a relatively short time period (58 days), a characteristic, site-specific allowance for dynamics is calculated.

Dawe (2003) and others (Chatterjee 1991; Zhang *et al.* 2000) make use of Dynamic Amplification Factors (DAFs) in their provisions for the dynamic increment of load effect. This paper uses an alternative measure of dynamics, Assessment Dynamic Ratio (ADR), defined by OBrien *et al.* (2009) as the ratio of characteristic total (static + dynamic) load effect to the characteristic static load effect. In general, different loading scenarios govern the characteristic total and characteristic static effects. In no previous study has this measure of dynamics been measured directly.

This paper presents the results of an analysis of strain measurements taken during vehicle crossing events on a bridge near Vransko in Slovenia, as part of the Work Package 2 of the 6th Framework project *Assessment and*

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Rehabilitation of Central European Highway Structures (ARCHES) and the results of a numerical plate model, simulating vehicle crossing events for a traffic population similar to that at the Vransko site. The influence of the errors in the Bridge WIM system predictions of static axle weights, and the resulting errors in maximum static load effect, are considered. In the case of both the measured and the numerically simulated vehicle crossing events, the feasibility of directly measuring ADR is demonstrated. The direct measurement of a characteristic ADR value is novel and the consideration of the errors (and resulting bias) in the Bridge WIM system calculations demonstrate the ability of the proposed method to predict accurate results.

The primary objective of this work is to demonstrate that it is feasible and indeed quite practical to measure directly a site-specific and accurate allowance for dynamics in the form of an ADR value. It is shown that the relatively short period of a couple of months (58 days have been used here) of data is required, coupled with numerical simulation.

2. Measured ADR

2.1. The Bridge WIM system

SiWIM (Slovenian Weigh-in-Motion) is a Bridge WIM system developed by the Slovenian National Building & Civil Engineering Institute, ZAG and manufactured by the company Cestel. The purpose of a Bridge WIM system is to find static axle and gross vehicle weights but it is used here to also measure total (static + dynamic) strains. Strain sensors, attached to the bridge soffit around midspan, are used to record strains as the vehicles pass overhead. The physical make-up of the system comprised ten (two on each of the five beams) strain sensors attached to the underside of the bridge, and master processing unit with a modular data acquisition module, a computer and a communication (GSM) module was located at the support to carry out the processing work. The installation was a Nothing-on-the-Road (NOR) system, as first reported by ZAG in the report of Work Package 1.2 of the 4th Framework project *Weighing-in-Motion of Axles and Vehicles for Europe (WAVE)*. As such, it did not include any axle detectors on or in the pavement to calculate vehicle inter-axle spacing and velocity. As an alternative to such surface mounted equipment for axle detection, additional strain gauges were used, one mounted upstream and one downstream of midspan (per instrumented lane). Using the recorded strains and the axle spacing and velocity

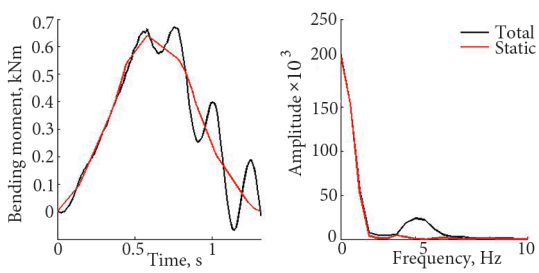

Fig. 1. Time and frequency domain bending moment responses

information gathered using the two off-centre strain sensors, an algorithm based on the concepts first proposed by Moses (1979) calculates the static axle weights of vehicles.

The approach developed by Moses (1979) remains the main constituent of most modern Bridge WIM algorithms. It is based on the assumption that the strain induced in a structure due to the passage of a moving load is proportional to the product of the influence line ordinate and the magnitude of the load. Using a matrix solution technique, the algorithm takes advantage of the fact that there are many measurements available during a crossing event to "smooth out" some of the effects of noise and vibration. Further details are given in the literature (Moses 1979; Rowley *et al.* 2008; Žnidarič *et al.* 2010) and in the final report of the COST 323 action *Weigh-in-Motion of Road Vehicles* published by the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR). In place of the theoretical influence line of the original algorithm, the Bridge WIM system used a "measured" influence line determined during the calibration procedure.

The SiWIM Bridge WIM system filters the measured signal before it is used in the algorithm to infer the static weights. Fig. 1 depicts the time and frequency domain representations of the bending moments of a typical 5-axle truck crossing a 25 m simply-supported bridge. This figure was prepared using the numerical model described in Section 3, making it possible to show both the total and static responses, presented here as bending moments.

The first natural frequency of the bridge simulated here was 4.33 Hz which corresponds to the noticeable "bump" in the total response (frequency domain). If one applies a low-pass filter to the total signal below this frequency, much of the dynamic component of the signal is removed, while keeping the static response, for the most part, intact. In this way, the algorithm removes much of the source of error, the dynamic component. The processed signal, in conjunction with the influence line, is used to calculate the static axle weights. It is of note that the cut-off frequency for the low-pass filter is site-specific or more accurately, bridge-specific, a major contributing factor being the first natural frequency of the bridge. The dynamic component is filtered based on an averaged Fast Fourier Transform (FFT) spectrum of multiple vehicle crossing events. The shapes of the spectra converge rapidly after averaging a few loading events, and generally indicate an optimum frequency cut-off point for the filter.

The estimation of the static axle weights has a degree of error associated with it. The magnitudes of the errors in the on-site system are unquantifiable as no exact static weights were available. Past work (Tierney *et al.* 1996) involving WIM on culverts has found that there is a tendency for the steer axle to be under-estimated. Considering this in conjunction with the knowledge that Bridge WIM systems estimate GVW much better than individual axle weights, it is concluded that there may be some re-distribution of load between the axles in the system predictions. This re-distribution of load has the potential to lead to a

bias in the system's prediction of maximum static load effect resulting from the inferred static axle loads. It is the second axle of a 5-axle articulated truck that typically makes the greatest contribution to the maximum load effect, and if the first axle is underestimated, the resulting re-distribution of load to the other axles would typically cause the second axle to be over-estimated. Hence the maximum static load effect may be overestimated and the DAF significantly underestimated. This is a "non-conservative" tendency or bias in the system and its effect on the Bridge WIM predictions of ADR are investigated in Section 4.

2.2. Site measurements

A bridge at Vransko in Slovenia was instrumented with the SiWIM Bridge WIM system. It is of beam and slab (girder) construction, simply-supported and 24.8 m long between supports. Further details are given in the report of Work Package 2 of the 6th Framework project *Assessment and Rehabilitation of Central European Highway Structures* (ARCHES) available online at http://arches.fehrl.org. A total of 147 524 vehicles were recorded in the period from 25th September to 21st November 2006, in a total of 58 days of measurement. Using the Bridge WIM system, the static axle weights of the recorded vehicles were inferred from the measured strains. Using the recorded strains, which include dynamics, and the inferred static weights, a site-specific ADR value was found for the 58-days.

Articulated 5-axle trucks with a group of three axles (tridem) are used to test this approach as it is the most common vehicle class in the database. Different vehicle classes will have different ADR's. For example, OBrien *et al.* (2010) have shown that heavy cranes tend to have smaller levels of dynamic amplification during crossing events, when compared to 5-axle trucks.

Approximately 74 000 articulated 5-axle trucks were identified in the Bridge WIM database. Fig. 2 shows a histogram of their Gross Vehicle Weights (GVWs).

The most frequent weight is 382 kN and there is a small but significant tail going up to the maximum recorded weight of 582 kN. Combining the measured total and calculated static GVW's of the Bridge WIM system, Fig. 3 shows the DAF values for each of the 5-axle trucks.

The contour plot of Fig. 3 shows the number of DAF values in each GVW range, illustrating the high frequency of low DAF values associated with heavier GVW. For example, the most frequent DAF for the 380–390 kN range is 1.03. The trend shown here, solely for the 5-axle articulated population, is in agreement with the trend for the entire measured vehicle fleet at the site, and also with the trend identified in recent theoretical work by OBrien *et al.* (2009) and others (Huang *et al.* 1993; Kirkegaard *et al.* 1997) and experimental findings discussed by Nowak *et al.* (2003).

ADR is defined as the ratio of characteristic maximum total response (static + dynamic) to characteristic maximum static response. Taking the data of Fig. 3 as n example, the 99.9 percentile characteristic total is 233.4 kN and the 99.9 percentile characteristic static is 232.8 kN,

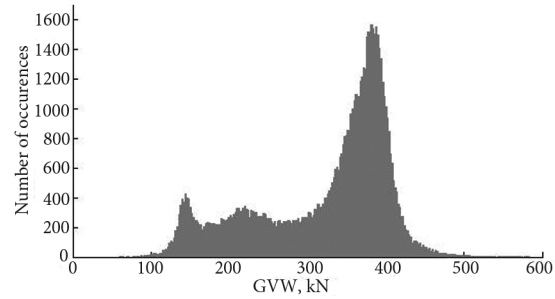

Fig. 2. Histogram of measured GVWs for the 5-axle truck population

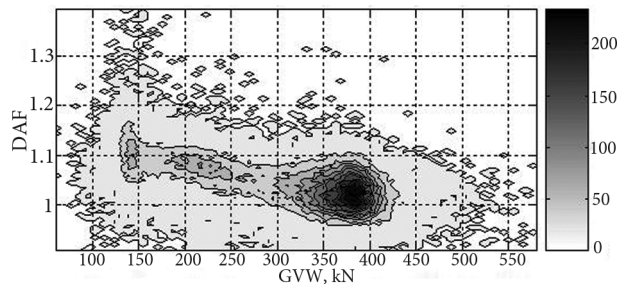

Fig. 3. Contour plot of measured DAF values for mid-span bending moment from the Vransko site

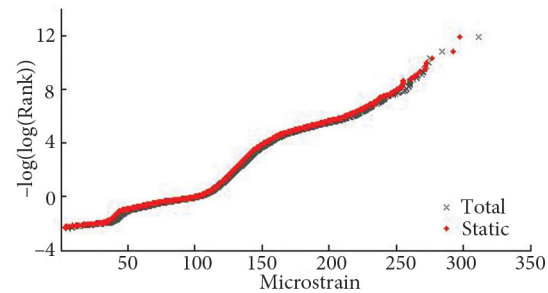

Fig. 4. Gumbel paper plot of measured total and inferred static strains

giving a 99.9 percentile ADR of 1.003. The 99.9 percentile characteristic DAF on the other hand is 1.33. The reason for the difference comes from the fact that the characteristic DAF corresponds to a very light truck and is not an appropriate measure of dynamics for bridge assessment.

2.3. ADR from measurement

Fig. 4 gives the total and static strains from the measurements at the Vransko site in the form of a Gumbel probability paper plot. The changes in curvature evident in the figure correspond to peaks in frequency, suggesting a number of sub-populations in the data. For example, the strains may be the result of a mixture of unloaded and loaded trucks. The most important feature for bridge safety is the curvature of the right hand tail.

In Fig. 5, a straight line is fitted to the Gumbel plot to extrapolate to the level corresponding to a 50 year return period, as an illustration. To perform an accurate risk analysis, a larger data set than the 58 days used here would be required (OBrien *et al.* 2009, for example). Authors have proposed different approaches to determining the number of points to fit in such cases (Cremona

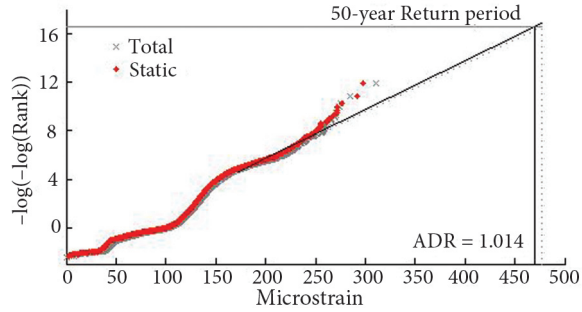

Fig. 5. Extrapolating to 50-year value

2001; Crespo-Minguillon, Casas 1997; OBrien *et al.* 2010). In this case the upper $2\sqrt{n}$ ($2\sqrt{74\ 426} = 545$) data points are used as recommended by Castillo (1988). The resulting characteristic total strain is just 1.4% greater than the characteristic static, i.e., ADR = 1.014.

3. Numerical simulation

The simply-supported bridge at Vransko is in total 26 m long, with a distance between the bearings of 24.8 m; the width is 12 m and there is no skew. It is of beam and slab construction. Rowley *et al.* (2009) describe a Finite Element Model of the Vransko Bridge, which was validated by experimentation, and is the basis for the orthotropic plate model used for the simulations described herein. The model was implemented using *Matlab* software. Properties of the plate model were: plate thickness = 1.46 m, plate density = 1400 kg/m^3, Poisson's ratio = 0.15, longitudinal modulus of elasticity = 35·10^9 N/m^2, transverse modulus of elasticity = 14·109 N/m^2 and the frequency of the first longitudinal mode of vibration was 5.32 Hz.

The vehicles which were simulated numerically were those from the top $2\sqrt{n}$ total strain measurements. The measured axle loads and inter-axle spacings were simulated directly (as opposed to Monte Carlo simulation from histograms from the measured population). Vehicle velocities were taken from the measured distribution at the site. This measured distribution is slightly skewed toward the right (similar to an extreme value distribution). A simple method of modelling the skew in this distribution was chosen, fitting a bi-modal normal distribution with closely spaced modes. Modes 1 and 2 had means of 22.17 m/s and 23.48 m/s; standard deviations of 1.81 m/s and 0.71 m/s and relative weights of 0.29 and 0.71, respectively. Using Monte Carlo simulation, vehicle velocities were generated for the numerical simulation.

Distributions were taken from the literature to vary (using Monte Carlo simulation) the dynamic properties of the vehicles, such as the tyre stiffnesses, suspension damping, etc. (Harris *et al.* 2007; Fu, Cebon 2002; Kirkegaard *et al.* 1997; Wong 1993). Hence, a randomly-generated fleet with characteristics representative of the vehicles with the top 545 measured total strains at Vransko was simulated using a 3-D vehicle model and the integrated plate model. These tyre and suspension properties are given in Table 1.

Fu and Cebon (2002) compiled a suspension database and from this it was assumed that 10% of all tractor suspensions and 50% of all trailer suspensions would be air, the remaining percentages being steel.

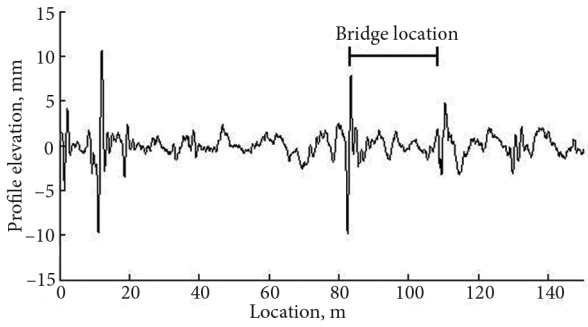

Fig. 6. Road profile measured at the bridge in Vransko

3.1. Road profile

A road surface profile was incorporated into the numerical simulations. This was measured on-site at the bridge in Vransko, using a longitudinal profilometer by a team from the Slovenian National Building and Civil Engineering Institute (ZAG). The 150 m International Roughness Index (IRI) of the pavement is 2.96 mm/m. In numerical simulation of this nature it is common to represent the road surface profile stochastically. However, this fails to account for local peaks or bumps in the profile, as sometimes occur adjacent to bridge joints. In Fig. 6, local bumps are evident at approximately 83 m and 110 m, corresponding to the ends of the bridge. The profile was measured for a single wheel track. A further benefit of the measured profile, as is highlighted in this case, is the inclusion of any irregularities in the immediate approach to the bridge, as these may have a very real effect on the DAF produced (OBrien *et al.* 2010).

As shown in the figure, the profile includes an approach length of approximately 80 m. Such an approach length allows the vehicle to reach dynamic equilibrium

Table 1. Tyre and suspension parameters (Harris *et al.* 2007; Fu, Cebon 2002; Kirkegaard *et al.* 1997; Wong 1993)

Parameter	Steer axle		Drive axle		Trailer axles	
	μ	σ	μ	σ	μ	σ
Axle mass, kg	700	100	1000	150	800	100
Air suspension stiffness coefficients, N/m	300·10^3	70·10^3	500·10^3	50·10^3	400·10^3	100·10^3
Steel suspension stiffness coefficients, N/m	300·10^3	70·10^3	1·10^6	300·10^3	1.25·10^6	200·10^3
Suspension viscous damping coefficients, Ns/m	5·10^3	2·10^3	5·10^3	2·10^3	5·10^3	2·10^3
Tyre stiffness coefficients, N/m	735·10^3	200·10^3	735·10^3	200·10^3	735·10^3	200·10^3
Tyre viscous damping coefficients, Ns/m	3·10^3	1·10^3	3·10^3	1·10^3	3·10^3	1·10^3

well before entering the bridge. As an indicator of the local conditions at the entrance to the bridge, IRI values of shorter sections of 10 m and 20 m (IRI_{10} and IRI_{20}) were also calculated as 5.20 mm/m and 3.30 mm/m respectively. These values correspond to a "good" road profile as defined by *ISO 8608:1995 Mechanical Vibration – Road Surface Profiles – Reporting of Measured Data*.

3.2. Simulation results

The plate model was used to simulate three sets of 545 vehicles. These vehicles were assigned the same axle loads and inter-axle spacings as the top $2\sqrt{n}$ vehicles recorded, but randomly generated velocities and tyre and suspension properties. Full dynamic simulations were carried out for these vehicles. Each set will contain identical static load effects but different total load effects, as it was only parameters affecting the dynamic response of the vehicle that were varied from simulation to simulation. Fig. 7 shows the results of the three simulations in a plot of total (static + dynamic) bending moment against static moment.

The variation in the dynamic portion of the response of the simulated vehicles is evident in the figure. Simulating the vehicles that caused the top measured strains produces alternative maximum total load effects for a single maximum static load effect. In general, the total load effects tend to be slightly larger than the corresponding static values.

The four sets of data, static moment plus three sets of total moment are plotted to a Gumbel scale in Fig. 8. The three simulations produce identical static responses and hence only a single extrapolation line (shown dotted). Each dynamic simulation produces a different total response and the figure contains the data points and extrapolation lines for all three for comparative purposes. However, the three sets of total responses are very similar and are difficult to distinguish from one another at the scale shown.

The ADR values for a 50-year return period are 1.013, 1.010 and 1.012 from the three data sets, which is very close to the measured value of 1.014. These values are in keeping with those obtained in other, very detailed studies (OBrien *et al.* 2010) involving a wide range of bridge spans, load effects and road surface profiles and roughnesses. In this study ADR was found to never exceed much more than 1.05, with a much higher majority of values found in around 1.01 or 1.02 as obtained here.

4. Quantifying the effect of errors in the Bridge WIM data

Bridge WIM systems, like all WIM technologies, are not completely accurate in their estimation of static axle weights. There are small but consistent biases in all Bridge WIM data. While the Gross Vehicle Weights are generally accurate, the individual axle weights are less so. There tend to be compensating errors between axles, i.e., if one axle is over-weighed, another will tend to be underweighed. Dynamic motions may be the reason. It is known that the forces applied by vehicle fleets to pavements are

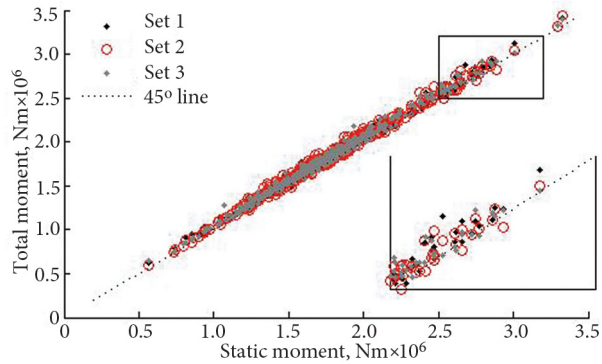

Fig. 7. Results of three simulations

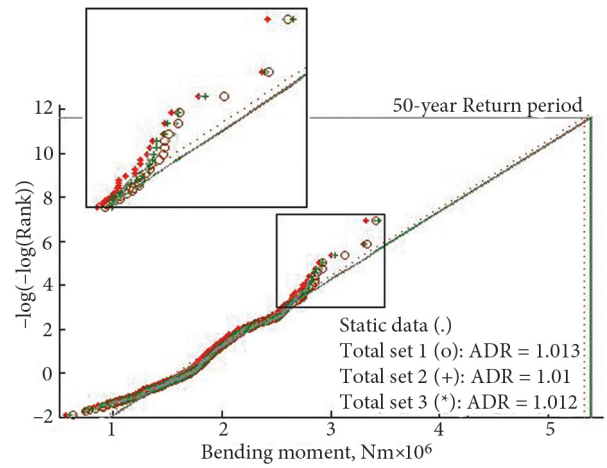

Fig. 8. Results of extrapolation of simulation results

'statistically spatially repeatable' (Wilson *et al.* 2006), i.e., the mean pattern of forces from all vehicles of the fleet is consistent and repeatable. This may explain why there are consistent mean errors in the weights of axles for a given vehicle type. It follows that there are consistent biases in the calculated static strain data.

The bias in the inferred static response of vehicles resulting from the redistribution of load between the axles is addressed here. The measured total and inferred static strains in Fig. 4 are the direct output from the Bridge WIM system, and hence the static readings contain the errors common in Bridge WIM systems. Understanding the effect of this error is an important component of a study on the feasibility of using such systems to calculate ADR.

In order to see how the redistribution of load between axles impacts on the predictions of ADR values, a Bridge WIM system is modelled using the plate model described in Section 3. A "measured" influence line is used for the Bridge WIM algorithm determined using the method of OBrien *et al.* (2006). The vehicle used to calculate the influence line was chosen to be representative of the vehicles of the sample. From Fig. 2 the most frequent GVW is found to be 400 kN. Selecting all the vehicles with this GVW, the mean loads for axle 1, axle 2 and the tridem were found to be 75 kN, 105 kN and 220 kN, respectively. Mean axle spacings of 3.40 m, 5.70 m and 1.30 m were found for spacings between the 1^{st}–2^{nd}, 2^{nd}–3^{rd} and axles of a tridem, respectively. This vehicle was simulated, with

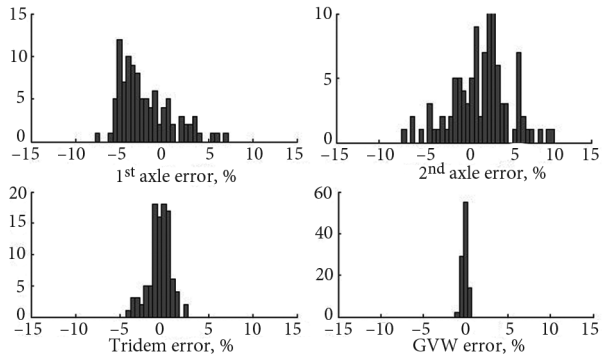

Fig. 9. Bridge WIM errors

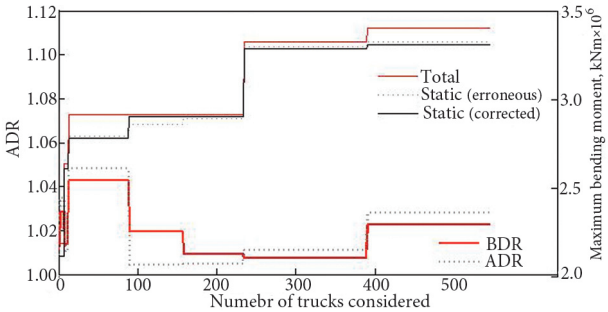

Fig. 10. ADR and BDR

the tyre and suspension parameters of Table 1, and velocity values selected from the distribution values at the site, and ten simulated crossing events of this vehicle were used to determine the influence line.

Simulations taking 100 of the vehicles causing the top $2\sqrt{n}$ loadings events were carried out and the axle weights calculated using the Bridge WIM system. The errors obtained in the calculated axle weights and GVWs are presented in Fig. 9.

The bias in the Bridge WIM predictions is shown in Fig. 9, with the mean error in the 1st axle weight predictions being an underestimation of 2.1% and the mean error in the 2nd axle weight predictions being an overestimation of 2.0%. The mean errors of the tridem weight and GVW are -0.4% and -0.08% respectively.

To show the effect of these errors on ADR predictions, the static bending moments of the 545 trucks modelled in Section 3 were re-calculated, introducing errors to the static axle weights calculated by the Bridge WIM system. The distributions of errors from Fig. 9 were used to subtract similar levels of error from the axle weights in proportion to their frequencies of occurrence, using Monte Carlo simulation. This is, in effect, compensating for the effect bias in the Bridge WIM system axle weight data. The static bending moments were recalculated using the new axle weights. The recalculated moments will be referred to as the corrected moments and those calculated by the Bridge WIM system as the erroneous moments.

Furthermore, the ADR values obtained from the corrected moments (allowing for the Bridge WIM error) are now the corrected ADR values and those calculated with the static moments calculated using the Bridge WIM axle weights (not accounting for the error) are the erroneous ADR values, or Bridge assessment Dynamic Ratio (BDR). Fig. 10 shows the total, corrected static and erroneous static moments and how they contribute to ADR and BDR for the 545 Trucks simulated. This Fig. represents a sequence of results that are updated as each new data point is added. The maximum static moments (refer to right-side axis) only increases as data is added, as does the total moment. In this graph the ADR (refer to left-side axis) is the ratio of maximum total to maximum static moment. This varies significantly when the quantity of data is small but tends to converge as more data is considered. BDR varies similarly.

Fig. 10 shows that, by tending to underestimate the steer axle and overestimate the 2nd axle, Bridge WIM systems tend to overestimate the maximum static response of a vehicle. This generally leads to an underestimation of ADR, i.e., BDR tend to be less than ADR as more data is considered.

ADR was defined by OBrien *et al.* (2009) as a tool for the estimation of characteristic maximum total response from a calculated characteristic maximum static response, i.e. a ratio of what is required (total) to what is available (static). The characteristic maximum static bending moment is available for design or assessment, as it is obtainable by simulation, based on WIM measurements taken in a relatively short period of time (e.g., 3 months). Total bending moment is measurable but there is generally insufficient measured data for a reliable estimate of its characteristic value. Total moment, is obtainable by simulation but this is computationally expensive and may be infeasible in practice at this time. Hence, ADR is a useful property to estimate from direct bridge measurements.

Considering that the aim of ADR (and so BDR) is the inference of characteristic maximum total response, the bias in the Bridge WIM system's prediction tends to cancel out. The characteristic value for erroneous static moment tends to be greater than the corrected value. This is then multiplied by a BDR which tends to be less than the corrected ADR. If the same quantity of data is used in all the calculations, then there is a direct cancellation. However, a more typical situation would involve an erroneous static moment obtained from an extensive simulation process and a BDR based on a limited quantity of measured data. Nevertheless, the overall tendency is for the errors to cancel. OBrien *et al.* (2009) found in the case of theoretical simulation that ADR reduces as return period increases. This trend is evident in Fig. 10 for both ADR and BDR though the quantity of data is too small to be reliable. This finding was confirmed by measurements according to *SAMARIS 2006: Guidance for the Optimal Assessment of Highway Structures*.

5. Conclusions

1. A Bridge WIM system was used to record the total response and infer the static response of about 74 000 5-axle trucks over the course of a 58-days. Using the measured total and inferred static bending moment due to this

population of vehicles, the site-specific ADR value is found for a 50-year return period for illustration purposes. Vehicles from the top $2\sqrt{n}$ total strains recorded were chosen for the extrapolation to the 50-year ADR value. As a means of capturing some of the variability in the dynamic response of the vehicle population, numerical simulations are performed for these loading scenarios, using Monte Carlo simulation, to vary those properties that influence the dynamic response. This process produces multiple sets of dynamic response data (one of which is measured on site) coupled with a single static response, in turn implying multiple Assesment Dynamic Ratio values allowing for variation in the dynamic response. The measured and numerically simulated data produce similar Assesment Dynamic Ratio values.

2. The effect of errors in the Bridge Weight-in-Motion system used to gather the data are also assessed. In particular, the resulting bias in the measured maximum static responses was analysed. This non-conservative error tends to lower the Assesment Dynamic Ratio values. However, the effect is small and is counteracted by a conservative bias in the inferred characteristic static response.

3. The demonstration of the capability of Bridge Weight-in-Motion systems to calculate a bridge's actual Assesment Dynamic Ratio value holds great promise for the accuracy of site-specific bridge assessment. It broadens the array of tools available to the Engineer for bridge assessment and has the potential to justify the safe retention in service of bridges that might otherwise have been repaired or replaced.

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