Appendix A Dynamic Amplification of Characteristic Lifetime Bridge Load Effect

A1 Introduction

This appendix relates to the calculation of appropriate allowances for dynamic interaction in lifetime bridge traffic load effect. Extensive static simulation, based on measured Weigh-In-Motion (WIM) data are used as the basis of a population of extreme loading events. These events are then analyzed, using finite element bridge-truck interaction models, to determine the total load effect, which results from the static and dynamic aspects of a crossing event.

A calibrated bridge model of the Mura River Bridge, Slovenia (Figure H1), is used in conjunction with WIM data from the A6 motorway near Auxerre, France, as the basis of the analysis. Using Monte-Carlo simulation, 10 years of bi-directional, free-flowing traffic data is generated for this notional site.

Figure H1. Mura River Bridge

A2 Load Effect Considered

The general arrangement of the Mura River Bridge is shown in Figure H1. The finite element model was used to determine the influence lines for each of the longitudinal girders. These influence lines, as well as polynomial fits to them, are shown in Figure H2H3. The polynomial fits are required as input to the simulation program.

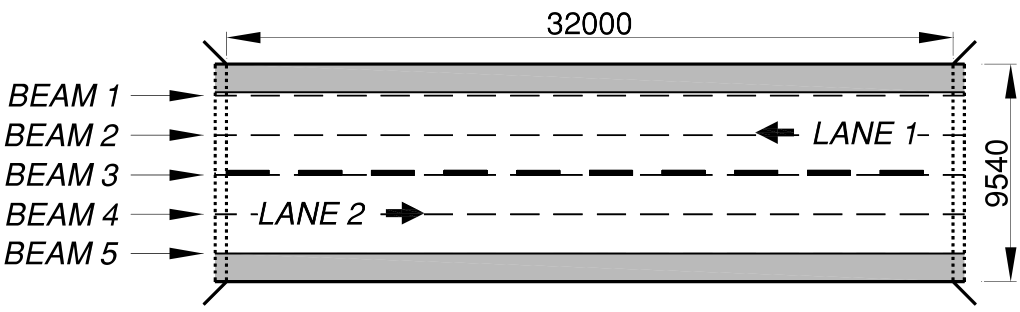


Figure H1: Mura River Bridge general arrangement.

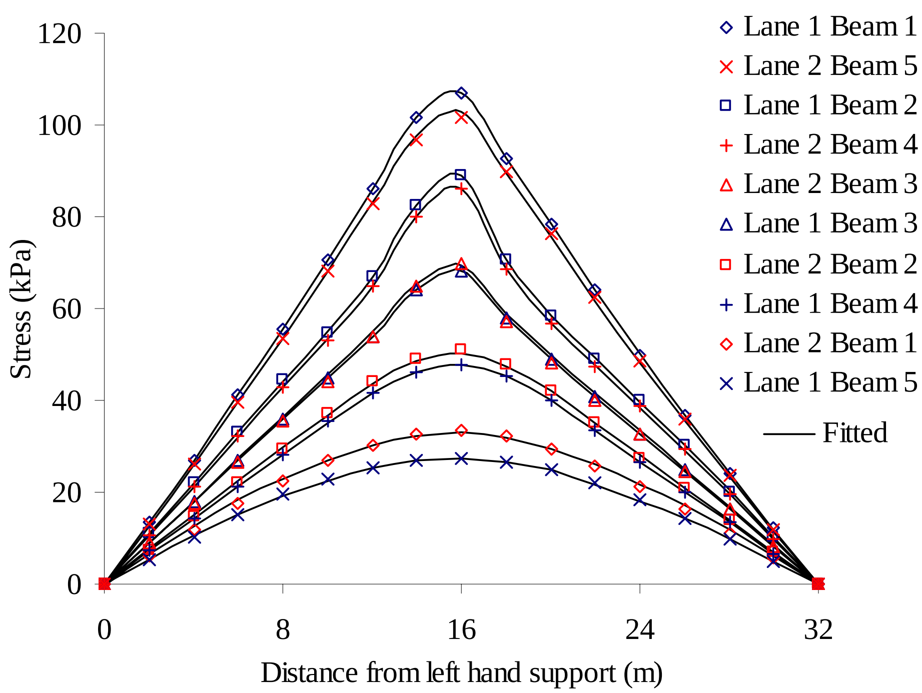
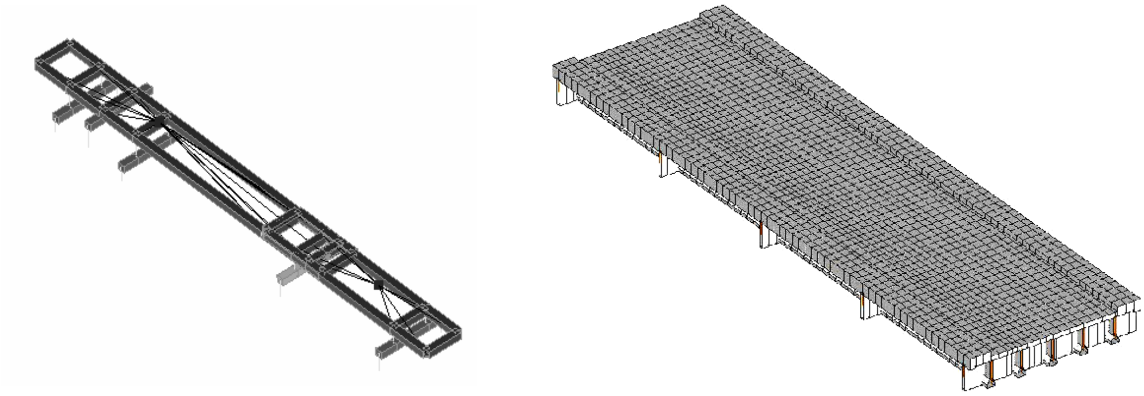


Figure H2: Finite element influence lines.

A3 Traffic Simulations

The traffic characteristics of the A6, Auxerre site were statistically modelled based on the WIM data obtained. Monte-Carlo simulation techniques were used to generate synthetic traffic whose characteristics match those of the measured site.

It is considered that there are 250 working days per year. Therefore, each year of simulation is broken into ‘months’ of 25 days each and there are thus 10 such months in each year of simulation. 10 such years of traffic was generated and was passed over the influence line for Beam 1 to determine the load effects that result. As a basis for further analysis, the events corresponding to monthly maximum load effects are retained for further analysis. This is done, regardless of the type of loading event, and this is acknowledged to be a simplification of the complexity of the bridge loading process, but is not considered inhibiting to the analysis that follows.



(a) (b)

Figure H3: Finite element models of (a) 5-axle truck and (b) bridge.

The 100 monthly maximum loading events obtained from the simulations described were analyzed using finite element bridge-truck interaction models developed at UCD. Figure H3 illustrates a sample truck model and shows the model used for the bridge. The load effects that result from these simulations are termed total load effect as they include both a static component and a component due to the dynamic interaction of the truck(s) comprising the event and the bridge. Further, the dynamic amplification factor (DAF) for a particular loading event is defined as:

$$\varphi = \frac{\sigma_{Total}}{\sigma_{Static}} \qquad (1)$$

Thus, the results of the simulation described is a population of 100 monthly maximum loading events for which both total and static load effects are known, and therefore the DAF for each event also. However, it should be acknowledged that DAF for particular events are not what is needed for bridge assessment. An assessor with access to conventional static load assessment techniques such as described elsewhere in this report, will be able to calculate the characteristic 1000-year static load effect. What the assessor needs is the characteristic 1000-year *total* load effect. Therefore, it is the ratio of these two characteristic values that is needed rather than a DAF for a particular example.

A4 Multivariate Extreme Value Analysis

To allow for the correlation between the total and static load effect values, it is necessary to use some form of statistical analysis. For this work, bivariate (i.e., 2-variable) extreme value distributions (BEVD) are adopted and fitted to the maximum-per-month data. In the first instance BEVD is used to model the parent distribution of monthly maxima, and later it is used to model the lifetime distribution.

The data is fitted using the Gumbel logistic bivariate extreme value distribution. The results of the fit can be seen in Figure H4. This figure shows a contour plot of the probability density function. Each point in the graph represents a maximum-per-month load effect with static effect on the *y*-axis and total load effect on the *x*-axis. There is clearly a strong correlation between static and total as would be expected, and total generally exceeds static as would also be expected. However, what is of particular interest is that the extent to which total exceeds static reduces as load effect increases. In other words, the contribution of dynamics reduces as the load effect becomes more extreme. This is not surprising as extreme events often involve more trucks with a greater number of axles and the probability of destructive interference between them is higher than for a less extreme loading event.

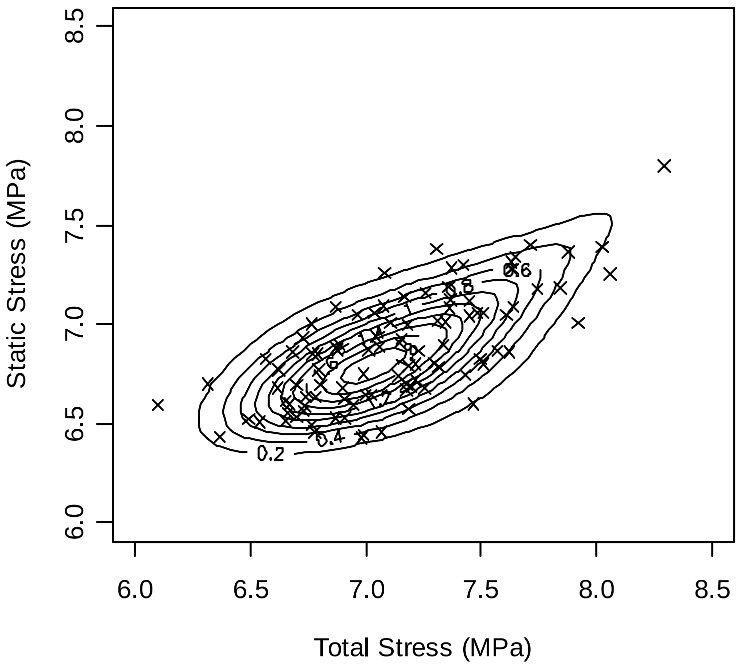


Figure H4: Results of the BEVD fit.

A5 Bootstrapping for Lifetime Load Effects

A parametric bootstrapping approach was used to extrapolate from the maximum-per-month data of Figure H4 to the maximum-per-lifetime situation. To simulate 100 year lifetimes, 1000 (100 years with 10 'months' per year) synthetic monthly maximum events were simulated based upon the parametric BEVD fit, and the worst identified. In other words, Figure H4 was sampled 1000 times, the worst static and the worst total of the 1000 were both identified and plotted in a new lifetime maximum plot. These values are therefore not related through an individual loading event. 1000 such bootstrap replications were noted and these points represent individual realizations of bridge lifetime maximum static and lifetime maximum total load effect. The results are illustrated, along with the original monthly-maximum data, in Figure H5.

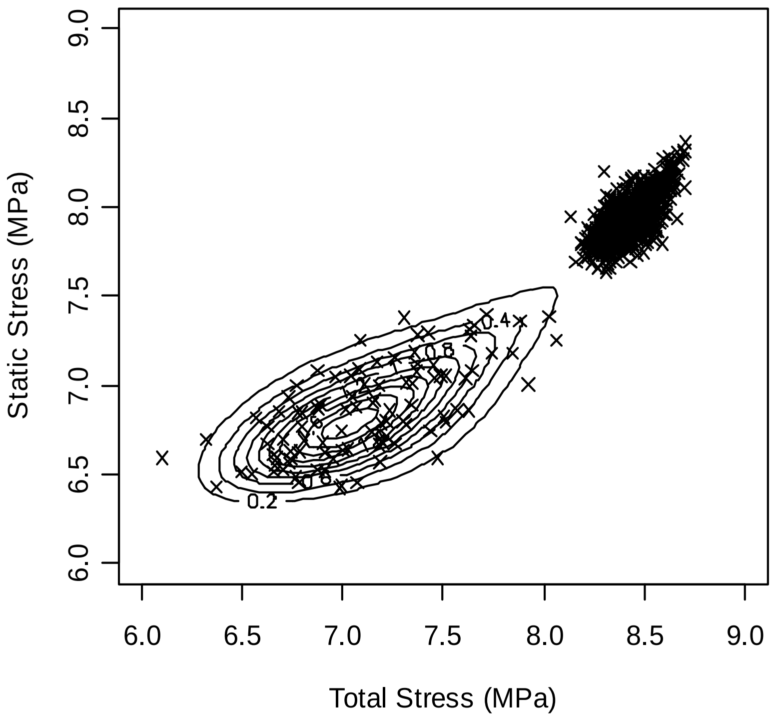


Figure H5: Parent and lifetime bivariate distributions.

The parent monthly maximum data (bottom left cluster) are clearly more variable and have lower load effect values. The 100 year lifetime maximum data (top right) is more tightly clustered and corresponds to higher load effects. It is of particular note that the orientations of the clusters are different. The relationship between total and static – represented by the slope of the clusters – has changed significantly. The lifetime maximum data has rotated significantly towards 45^{o}, i.e., the dynamic effect has reduced.

The ratio of simulated static lifetime load effect to total lifetime load effect is termed here as the Bridge Lifetime Dynamic Ratio (BLDR). This recognizes that a single event is not responsible for both the total and static load effect.

A6 Assessment Dynamic Ratio

It is not the distribution of BLDRs that is of interest, rather, a BLDR that corresponds to a certain percentile for each of the marginal distributions. Such a BLDR is termed an Assessment Dynamic Ratio (ADR) in this work. For design the Eurocode (EC1) specifies the load effect with a 10% probability of being exceeded in its 100-year lifetime, often referred to as the 1000-year characteristic load effect. This corresponds to the level of load effect which 10% of data exceeds. This is illustrated in Figure H6.

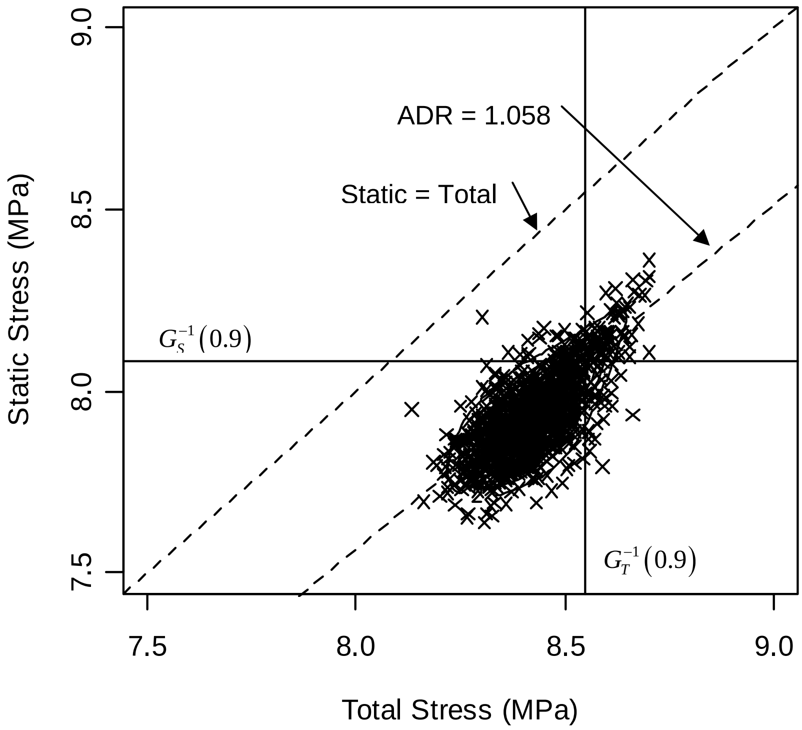


Figure H6: Bivariate extreme value lifetime maximum load effect distribution.

The characteristic static lifetime load effect – about 8.2 in this example – is what can be calculated using conventional methods of load assessment. The characteristic lifetime maximum total load effect – about 8.6 in the figure – is what is sought. Hence the assessment dynamic ratio is the ratio of these two values.

For bridge load assessment, in the 100-year lifetime of this bridge and traffic as measured, the the corresponding ADR is 1.0582. It is this value that is considered appropriate to relate lifetime static load effect values to total load effect values in this sample application.

A7 Summary

A method for deriving the dynamic allowance to be applied to characteristic lifetime static load effects to determine characteristic lifetime total load effect is given. Bivariate extreme value analysis has been used throughout, in conjunction with bootstrapping techniques. It is shown that the dynamic allowance appears to reduce with increasing load effect and that, for the bridge and traffic studied, the dynamic allowance required is 5.8% of the static load effect. Whilst this particular dynamic allowance is specific to this bridge and traffic, the method presented is general, and the convergence of dynamic allowance to low values is thought to be general also. However, such an inference does not currently have sufficient evidence to hold for the general population of bridges and traffic characteristics. Therefore more studies of different bridges and traffic characteristics are required to determine the general nature of the problem.

Further details of this study are given in [1] and [2].

1. Caprani, C.C., González, A., Rattigan, P.H. and OBrien, E.J. (2006): 'The calculation of characteristic dynamic effects of traffic loading on bridges', *Journal of Bridge Engineering, ASCE*, under review.
2. Caprani, C.C. (2005): *Probabalistic Analysis of Highway Bridge traffic Loading*, PhD Thesis, School of Architecture, Landscape and Civil Engineering, University College Dublin, Ireland.