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Autor: Bailey, Simon / Bez, Rolf
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Site Specific Traffic Load Models for Bridge Evaluation

Modèles de charge de trafic actualisés pour l'évaluation de ponts-routes

Nachgeführte Verkehrslastmodelle zur Beurteilung bestehender Brücken

Simon BAILEY
Research Engineer
Swiss Fed. Inst. of Technology
Lausanne, Switzerland

Simon Bailey, born in 1963, graduated from Southampton University, UK, in 1984 and joined a firm of consulting engineers in London. Since 1990, at ICOM, he is currently preparing a doctoral thesis on bridge evaluation.

Rolf BEZ
Research Associate
Swiss Fed. Inst. of Technology
Lausanne, Switzerland

Rolf Bez is a graduate of EPFL, where he also received his doctorate. Since 1980 he has been working at ICOM, mainly in the field of bridge loading. He is the Swiss Technical Contact for traffic loads on road bridges for Eurocode 1.

SUMMARY

This paper describes work carried out to develop a method for considering actual traffic loads during bridge evaluation. This method is based on the use of load correction factors which have been determined using a probabilistic analysis of bridge loads and resistance. Load correction factors and used in order to modify load effects calculated using a design traffic load model. This approach enables the accurate evaluation of bridges which carry a known traffic. If this traffic is less aggressive than that assumed by the design loading code, acceptable reliability may be verified for structures which are damaged or deteriorated, thus avoiding the need for strengthening or traffic restrictions.

RÉSUMÉ

Cet article décrit une méthode considérant les charges de trafic actuel pour l'évaluation de ponts existants. Elle est basée sur l'utilisation de facteurs de correction, déterminés par une analyse probabiliste des charges de trafic et de la résistance des ponts. Ces facteurs sont utilisés pour modifier l'effet des charges calculées avec des modèles de charge de trafic selon des normes de dimensionnement. Cette approche permet une évaluation précise de ponts sur lesquels circule un trafic connu. Si ce trafic est moins agressif que prévu par les normes de dimensionnement, une sécurité suffisante peut être vérifiée pour des structures endommagées, évitant ainsi des renforcements ourestrictions de trafic.

ZUSAMMENFASSUNG

Der Artikel beschreibt eine Brückenbeurteilungsmethode, welche das reelle Verkehrsaufkommen berücksichtigt. Die Methode verwendet Lastkorrekturfaktoren, die auf einer probabilistischen Untersuchung des Verkehrsaufkommens und des Tragverhaltens von Brücken basiert. Die Lastkorrekturfaktoren modifizieren die in den Lastnormen berücksichtigten Lastmodelle. Diese Annäherung ermöglicht eine genaue Beurteilung von Brücken unter bekanntem Verkehrsaufkommen. Falls das Verkehrsaufkommen kleiner als jenes der Lastnormen ist, kann die genügende Zuverlässigkeit eines beschädigten Tragwerks nachgewiesen und Verstärkungsarbeiten oder Verkehrsbeschränkungen verhindert werden.

1. INTRODUCTION

1.1 Motivation

Road traffic load models which are used for design are inherently conservative because of the high uncertainty about traffic loads at the design stage and because the models must be valid for structures of all types and sizes. The increased cost of construction due to the use of a conservative design load model is small and necessary to allow for uncertainty and to simplify the design process. However, once a structure is in service, the cost of an over-conservative evaluation could be much greater, thus justifying the use of an approach which considers actual traffic and the effects it produces in a given structure.

The most accurate way for an engineer to consider actual traffic would be to carry out a probabilistic analysis using site traffic data. However, this is a time consuming process, involving a considerable understanding of probabilistic methods, and could only be justified for the assessment of a major structure. The aim of the study described in this paper was therefore to develop a simple method for the consideration of site specific traffic loads as a function of parameters describing the bridge and traffic, referred to as site characteristics.

1.2 Approach

The proposed evaluation method uses correction factors which are applied to effects calculated using the design traffic load model in order to consider actual traffic. Figure 1 illustrates the probabilistic approach adopted for deriving these factors. This approach is based on the comparison of live load carrying capacity (R-G) and applied traffic loads (Q). An underlying criterion is that the target reliability implicit in a bridge evaluation must be equal to that implied by the existing design codes. The main stages of this approach are outlined below.

① The reliability of a structure designed using the design codes is calculated, considering an aggressive highway traffic which is taken as the traffic represented by the design loading code. The reliability index thus calculated is denoted β_{des}.

② The calculation is repeated considering an updated traffic representing the actual loading of an existing bridge. A reliability index β_{actual} is calculated, which is generally greater than β_{des} because the traffic which actually passes over a structure is less aggressive than that assumed at the design stage.

③ The aim is then to find a factor, α, by which the live load carrying capacity of the structure can be divided in order to produce a reliability index, β_{eval}, equal to β_{des} for the actual traffic.

④ The factor α could also be defined as that by which the actual traffic loading could be multiplied in order to produce a reliability β_{eval} for $(R\text{-}G)_{des}$. If we compare ① and ④ we note that $\alpha Q_{actual} \approx Q_{des}$.

⑤ We can therefore allow a live load carrying capacity which is lower than that assumed for design and still have a reliability $\beta_{eval} = \beta_{des}$.

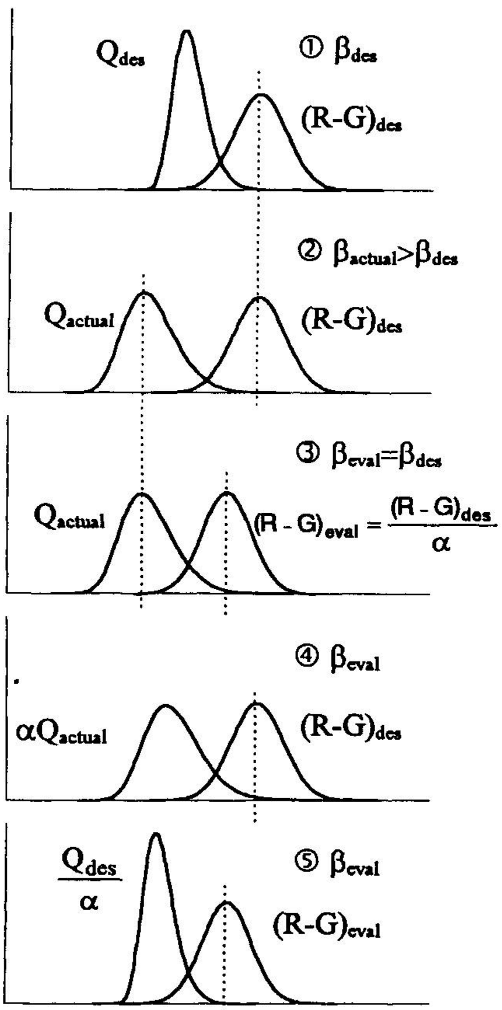

Fig. 1 Probabilistic basis for the determination of traffic load effect correction factors

Correction factors derived in this way can then be used in a deterministic evaluation of a bridge, using the same partial factor formulation adopted in design codes ;

$$S_d = S\left(\gamma_G G_m + \gamma_Q \frac{Q_r}{\alpha}\right) \leq \frac{R}{\gamma_R}$$

2. TRAFFIC LOAD EFFECTS

Traffic load effects on a given bridge may be described by a certain frequency distribution, which in turn determines the load effect values to be considered in limit state calculations. The first goal of this study was therefore to identify the most suitable probabilistic model for this frequency distribution. Subsequently, a parametric study of the influence of certain site characteristics on this probabilistic model was carried out.

It would be very difficult, if not impossible, to use analytical methods in order to derive frequency distributions of traffic load effects from a complete statistical model of traffic loads. An analytical approach would only be feasible for a simplified representation of traffic, which could compromise the validity of results. The study described in this paper has therefore been carried out with the aid of a numerical simulation program in which random traffic loads were generated for defined traffic types and effects calculated for different structures. A description of this program and the modeling of traffic loads is given in [1, 2].

Traffic load simulations have shown that a type III extreme value distribution provides the best probabilistic model for maximum traffic load effects. This type of distribution results when maximum values are sampled from a frequency distribution having a finite upper bound which is approached polynomially [6]. The cumulative probability density function for maximum values, s^*, is :

$$F_{s^*}(s^*) = \exp\left[-N \cdot \left(\frac{W - s^*}{\chi \cdot W}\right)^k\right]$$

In this expression it can be seen that a type III extreme value distribution is characterized by four parameters; W, k, χ, and N. The parameter W is the finite upper bound, k is an inverse measure of the dispersion of the distribution and the parameter χ influences the position of the mean with respect to the maximum value, W. The parameter N is a measure of the return period for the maximum value, which in this case is the number of vehicles which pass over a structure within the period of interest.

Simulation results have been used to investigate the relationships between site characteristics and the parameters of fitted type III extreme value distributions of maximum traffic load effects. It was found that W can be calculated using the 99.9% fractile values of total vehicle weight and vehicle weight per unit length. These values of point load and uniformly distributed load are placed independently on the appropriate influence surface and the most unfavorable load case is adopted (for short span bridges, the point load predominates). The parameter k is proportional to the number of vehicles that contribute to the maximum effect and the standard deviation of vehicle loads. For the effects and structures simulated, k varied between 8 and 40. The parameter χ is determined by the form of the frequency distribution of vehicle loads, and varies between 0.75 and 1.1.

The results of fitting type III extreme value distributions to simulated traffic load effects were used for the probabilistic analysis of bridge loading and resistance, with distribution parameters being varied in order to represent different types of traffic. This is described in the next section.

3. PROBABILISTIC ANALYSIS OF BRIDGE LOADING AND RESISTANCE

As described in section 1.2, the determination of load correction factors was based on a probabilistic analysis of bridge loading and resistance. A first order second moment method was used in order to calculate a reliability index for different types of bridge, sections, materials and load effect. This index was used as the basis for comparing the effect of different types of traffic. Bridge deck sections were designed according to Swiss design codes in order to identify the critical limit state functions and to determine appropriate values for design variables.

The probabilistic characteristics assigned to design variables are summarized in Table 1. Values were selected as a result of a literature study of work by others [3, 4, 5, 7]. These values are not critical since the reliability indices were used only for comparing different types of traffic, but it is important that their selection is realistic so as to reflect the relative importance of traffic loading within limit state functions. Different traffic types and flow conditions were adopted in order to cover highways, main roads and feeder roads, with unrestricted and restricted traffic (limited to 16 tonnes maximum gross vehicle weight and vehicle crossing prevented). The different types of traffic considered are presented in Table 2.

Variable		Dist. type	Bias (mean / nominal)	Coeff. of variation
Steel elastic limit	rebar	LN	1.25	0.10
	prestress	LN	1.05	0.04
	plate	LN	1.19	0.08
Concrete strength		N	1.28	0.11
Sectional dimensions		N	1.0	0.01
Traffic loads		Ex III	see section 2	
Self-weight	steel	N	1.05	0.03
	concrete	N	1.05	0.10
Permanent loads		N	1.05	0.25

Table 1 Probabilistic characteristics of design variables

Type	Lanes	Route	Limits	N_{vehs} ($x10^6$)	Years
0	2 →	highway		250	50
1	1 →	highway	≠	2.5	1
2	2 →	main		250	50
3	2 ↔	main		250	50
4	2 ↔	feeder		125	50
5	1 →	main	≠	125	50
6	1 →	feeder	≠	65	50
7	2 →	main	16t	250	50
8	2 ↔	main	16t	250	50
9	2 →	feeder	16t	125	50
10	2 ↔	feeder	16t	125	50
11	1 →	main	16t, ≠	125	50
12	1 →	feeder	16t, ≠	65	50

↔ : bi-directional, → : unidirectional
16t : total weight restricted to 16 tonnes
≠ : vehicle crossing prevented

Table 2 Types of traffic

Limit state functions were formulated for midspan moment and support moment for composite, reinforced concrete and prestressed concrete box-section and slab-on-beam continuous bridges of different span lengths. All bridges studied carried two lanes of traffic. In total, 13 different types of traffic were considered for 19 limit state functions.

4. TRAFFIC LOAD EFFECT CORRECTION FACTORS

Using the probabilistic approach outlined above, traffic load effect correction factors were derived for different types of traffic. Figure 2 shows the factors calculated for support bending moment in composite slab-on-beam bridges. It can be seen that there is very little variation in correction factor as a function of bridge span and that the variation is mostly due to a change in traffic type. This was found to be the case for all structures considered. Similarly, correction factors were found to be approximately equal for midspan and support moments in the same structure. However, it was found that factors were significantly higher for box section bridges than for slab-on-beam bridges, particularly for the case of a traffic where vehicle crossing is prevented.

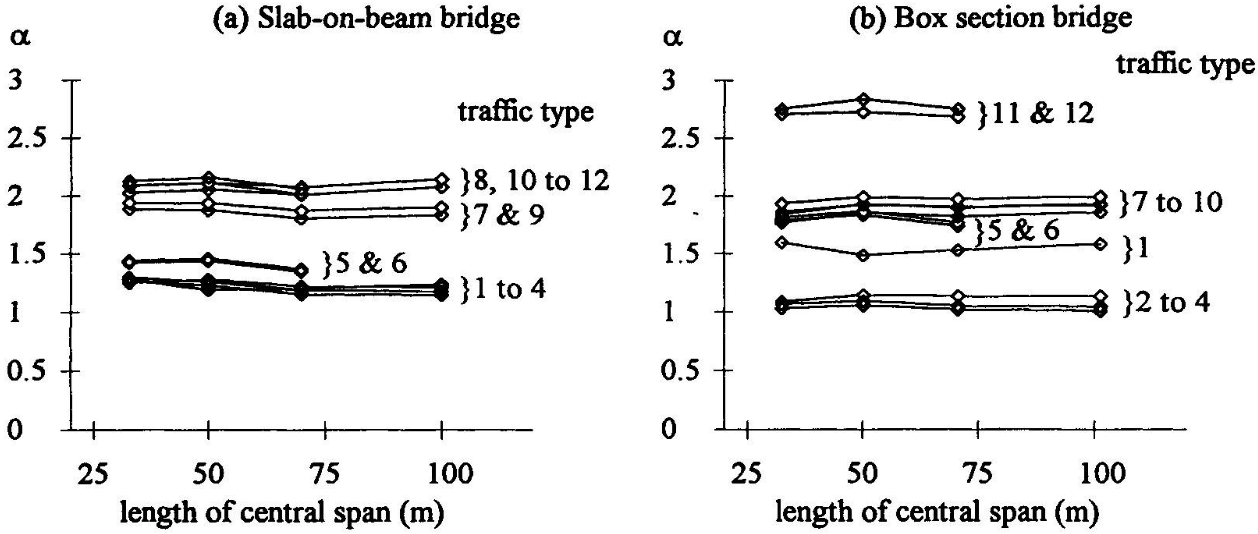

Fig. 2 Traffic load correction factors calculated for support bending moment in composite bridges

Figure 3 shows, for all the cases considered, the calculated factors as a function of traffic type. It can be seen that even though there is some variation in values as a function of effect type, bridge type and length of central span, a clear relationship between traffic type and minimum correction factor emerges.

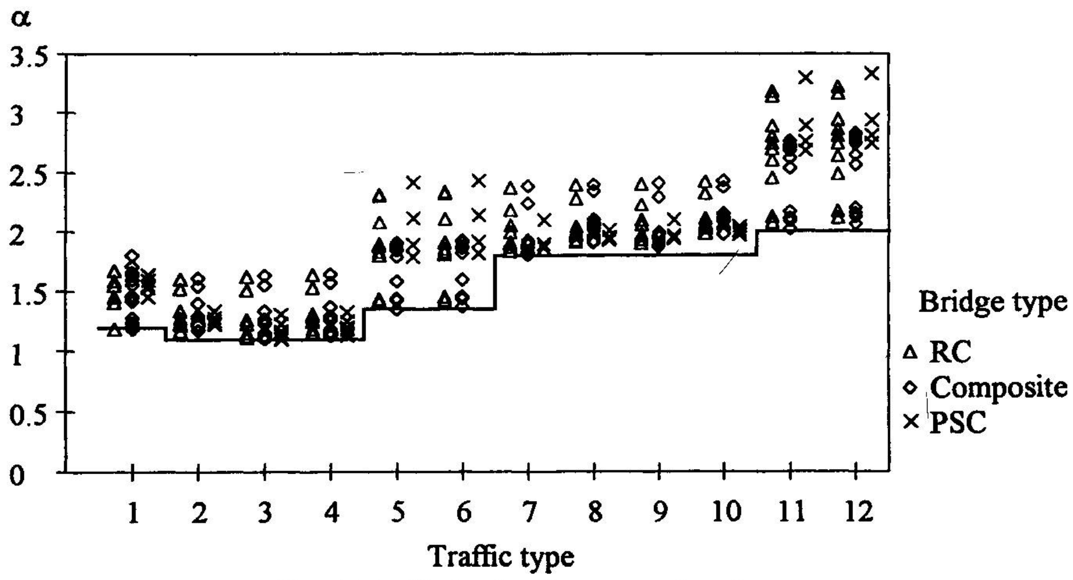

Fig. 3 Traffic load effect correction factors

The design traffic load effect correction factors ranged between 1.1 and 3.3 as shown in Figure 3. For the purpose of providing the simplest set of values for practical bridge evaluation it was decided to propose minimum factors as a function of only traffic type. These values are given in Table 3. It would however be possible to make more distinction between different types of bridge, and possibly even the type of load effect, in order to have a greater range of correction factors, and this is currently under review.

Route	Vehicle crossing prevented	Free traffic	16 tonne limit
Highway	no	1.00	-
	yes	1.20	-
Main or feeder	no	1.10	1.80
	yes	1.35	2.00

Table 3 Traffic load effect correction factors as a function of traffic type

The approach used for deriving correction factors relies solely on a comparison of different types of traffic and is largely independent of partial factors adopted by the design codes. The same method could therefore be used for deriving correction factors for other loading codes.

6. CONCLUSIONS

The results of this study are summarized as follows :

- Relationships have been found which enable the frequency distribution of maximum traffic load effects to be determined as a function of site characteristics. These relationships were used as the basis of a comparison of the effect of different traffic types within a probabilistic analysis of bridge loading and resistance.
- Traffic load effect correction factors have been determined which enable the effects calculated using the Swiss design traffic load model to be modified as a function of site characteristics for the purpose of deterministic bridge evaluation.

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