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The Determination of Site-Specific Imposed Traffic Loadings on Existing Bridges

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INTRODUCTION

A great deal of attention has been centred in recent years on the assessment of the load carrying capacity of existing bridges. In contrast, the traffic loadings which bridges are required to carry are often notional and, consequently, in less heavily trafficked regions, they can be excessively conservative. BA79/98 [1] on the management of sub-standard structures, recommends detailed load modelling for the accurate determination of the level of reliability of existing structures. Such modelling requires knowledge of advanced statistical concepts and thus is not practical for a majority of engineers. This paper describes the development of a simple statistical approach to determine the critical loadings to which a structure will be subjected without the requirement for complex statistical analysis. The background to the development of the simple statistical approach for the assessment of single lane, bi-directional, highway bridges is presented. The simple approach is validated by comparison with a more complex statistical approach. Finally, the robustness of the approach is demonstrated for a number of different sites with different traffic flow characteristics.

TRAFFIC SIMULATIONS

Traffic data obtained from Weigh-In-Motion (WIM) systems is required to generate traffic simulations. Using WIM data, the distributions of gross vehicle weight (GVW), speed and spacing between vehicles may be determined and modelled by statistical distributions - see for example, Figure 1. The modelled distributions are validated using statistical goodness-of-fit tests such as the Kolmogorov-Smirnov (K-S) test [2]. For each traffic file the site-specific proportion of trucks (i.e., vehicles with GVW > 3 500kg) per class of axles may also be obtained where a class of axles contains all trucks having the same number of axles.

In this study the sample files of real data used have been obtained from WIM stations on the A6 motorway at Auxerre (France) and the RN10 near Angers (France) [3]. Both sites have four lanes (2 in each direction) but traffic was recorded in the slow lanes only. A full week of data was recorded at both sites (from the 26/05/1986 to the 02/06/1986 for Auxerre and from the 07/04/1987 to the 14/07/1987 for Angers).

Full traffic simulations are performed using the modelled distributions of GVW per class of axle, speed and of time interval between consecutive trucks. Significant differences may exist in the GVW distribution moments for the opposing directions. Consequently, directional distributions were derived. In addition, for each class a typical truck was derived with fixed axle spacings and proportions of weight carried.

The program developed to generate traffic files theoretically allows for any time period, but due to time and memory limitations the simulations usually represent from 1 week to 2 months. A period of 1 month was selected for this study.

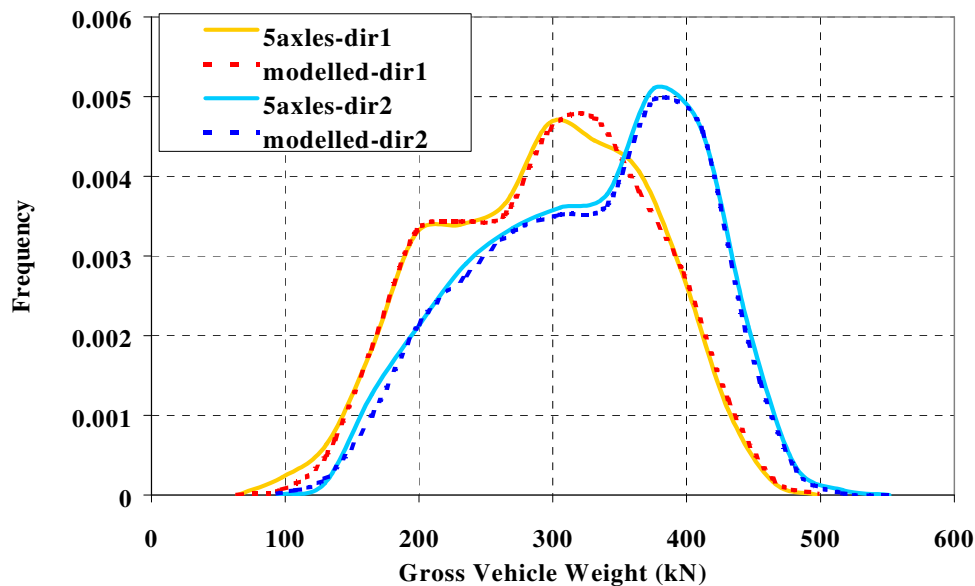


Figure 1 - Probability Density Functions of GVW for 5-axle trucks - Angers 1987

DETERMINATION OF LOAD EFFECTS

Two-lane simply supported and two span continuous bridges ranging from 20 m to 40 m (i.e. ‘short’ bridges) are considered. The extreme loading cases are governed by the meeting of two heavy trucks within a critical influence zone on the structure. For bridges exceeding 40 meters, meeting events with more than two trucks begin to influence the extremes. In this study, four load effects are considered:

- 1: bending moment at mid-span of a simply supported bridge,
- 2: moment at central support of a two-span continuous bridge,
- 3a, 3b: shear on left-end and right-end support of a simply supported bridge,
- 4a, 4b: shear on left-end and right-end support of a two-span continuous bridge.

An influence line can be defined as a diagram which shows the variation of a load effect (i.e., bending moment, shear force, etc.) at a given position in a structure as a unit load travels across it [4]. The influence lines corresponding to the load effects considered are illustrated in table 1. In this study the notion of influence line was extended from that of a unit load, to represent the effect induced by a ‘unit truck’. Indeed it is extremely useful to show the variation of the load effect at a given position in the structure as a ‘unit truck’ (i.e., a truck with GVW of 1) travels across it. This function has been termed the ‘*characteristic response*’ of the structure.

The characteristic response can be determined by adding the effects of all the axles when the spacings between the axles and the proportion of GVW carried by each axle are known. Figure 3 shows the characteristic response of a ‘*unit 5-axle truck*’ with the properties shown in table 2 and illustrated in figure 2. Irregularities in the curve correspond to the arrival/departure of one of the axles on/off the bridge. This concept of characteristic response is very useful in developing the simple approach described in this paper.

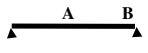
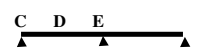

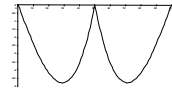

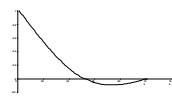
	Simply Supported 	2 Span Continuous 
Lengths (meters)	20 - 30 - 40	20 - 30 - 40
Influence lines	 Moment at A	 Moment at E
Influence lines	 Shear at B	 Shear at C

Table 1 - Influence lines

	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
Proportion of GVW carried per axle	13 %	30%	19 %	19 %	19 %
	Spacing 1-2	Spacing 2-3	Spacing 3-4	Spacing 4-5	
Axle-spacing between consecutive axles	3.1 m	5.0 m	1.1 m	1.1 m	

Table 2 - Characteristics of a 5-axle truck modelled using real data from Auxerre

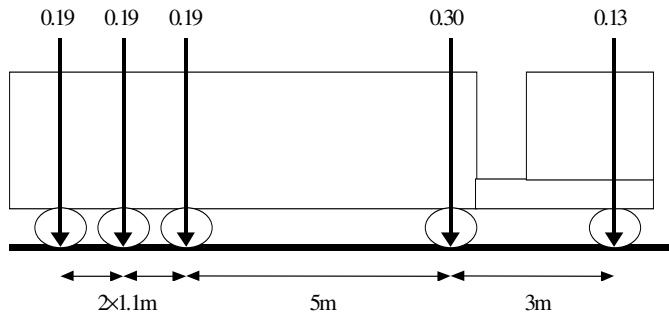


Figure 2 - Typical 5-axle truck used in the simulation for Auxerre

In figure 3 the X-axis goes from 0 to 30.2 meters since the 1st axle of the 10.2 m long truck is located at X = 30.2 when the 5th axle of the truck is at the end of the 20 m long bridge. For the moment at mid-support of a two-span continuous bridge, the maximum value induced by a 5-axles truck (with characteristics given in table 2 and GVW of 1) is 0.89 and occurs when the 1st axle of the truck is located at X = 15.5 meters.

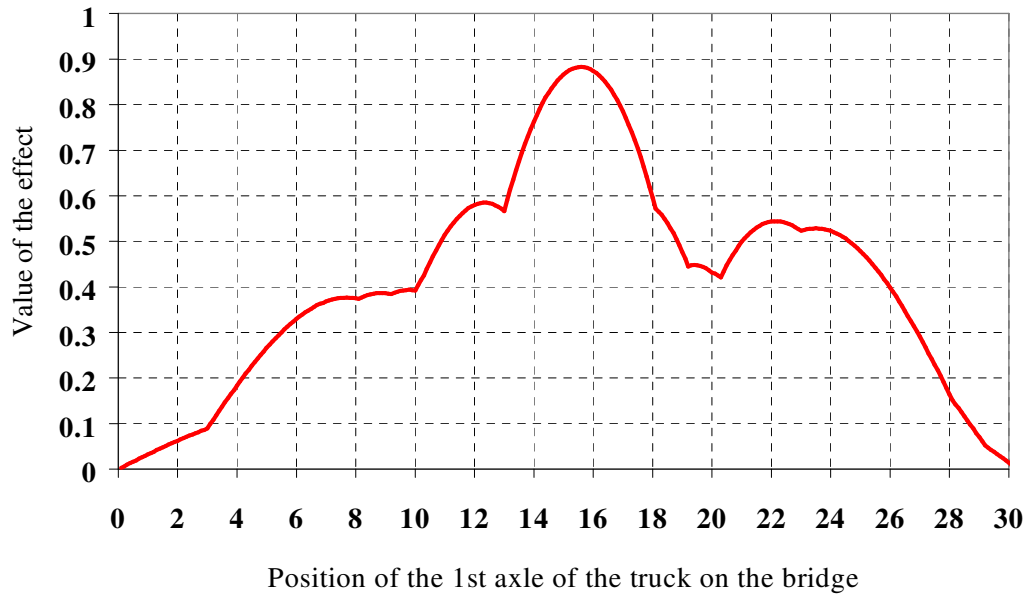


Figure 3 - Characteristic Continuous Support Moment Response, Total Length 20m

MONTE CARLO SIMULATION AND LOAD EFFECT CALCULATION

Monte Carlo simulation is used to generate traffic records, with corresponding truck characteristics (GVW, speed and arrival time) generated using the probability distributions obtained from WIM records [5]. The simulations performed represent one month of traffic. The critical loading events are determined through identification of a meeting event in the traffic file, i.e., two trucks meeting on the bridge. Events where only one truck is present on the structure are not considered as critical. For every critical loading event identified, the load effects are calculated repeatedly as the trucks move at 0.1 m intervals along the bridge. Only the maximum value for each load effect is recorded.

The maximum values recorded for each of the critical loading cases form a statistical distribution of extreme values. This distribution can be fitted to a known distribution of extreme values: Gumbel (type I), Fréchet (type II) or Weibull (type III) [6]. A program is used to calculate a first estimate of the parameters characterising the distribution and then to optimise these parameters using a weighted least-squares method.

Generally the distributions of extreme values of the load effects have been found to be well described by a Weibull (type III) distribution. Following optimisation of the parameters of the distribution, the characteristic value (i.e., value with a specified probability of exceedance, α , during the design lifetime of the structure) can be determined by extrapolation to an appropriate return period [7], R :

$$R = R_{y\alpha} \cong \frac{-T}{\ln(1-\alpha)} \cong \frac{T}{\alpha} \quad \text{if } 0 < \alpha \ll 1 \quad (1)$$

The characteristic values for extrapolation of the traffic effects, were determined such that the probability of exceeding the load effect during the specified design life of $T = 50$ years was calculated with a 0.95 fractile probability that y_α is exceeded during T . From equation (1), a return period of $R = 1000$ years is required. The characteristic value changes slightly from one

simulation to another as the traffic is never exactly the same. Therefore a number of full simulations were run in order to get a statistical distribution for the characteristic value.

DEVELOPMENT OF A SIMPLE APPROACH

The aim of the simple approach is to provide an accurate estimation of the characteristic value of load effect due to imposed traffic loading on existing bridges without performing large scale simulation which requires a lot of computation time.

The critical loading situations for each of the load effects for the bridges considered is given by the meeting of two 'heavy' trucks within a critical influence zone. It is easier to analyse the situation in terms of characteristic response than in terms of influence line since the 'heavy' trucks are long (9 to 10 meters) and the bridges considered are short (20 to 40 meters). The load effect is highly sensitive to the location of the truck on the bridge and thus cannot be easily anticipated. An examination of the characteristic response allows the identification of the critical location(s) of the truck (i.e., the location(s) of the truck that induces the maximum effect).

The simple approach developed requires a knowledge of:

- the number of axles and axle spacings for each 'heavy truck',
- the critical location(s) for the 'heavy trucks'.

In order to answer the first question, the distribution of gross vehicle weights of all the 5-axle trucks going in the same direction is used. By obtaining this WIM data and modelling it using a Weibull type distribution, typical site specific weights for 'heavy trucks' can be generated. To obtain the critical locations corresponding to each load effect, the characteristic response for that particular effect and span length needs to be examined.

Figure 4 shows the Weibull distribution of GVW for all 5-axle trucks in 'Angers 1987'. The best-fit estimation of the parameters of the distribution was done for the right tail of the curve as only the extreme values are of interest.

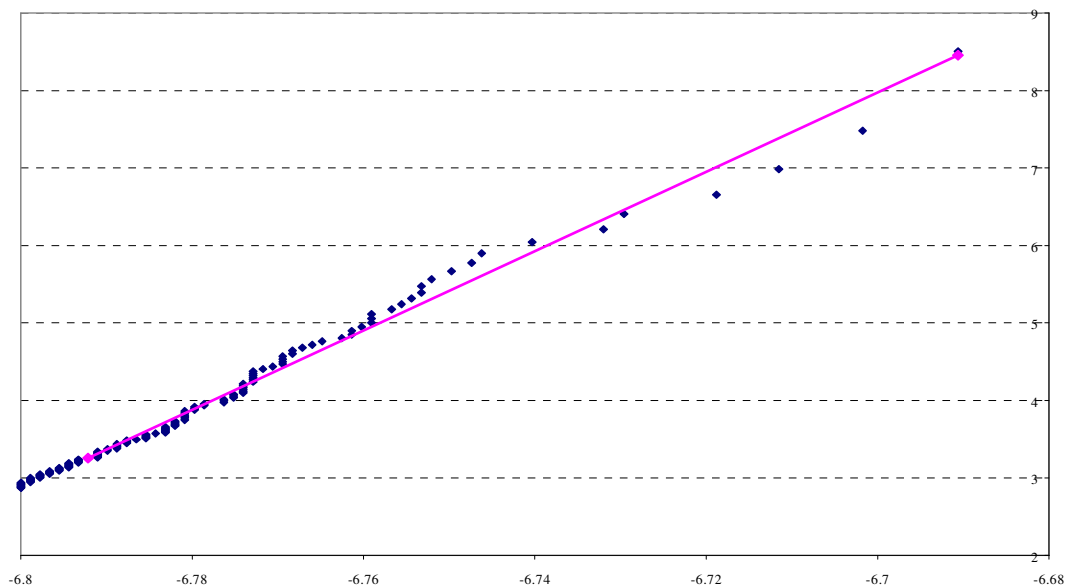


Figure 4 - GVW distribution on Weibull probability paper, Angers 1987 – direction 2

Table 3 shows the characteristic gross vehicle weights for different probabilities, sites and directions. The difference from one site to another and from one lane to another can be seen.

There are two possible ways to place the trucks on the bridge in order to induce the maximum effect:

1. The trucks can be placed at one particular location (such as the critical point on the influence line) and will induce a given load effect. This is the traditional approach.
2. The trucks can be placed in a zone and will induce a different load effect depending on their location inside that zone.

In the first case the load effect is known once the location is fixed (as the axle-spacings and the axle-weights are fixed). The value of the load effect is equal to the product of the characteristic response and the GVW of the truck. In the second case the load effect will lie somewhere in a fixed range defined by the zone in which the truck is located.

The first approach was initially used to determine an estimate of what the maximum load effect is when the two trucks are located at the critical location of the bridge. The second more accurate approach was then used to obtain a distribution of values and determine the mean and variance of that distribution.

	Direction	Parameters of the Weibull distribution			0.98	0.985	0.99	0.995
		Lambda λ	Delta δ	Beta β	X (y=0.98)	X (y=0.985)	X (y=0.99)	X (y=0.995)
Angers	Dir1	528	189	6.12	428	433	439	448
	Dir2	1748	1351	83.4	459	463	470	480
Auxerre	Dir1	1941	1583	36.91	517	528	544	570
	Dir2	873	422	10.23	585	593	604	622

Table 3 - Extrapolated values (kN) for gross vehicle weight for different probabilities and sites/directions

For a given load effect and span length, there is a location on the bridge for which the load effect is maximum (i.e., the maximum ordinate on the characteristic response plot) - see Figure 5. Different zones have been identified using the characteristic responses: zones in which the load effect induced would be at least $X\%$ of the maximum value. By decreasing the value of X , the mean of the load effect distribution is decreased and the spread of the distribution increased. Typical values of 80%, 85% and 90% were used in the simple approach.

RESULTS OF SIMPLE APPROACH

100 full simulations were run for each site and for each bridge length (20m, 30m and 40m). The distribution of the 100 characteristic values obtained was modelled as a Normal distribution, with optimised moments and the mean was found. The simple approach used 1000 critical meeting events (i.e., two trucks of fixed GVW placed randomly in the critical zone) for each site and bridge length. The distributions obtained from the 1000 values were found to be well fitted by a Normal distribution; the mean critical value was used.

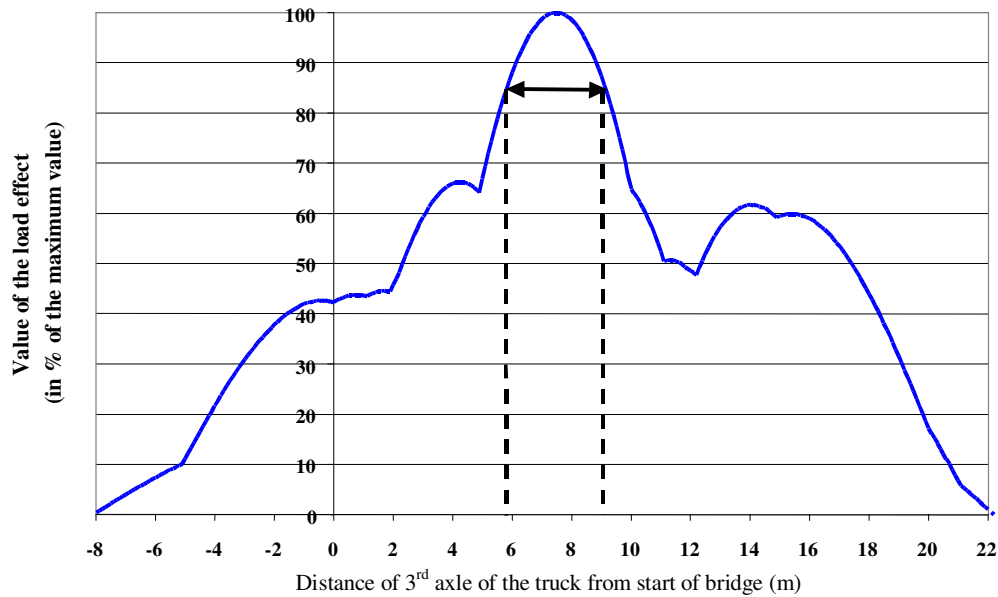


Figure 5 - $X=85\%$ zone for the characteristic response of Central Support Moment in Two-span continuous bridge, 20 m long

Table 4 shows the comparison of mean values of the characteristic load effects listed in table 1 for the 2 sites, 'Angers 1987' and 'Auxerre 1986'. The results presented in table 4 have been obtained using an 85% zone for the characteristic response and a value of $Y=0.99$ for the fixed gross vehicle weight. The 'SM' columns show the relative difference (in %) between the mean characteristic value from the full simulations and the corresponding value calculated by the simple approach. For the 3 span lengths considered, the results corresponding to effects 1 and 3a/3b are very similar for the full simulation calculation and the simple approach calculation. Results for effects 2 & 4a/4b demonstrate the sensitivity of the simple model to the shape of the characteristic response. However, the simple approach is still within 14.3% of the full simulation for all cases. The root mean square difference for all spans, effects and data is 7.34%.

Length (m) and Data Source	Effect 1			Effect 2			Effects 3a & 3b			Effects 4a & 4b			
	FS kNm	SM (%)	TR (%)	FS kNm	SM (%)	TR (%)	FS kN	SM (%)	TR (%)	FS kN	SM (%)	TR (%)	
20	Angers	2920	1.7	11.8	740	8.1	17.6	605	7.4	20.2	385	14.3	32.5
	Auxerre	3550	5.6	24.0	930	8.1	26.1	765	2.0	28.4	495	11.1	39.2
30	Angers	5200	0.4	10.6	1040	-7.7	8.1	685	6.6	18.1	490	10.2	24.5
	Auxerre	6500	1.4	19.2	1340	-9.7	13.1	875	5.1	24.8	620	9.7	32.9
40	Angers	7450	0.1	9.9	1645	-10.6	-1.9	730	2.7	16.0	560	7.1	21.1
	Auxerre	9350	0.8	18.0	2075	-10.8	4.8	965	-0.5	18.4	710	5.6	29.0

Table 4 - Results of Full Simulation (FS), Simple Method (SM) & Turkstra's Rule (TR)

The effects were also calculated using Turkstra's rule, i.e., by putting a 1000 year (return period) truck alongside a 20 week (return period) truck at the critical location for each effect considered. The results obtained from Turkstra's rule range from 1.9% below to almost 40% in excess of those obtained from the full simulation. The root mean square difference for all spans, effects and data is 21.6%.

CONCLUSIONS

This paper describes the development of a simple statistical approach to determine characteristic load effects in short- and medium-span bridges without the requirement for complex statistical analysis. The simple approach has been validated by comparison with a more complex statistical approach based on direct simulation. The accuracy of the approach has been tested for two different WIM sites with different traffic flow characteristics and for a range of spans and load effects. The results obtained demonstrate the sensitivity of the approach to the shape of the characteristic response. Overall, the simple approach is shown to be quite accurate, always being within 14.3% of the result of a full simulation. The conventional Turkstra's Rule, on the other hand, is significantly less accurate with errors of up to 40%.

REFERENCES

- [1] BA79/98 (1998), *Design Manual for Roads and Bridges*, Department of Transport, London.
- [2] ANG, A.H.S., Tang, W.H., *Probability concepts in engineering planning and design*, Volume 1, Wiley and Sons, 1975.
- [3] JACOB, B.A. et al., *Traffic data of the European countries*, Report of WG2, Eurocode 1 part 3, March 1989.
- [4] GHALI, A., *Structural Analysis*, E&FN Spon, 1997.
- [5] O'CONNOR, A.J., Jacob, B., O'Brien, E.J. and Prat, M., 'Approche probabiliste des valeurs extremes de charges sur les ponts routiers', Seconde Conference Nationale, 'Fiabilite des Materiaux et des Structures', Champs sur Marne, France, Hermes, Nov. 1998.
- [6] CASTILLO, E., *Extreme Value Theory in Engineering*, Academic Press, 1991.
- [7] JACOB, B.A., 'Methods for the prediction of extreme vehicular loads and load effects on bridges', Report of Subgroup 8, Eurocode 1.3, LCPC Paris, 1991.