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A methodology for calculating congested traffic characteristic loading on long-span bridges using site-specific data

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ABSTRACT

A probabilistic methodology is developed for the evaluation of characteristic maximum traffic load on long-span bridges for which congestion is the governing condition. It considers all the congestion types that can occur such as stop-and-go waves and oscillating congested traffic. The approach uses site-specific traffic data, such as flow and incident data. Statistics on driver behaviour and traffic incident frequency are assembled from the literature. As an example application of the method, a calibrated traffic microsimulation model is used to obtain the input data for the proposed methodology. The results counter many of the prevailing assumptions for long-span bridge loading.

1. Introduction

Traffic loading for long-span bridges is not addressed in most codes of practice and available load models for shorter spans are often based on simplified and conservative assumptions. Recently, traffic micro-simulation has been used to achieve more realistic representations of traffic, with the notable advantage that widely-available Weigh-in-Motion (WIM) data can be used in simulations of congested traffic scenarios. OBrien et al. [31] study a long-span bridge in the Netherlands and calibrate a commercial micro-simulation tool using WIM data, videos and strain gauge measurements. Chen and Wu [10] use the cellular automaton approach (initially proposed by Nagel and Schreckenberg [29]), in which the bridge is divided into 7.5 m cells. However, the cellular structure does not allow for the variability of vehicle lengths and gaps between vehicles, and this is quite important in bridge loading. Caprani [5] uses micro-simulation to calibrate a simple congested load model for short- to medium-length bridges.

A probabilistic approach to long-span bridge loading requires the expected number of congestion events over the specified reference period. Ricketts and Page [37] acknowledge the importance of congestion frequencies. They state that only standstill traffic is critical for bridge loading, and that this happens for only 2% of the congested time. For the background work to the ASCE long-span bridge load model [12], Buckland et al. [3] assume 800 standstill traffic events per year, with 15% of them involving two or more lanes. The Flint and Neill Partnership [15] assumes one jam with a queue with vehicles at minimum bumper-to-bumper distances for every 80000 km travelled (equal to 12.5 jams for every million vehicle kilometre travelled). Ditlevsen and Madsen [13] consider a queue occurrence of 1.27 queues per km and per year, based on data from a German motorway. In a companion work to this paper [32], realistic congestion frequencies are used to compute bridge loading for sites exposed to congestion on a daily basis (a form of recurrent congestion, as will be explained in Section 2). However, many existing highway bridges, especially in rural areas, do not experience congestion frequently, if ever. In general, bridges carrying low or moderate traffic are less exposed to extreme scenarios than bridges over busy roads. In other long-span bridge loading studies it is not clear which congestion frequencies are considered [19,36,30,10].

It is clear that a modelling framework is needed that takes into account different congestion states and their frequency of occurrence. The types of congestion have not been comprehensively considered in most previous research. In recent times, data about traffic disruptions is becoming increasingly available, especially due to traffic incidents, and this information can be used to good effect in traffic loading studies.

In this work, a methodology is proposed to compute characteristic load from a consideration of different congestion states and their frequency based on site-specific traffic features.

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Micro-simulation is used to model traffic congestion. This methodology is applicable to existing long-span bridges that do not suffer from recurrent congestion, but only from occasional congestion due to unpredictable events (non-recurrent congestion), such as incidents. Data from the literature is used to apply the proposed methodology for computation of total loading on three long-span bridges with two same-direction lanes. The influence of several traffic features and assumptions on the characteristic load is analysed. The methodology is general and can be extended to any load effect of interest, multiple lane roadways or site-specific traffic features.

2. Non-recurrent congestion

Congestion is typically divided into non-recurrent and recurrent. Oddly, this classification is not usually made on their frequency, but rather on the cause. *Non-recurrent congestion* is caused by incidents, work zones, special events or inclement weather [14]. Among those causes, incidents have the biggest impact [4,26]. They are typically unpredictable and infrequent. *Recurrent congestion* is caused by anything else (the main example being insufficient road capacity). In this case, the jam location is typically easy to predict (for instance in proximity of an on-ramp at peak hours) and congestion often happens on a daily basis.

2.1. Incidents

An incident can be defined here as any event caused by one or more vehicles that reduces the road capacity, such as collision or breakdown. Accidents are incidents that results in significant damage or injury. Whereas data about accident frequency is abundant in the literature, data about incident frequency is more limited, although it is becoming increasingly available. Incident rates, I_r, are usually given as the number of incidents per million vehicle kilometres travelled (I/MVkmT). The total number of incidents, N_t, over a stretch of road, L (km), and a certain period, t (day), with average daily traffic, ADT (veh/day), is:

$$N_t = \left[\frac{I_r \cdot ADT \cdot L}{10^6}\right] t \tag{1}$$

Incident rates vary greatly. Many factors can affect the measured rate: inclusion of very small incidents, different incident detection techniques (e.g., cameras, patrols, tow trucks, loop detectors), different definitions of what is considered to be an incident, or site-specific differences in alignment and layout.

Incidents may be classified by their cause (collision, breakdown, etc.), severity (injuries, property damage, etc.), location (shoulder, driving lane), or number of lanes blocked. This latter parameter is most relevant to long-span bridge loading as it affects the road layout, reducing the road capacity and being a potential source of congestion. However, the majority of incidents do not block driving lanes. The proportion of incidents causing the closure of one driving lane can be up to one third [44]. Unsurprisingly, smaller proportions are found for closures of two or more lanes. Incidents causing the closure of two or more lanes are here considered to fully block the road, so the corresponding rate is named *full-stop rate*, FS_r (FS/MVkmT), which corresponds to the full-stop situation commonly referred to in the long-span bridge loading literature (see Section 1).

The incident rates and the proportions of lane-blocking incidents that can be deduced from several studies of observed incident data are summarised in Table 1. It is clear that the values vary significantly from site to site. Surprisingly, while the incident rates are spread over a wide range, the full stop rates extend over a much smaller range. This may be due to the fact that many small incidents can be unnoticed, while it is unlikely for a large incident causing lane closures to go unrecorded. It is notable that the full stop rates in Table 1 are much lower than the 12.5 FS/MVkmT used by the Flint and Neill Partnership [15] in the UK interim design standard. Only the most complete and relevant studies for bridge loading applications are reported in Table 1. Further details can be found in the quoted studies and in OBrien et al. [32]. Several other studies about incidents are available [38,33,34,14,2,25,35].

2.2. Capacity reduction

Once an incident occurs, the road capacity, $Q_{\max}$, is reduced. The capacity $Q_{\max}$ can be defined as “the maximum number of vehicles than can pass a given point during a specific period under prevailing roadway, traffic, and control conditions” [46]. Clearly, a full road blockage leaves no capacity available, whereas a lane closure disproportionately affects the traffic in that the proportion of capacity available is less than the proportion of lanes closed. The Highway Capacity Manual (HCM) [45,46] reports that the capacity available drops to 35% when one lane out of two is blocked, whereas a shoulder accident drops the capacity to 81%. Knoop et al. [23] find a 28% reduction in the queue discharge rate, Q_{out}, from 20 shoulder lane closures on a 3-lane motorway in the Netherlands. The queue discharge rate, or *dynamic capacity*, Q_{out}, can be defined as the flow coming out of a queue and is less than the static capacity, $Q_{\max}$, which can be attained only in uncongested flow [20,9,46]. Roberts et al. [38] suggest an average 1-min flow of 1670 passenger cars per hour per lane (pc/h/lane) following a lane closure on a two-lane highway, which corresponds to an available capacity of 38% when both lanes are considered.

It is not clear whether the available capacities stated in the HCM and Roberts et al. [38] refer to the reduced capacity of the road, $Q'_{\max}$, or to the reduced queue discharge rate due to the incident, Q'_{out}. The HCM refers to capacity, without mentioning any queue discharge rate. However, to measure the reduced capacity, $Q'_{\max}$, the traffic should be uncongested. Otherwise, the reported values are to be understood as the queue discharge rates due to the incident, Q'_{out}. To clarify, Knoop et al. [23] state that “there has been no research on the maximum possible flow in free flow around an incident location”. Therefore, all the values in previous research are assumed here to be queue discharge rates in the presence of an incident Q'_{out}, and not reduced capacities, $Q'_{\max}$. Accordingly, the values from the HCM and Roberts et al. [38] are considered as the ratios of the queue discharge rates in the presence of an incident Q'_{out} to the corresponding (pre-incident) road capacities, $Q_{\max}$:

$$i = \frac{Q'_{out}}{Q_{\max}} \tag{2}$$

The capacity reduction is the complement of the capacity available, i.

2.3. Other causes of non-recurrent congestion

Work zones are included among the causes of non-recurrent congestion, but they are usually planned by the road agency, and thus they are easier to predict. The HCM suggests that the capacity at a short-term work zone is 1600 pc/h/lane, regardless of the lane closure configuration. Sarasua et al. [40] propose 1460 pc/h/lane. These values have to be adjusted for a heavy-vehicle adjustment factor f_{hv}, as the presence of trucks further reduces the capacity [46].

Inclement weather is another cause of non-recurrent congestion. Its probability of occurrence should be assigned based on site-specific expected weather conditions. The HCM suggests little