SITE-SPECIFIC PROBABILISTIC LOAD MODELLING FOR BRIDGE RELIABILITY ANALYSIS

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Abstract

Reliability assessment of a short span beam-slab reinforced concrete bridge in Vienna is proposed using site-specific traffic data recorded using the Slovenian Weigh in Motion (SiWIM) system. An initial evaluation of the bridge using a deterministic approach shows that the critical limit state is bending. This paper describes the statistical analysis of the SiWIM data and the traffic flow simulations performed to predict the characteristic extreme load effects to which the bridge may be subjected during its remaining lifetime. These values are compared to the magnitude obtained from a deterministic approach. The influence lines used in the simulations are the real structural response obtained from SiWIM instrumentation and the theoretical influence line for bending moment at mid-span. It is argued that reliability assessment of existing structures using actual traffic loading data is more realistic than the use of deterministic loading models.

1 Introduction

Bridges deteriorate with time due to aggressive environment and increasing traffic volumes and loads. The assessment of these structures is a complex problem requiring modelling of the load and the response to the load. A theoretical approach to the assessment of in-service structures is fraught with difficulty. The use of generic standards and loading models in the assessment process is inherently conservative because, by their very nature, they have to be valid for a large range of possible construction types and spans, loading types and combinations, as well as a variety of geographical locations and climatic conditions.

The load on the highway bridge includes dead load, live load, dynamic load, environmental load, special load (breaking and collision forces), etc. where traffic load is the predominant variable action. Traffic varies from site to site and with time; the uncertainty associated with traffic action is relatively high compared to other variable actions (Bailey 1996). Design traffic load models can be therefore be conservative in many cases because they are based on the most aggressive traffic to be found in the region of application of the given design code. There is a great potential for reducing traffic action models by considering actual traffic during the evaluation of an existing bridge (O'Connor and O'Brien 1999, Bailey 1996).

The bridge chosen for this paper is a two-lane structure in the city of Vienna. The reliability of the structure was previously assessed using deterministic loading models. It is argued that a better indication of the structural reliability would be obtained using real traffic data from the site. SiWIM installed their equipment on the structure to provide site-specific, continuously recorded, data on truck weights, speeds, time of arrival, headway, axle configuration, volume, etc.

The paper presents the prediction of characteristic extreme load effects to which the bridge may be subjected using the measured traffic flow data from SiWIM and theoretically generated Monte Carlo (MC) traffic files. The accuracy of the later is directly proportional to the amount and quality of measured information available (O'Connor and O'Brien 1999). Statistical extrapolation of the results of simulations, under the assumption of stationarity, permits determination of the characteristic load effects (Jacob 1991) for the chosen structure.

2 Equipment installation and main Components

SiWIM was installed in a simply supported beam slab reinforced concrete bridge in Vienna, 23rd district, National road No. B 224. The structural system has two individual bridges; one built in 1953 and the other in 1961. Each bridge has two lanes and the flow of the traffic is unidirectional. The main components of the SiWIM systems are the pneumatic axle detectors and strain transducers. These units are connected to the signal acquisition units by the cable system so that the output can be obtained using a personal computer. Installation of this equipments take about half a day, calibration of the system takes about 2 hours.

Strain transducers (ST)

Strain transducers are used for strain measurements. They are electro-mechanical devices which convert strain into electrical voltage. These units are attached to the bottom flange of each beam at 4 locations at the middle span of the 1953 bridge approximately. They are fixed using 2 holes per sensor, by inserting steel anchors and using washers and bolts.

Axle detectors

Axle detectors are essential parts of a bridge weigh in motion algorithm, as they provide information about axle spacing and velocity of the vehicle. This data is needed to calculate the axle loads, vehicle length, speed and class (category or type of the vehicle). To obtain this information road hoses were installed at two locations, separated by a distance of 4m, parallel to each other. These units are less durable and require frequent checking.

Bridge calibration

A three-axle truck having 8.75t, 8.05t and 7.85t of the first, second and third axle weight with 3.85m and 1.40m axle spacing respectively were used for calibration. A serious bouncing effect was observed due the roughness and crack at the entrance. Several runs with different speeds were done along the first and second lane for the purpose of calibration (SiWIM manual).

Data collected
After calibration, data was collected as indicated in Table 1.

Table 1 – Traffic data description (N: number of lanes, n: number of lanes monitored).

Site	Year	Lanes		Measured directions	Date	Recording period (days)	No. of trucks
		N	n				
Vienna (B224)	2002	4	2	2	June 10-14	4	16663*

* Data before filtration.

3 Traffic simulation

Simulations were performed using programs developed at University College Dublin (Caprani 2002b, Grave 2001) to determine the characteristic values of the mid-span moment of a simply supported two lane bridge. For such a structure it is clear that the free flow scenario in two lanes will govern the extreme (O'Connor 1999). No dynamic magnification was applied to the calculated load effects at this stage. However in free traffic some dynamic factor should be applied to allow for dynamic interaction between the vehicle and the bridge. The factor will increase the free traffic characteristic load effect values.

Simulation from WIM data
The newest SiWIM systems provide a much more accurate picture of the random variables governing traffic flow, i.e., vehicle gross weights, axle loads, spacing, speed, headway etc. As such it may be expected that characteristic values determined from scenarios generated with actual SiWIM data will be more representative than those determined form artificially generated traffic files (O' Connor and O'Brien 1999).

Monte Carlo Simulation
Monte Carlo simulation is the process by which vehicles are randomly generated using known or assumed statistical distributions for vehicle & axle weight, speed and spacing etc. within assumed vehicle classes. The vehicle classification system adopted for this study is illustrated in Table 2 (O'Connor 2001, Bailey 1996). In total twelve vehicle classes are adopted, demonstrating the varying vehicle forms for a given number of axles.

Figure 1 demonstrates the bimodal distribution of Gross Vehicle Weight (GVW) for different classes, this form of distribution is typical for gross weight. The first mode contains the partially loaded trucks while the second involves the fully loaded trucks. The parameters of this distribution are fitted using a χ^2 Goodness of Fit algorithm, with initial estimates made directly from the histograms.

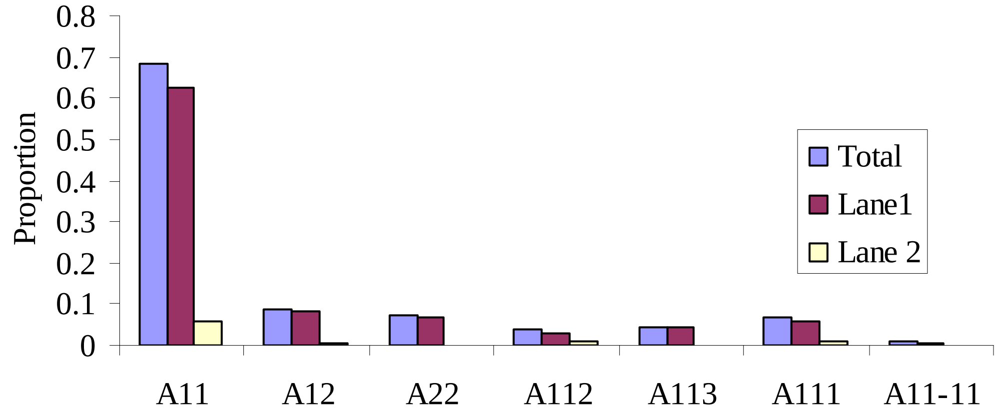
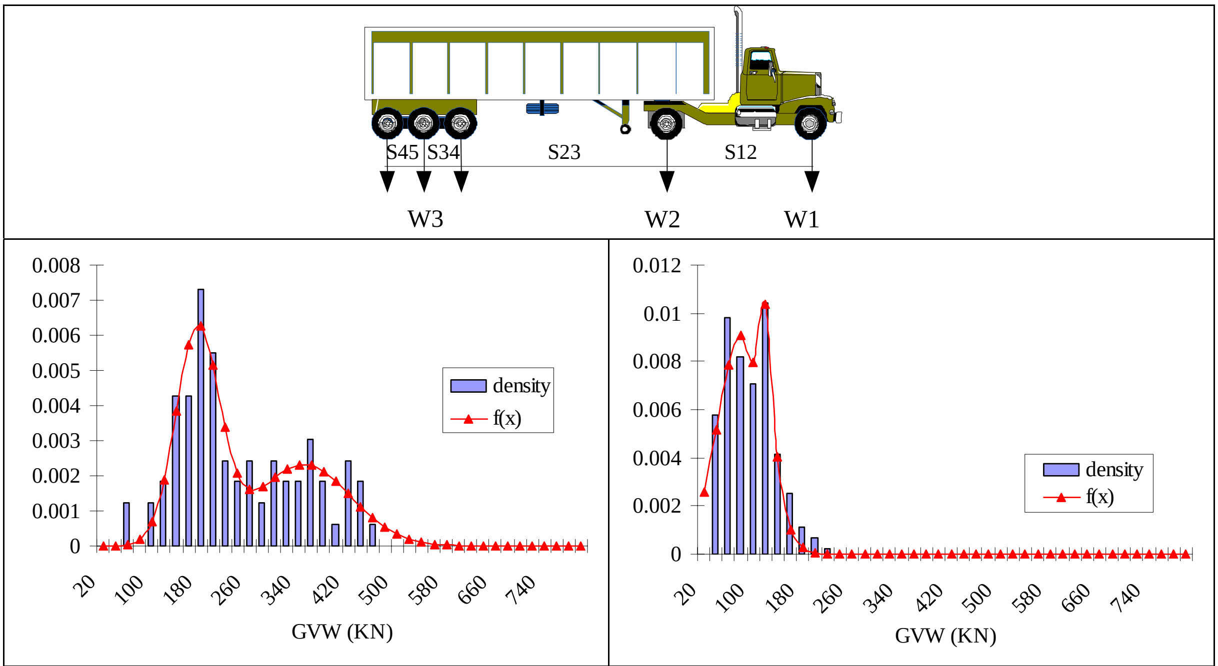


Figure 1 – Truck proportion by Lane**.**

The dominant type of heavy truck modelled in the two lanes is indicated as an example below in Figure 2. In modelling the tandem and tridem, groups are defined as a set of successive axles with a spacing of less than 2 m (O'Connor et al 1998). In generating axle weights and spacing, correlations between the vehicles gross weight and the governing axle or axle group is identified. Subsequent correlation between axles is employed to determine individual axle weights. The relationship found for the A113 class is indicated in Figure 3. The correlation between gross weights and the weight of the governing axle group is demonstrated in Figure 3(a). Thus for a known GVW the weight of the governing axle group may be estimated using MC generation. Similarly, correlation between the principal axle group (W3) and second axle (W2) may be used to estimate its weight etc.

Table 2 – Vehicle Classification System

2-Axle	3-Axle	4-Axle	5-Axle	6-Axle
A11	**A12**	**A22**	**A113**	**A123**
	A111	**A112**	**A122**	**A1212**
		A11-11	**A11-12**	
			A12-11	



a) Lane one — b) Lane two

Figure 2 – Gross Weight distribution Class A113

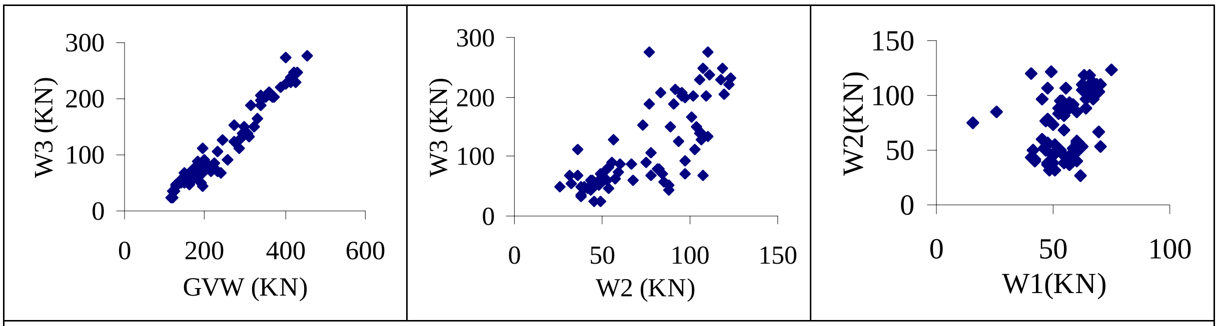


Figure 3 – Weight correlation's by Axle Class A113

It is observed that no statistically significant correlation exists between gross or axle weights and axle spacing as indicated in Figure 4, i.e. axle spacing within a given class are relatively constant independent of vehicle or axle weight. Inter-vehicle distances are modelled using an exponential distribution (Grave 2001, O' Connor 2001). Data showed that the velocity in each lane is well fitted by a normal distribution and therefore it is modelled as such.

The simulations were run and to save processing time, only events likely to be significant were analysed. These events are deemed to be single trucks of GVW greater than 45 tonnes or any occurrence of multiple trucks on the bridge. Filtering of unrealistic truck arrangements was also carried out. For example, though it may be statistically possible, given the data available for modelling, it is not physically possible that an axle weight of less than 1 kN could form part of a truck crossing the bridge. Such events were ignored and another generation carried out in its place.

The simulations were run for both the SiWIM and theoretical influence line. For this purpose the SiWIM influence line is fitted with seven equations as the programs developed require an equation(s). The normalised influence line is provided in Figure 5.

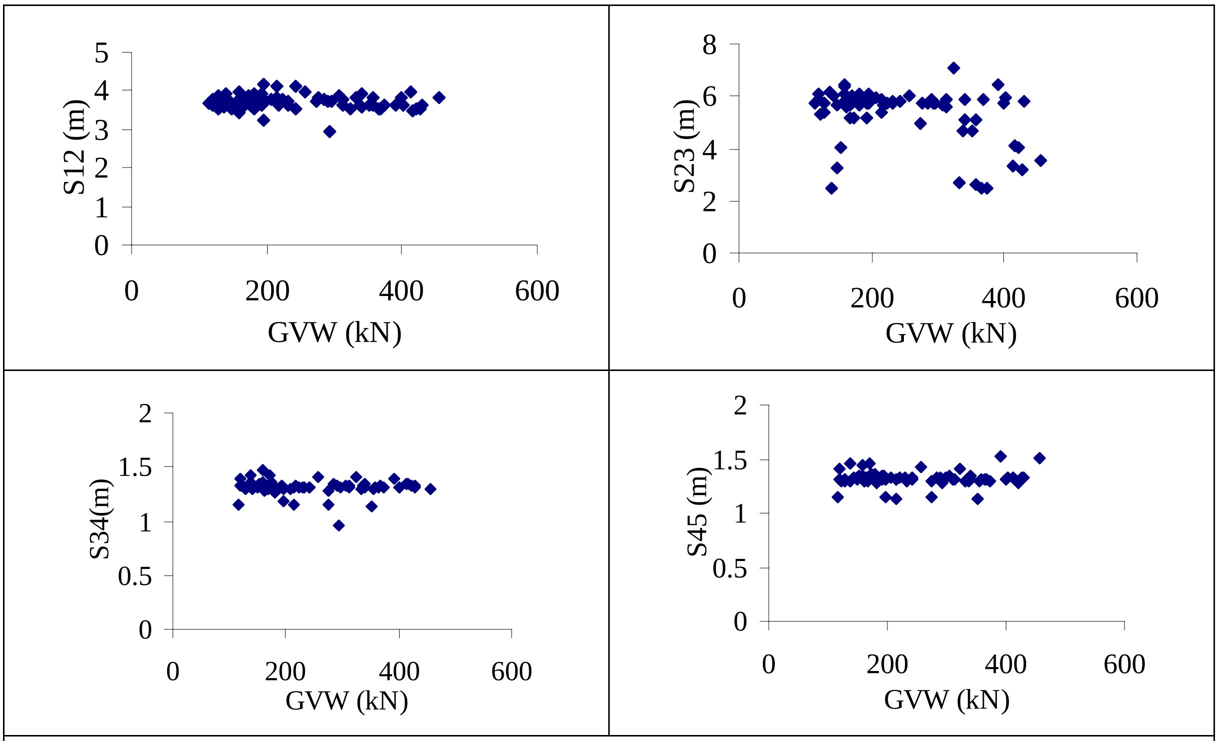


Figure 4 – GVW verses axle spacing

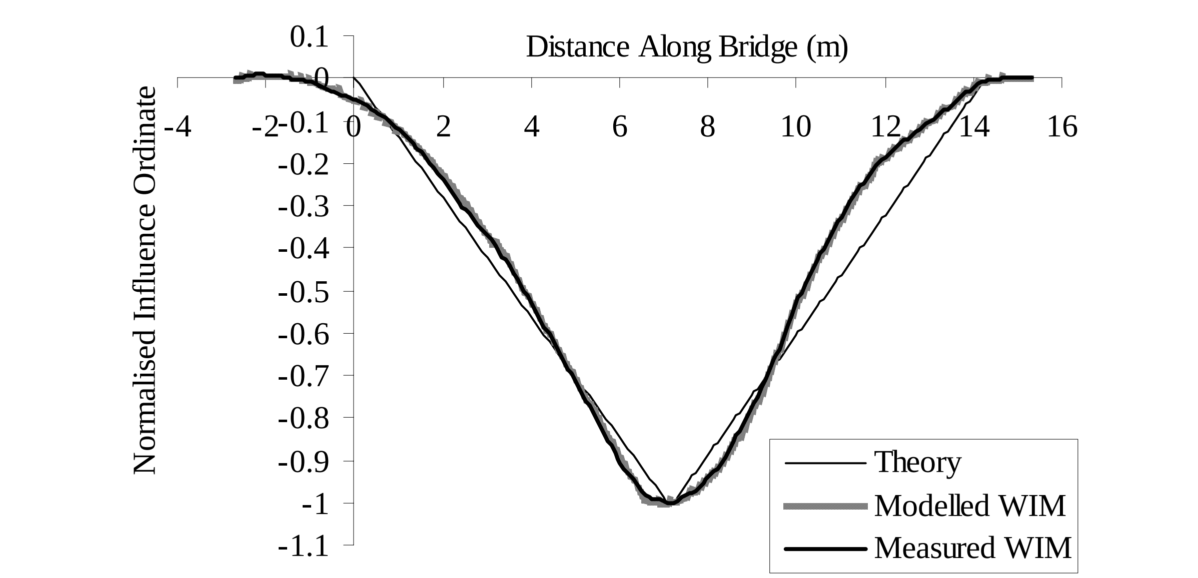


Figure 5 – Influence lines.

4 Prediction of Extremes

The prediction of the extremes, can be calculated from Rices extrapolation, Extreme Value Type III (Weibull) or Type I (Gumbel), and can also include checking the suitability of the distribution to the mathematical model in the later case (O'Connor and O'Brien 1999).

In this paper the prediction of the extreme value was performed using the Extreme Value Type I (Gumbel) distribution. This model can indicate whether the Type III (Weibull) distribution would be a better fit by observation of the tail behaviour of the graph. Details about the prediction methods has been provided by Caprani et al (2002). The extrapolations have been carried out for varying periods as the structure has already been in service for much of its design life and thus a lower return period than for a new bridge may be applicable.

5 Results

A period of 50 days, representing 10 working weeks, was simulated in each of the five runs carried out due to the low truck flow rate of the site. The extrapolated results are shown in Table 3 for various return periods and for both influence lines investigated. It is to be noted that the absolute values of the results can only be taken as approximate as this is a preliminary analysis of the site. However, any inaccuracies will affect both sets of results equally and thus the relative differences are considered to be an accurate measure. It is apparent from the table that the measured influence line consistently gives higher values than the theoretical influence line. Thus it would appear prudent, in any assessment, to model, whether by WIM or finite element analysis, the structure under investigation as a more realistic analysis would be obtained, whether more or less onerous than the theoretical result.

Table 3 – Mean extrapolated results from five full simulations.

Return Period (years)	Measured Influence Line	Theoretical Influence Line	Percentage Difference*
1000	3492	3212	8.7
500	3363	3100	8.5
200	3191	2952	8.1
100	3062	2840	7.8
50	2932	2728	7.5
20	2761	2580	7.0
5	2502	2356	6.2
1	2201	2096	5.0

*Expressed as a percentage of the theoretical value.

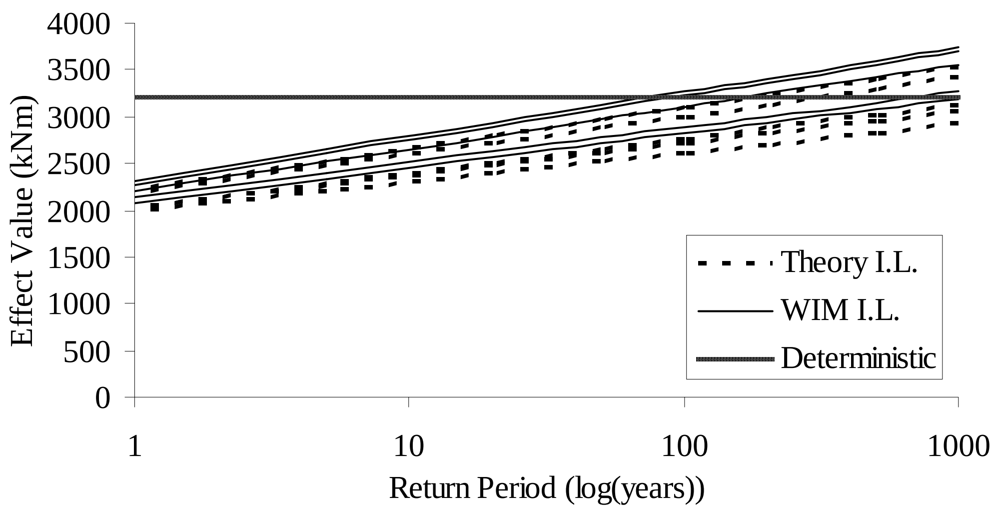


Figure 6 – Extrapolated results for all runs and influence lines.

Figure 6 shows the results of each of the runs and also shown is the result of the original deterministic analysis of the structure. It can be seen that the extrapolated values are all lower than the deterministic values up to a return period of about 90 years. Further, the average of the WIM-based extrapolations is lower than the deterministic value below a return period of about 250 years, or 25 years further service with 10% probability of load effect exceedence.

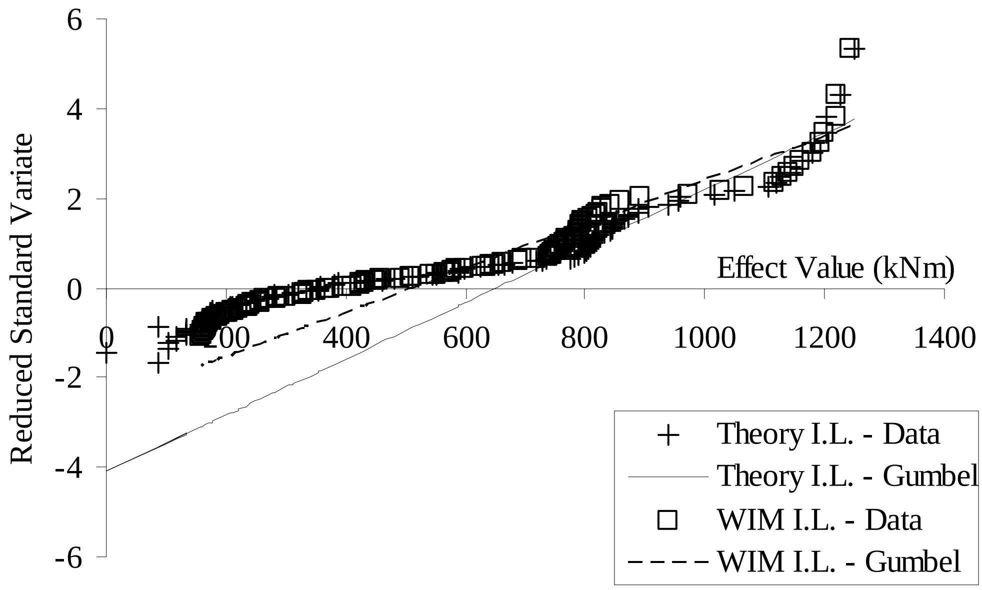


Figure 7 – Gumbel plot for both influence lines from Run 5.

An example of the Gumbel plots used in the extrapolations is given in Figure 7. It can be seen that the slope of the WIM-based extrapolation line is less that that of the theory and thus a higher extrapolated value results. Of more interest is the tail behaviour of the graph; the upturned end would suggest that the data conforms better to a Weibull distribution. This distribution is characterised by its limiting value for extrapolation, which in turn infers a physical limit on the values of the load effect to which the bridge may be subjected. This is not an unexpected result as the physical limitations of loading the short length of the bridge would suggest that a distinct maximum value of load effect is possible. Further analysis of this should reveal the limiting load effect value and also the associated return period. Knowledge of these values would greatly aid decision making in the assessment of short-span bridges.

Also of note in Figure 7 is the kink which occurs at about 800 kNm. This is due to a change in the governing arrangement of trucks; below this value two-truck presence events are the critical arrangement. However, above this value single truck events govern and in turn are most important in determining the extrapolated extremes. As the single truck events have been filtered for trucks of GVW greater than 45 tonnes only, the sensitivity of the extrapolated values to this 45 tonnes filter should be examined.

6 Conclusions

This paper showed how probabilistic load modelling could be easily applied in practice with traffic data gathered using Weigh-in-Motion technology. The use of a site-specific traffic load model rather than a design load model has demonstrated a reduction in the characteristic extremes to which the bridge may be subject and this clearly has an important role in the reliability analysis of the critical limit state identified. It is clear from the comparison of influence lines that in any assessment it would be prudent to model the structure using WIM or finite element modelling to determine the actual influence line. Also of note is that, for this site, the modelling has shown that single truck events are more critical than multiple truck events; there may exist a limit on the maximum load effect to which the bridge may be subject and that this would have an associated return period; the extrapolated extremes may be sensitive to the single truck GVW limit of 45 tonnes chosen for the simulations. It is clear that the use of WIM and appropriate simulation and statistical techniques yield valuable data upon which informed decisions may be made.

7 Acknowledgement

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