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Live Load Models for Long Span Bridges

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Abstract: **In the dissertation a live load model for long span structures was derived. The live load model is valid for spans between 600 ft. and 5000 ft. and it is intended to reflect current traffic patterns, quantities of trucks and their weights. The live load models available were developed for short and medium span bridges. Those models were not appropriate for long span bridges due to different types of structure and critical traffic patterns. Live load on long spans depends on traffic mix. One heavily overloaded truck does not have significant influence. Moreover, the continuous increase in the number of the trucks, their weights, and high percentage of overweight trucks led to a search for the newest traffic data. The database includes variety of sites within many different states. A numerical procedure was developed to process the database and simulate traffic jam situations. From the simulation the values of uniformly distributed load were derived. Results of the simulations were plotted as a cumulative distribution function of uniformly distributed load for considered span lengths. For longer spans, uniformly distributed load decreases and is closer to the mean value.**

I. INTRODUCTION

The live load models available were developed for short and medium span bridges. This doctoral dissertation deals with the development of a live load model for long span structures. The developed live load model is valid for spans between 600 ft. and 5000 ft. In contrast to short and medium spans, a long span live load must include the possibility of multiple trucks being present. The continuous increase in the number of the trucks and their weights led to a review of traffic data for live load. Observing traffic statistics helps to realize the rate of those changes, their importance, and to draw some conclusions regarding design. In the last 30 years, the number of the vehicle miles logged annually on American highways has increased 225%, with heavy truck traffic increasing 550%. Some percentage of trucks runs overweight, particularly if it is to their economic advantage. Therefore, a new live load model for long span bridges had to be developed and it had to be based on the newest traffic data obtained from highway and bridge administrators. During the AASHTO LRD calibration, the live load model for short and medium span bridges was developed based on a set of truck weight and load effect statistics that were presumed to be valid for any typical bridge site in the U.S. The live load model may not represent the actual loading conditions at a particular bridge site or bridges in a state. Nowadays, several states are using Weigh-In-Motion (WIM) systems to collect vast amounts of truck weight and traffic data that can be used to obtain site-specific and state specific live load models for bridge design and load capacity evaluation. This could allow individual states to adjust the AASHTO live load factors to take into consideration the particular truck traffic conditions throughout a state, a region, or for a particular route. Site-specific or state-specific live load models may be developed based on actual truck weight and traffic data collected at the site or within the state. Traffic varies for different sites within each state. As a result, site specific models depending on average daily truck traffic and participation of heavily loaded vehicles seem to be more practical. To amend this, a new approach to model uniformly distributed load had to be developed and new value of uniformly distributed load had to be proposed. Current multilane reduction factors and dynamic allowance also may not be appropriate for long span bridges. Review of those topics was necessary.

The structures and their components should be designed to have a desirable level of reliability, which would assure their good performance to account for actions applied during construction and service. For this purpose civil engineering uses a probabilistic evaluation of reliability. The design of new structures as well as the evaluation of existing structures requires verification of limit states, which when exceeded lead to structural failure (ultimate limit states) or make use of the structure impossible (serviceability limit states).

The actions (loads, Q) and structural resistance (capacity, *R)* are the variables that decisively influence the state of a structure. They include uncertainties coming from mechanical material properties, geometry of a structure, loads, etc. Those uncertainties can be measured only with the use of probability. Therefore, the design of structures is a process in which decisions are made under uncertainty and limits. Their rational treatment, and agreement between real-input data and a mathematical model of phenomenon, is a concern of structural reliability.

II.OBJECTIVE AND BENEFITS OF THE STUDY

The objective in this study was to develop a live load model for long span bridges. The model is valid for spans between 600 ft. and 5000 ft. It is intended to reflect current traffic patterns, quantities of trucks and their weights. The newest available traffic database from a variety of sites within many different states is used. Based on the analysis of traffic records (weigh-in-motion and videos) the design live load is developed and recommended to be taken into consideration in the bridge design code. Reliability analysis is used to verify the developed live load model. In accordance with the stated objective, the first stage was to study previous research and current international codes' provisions on the topic.

The second stage of the research was the collection of state of the art traffic data from highway and bridge administrators. The data obtained had to be analysed and filtered out from erroneous readings of measurement instruments. Then a new uniformly distributed load was derived. The magnitude of the database obtained for the scope of this research has to be underlined.

A derivation of uniformly distributed load from WIM data required developing a numerical procedure of calculation to process the extensive database. Cumulative distribution functions were plotted for all data, as well as for maximum daily and maximum weekly uniformly distributed load. New uniformly distributed load was proposed. Statistical parameters for live load (bias and coefficient of variation) are derived. Relationship between site characteristics (ADTT, percentage of overloaded loaded vehicles) and calculated values of uniformly distributed loads were studied. The problems of multilane reduction factors and the dynamic factor were also discussed.

The final step of this dissertation was reliability analysis. Reliability analysis was performed in order to assess how the increase in live load influences reliability indexes. An exemplary suspension bridge, the bridge component and a limit state function that are the most influenced by live load were selected.

The calculations were performed for the current AASHTO LRFD design live load and increased load values obtained from real traffic data. For the scope of this study, new statistical parameters for uniformly distributed load were used and statistical parameters of resistance were derived based on the newest material, fabrication and professional factors. The outcome of this research is the recommendation of a live load model for long span bridges. There is a recommended value of uniformly distributed load for bridges carrying low and average ADTT. In addition, there is a recommendation for an increase of the live load model for the long span bridges in heavily loaded urban and industrial areas.

III.PRIOR INVESTIGATIONS

- Prior Investigations on Live Loading on Short and Medium Span Bridges

Live load models for short and medium span bridges were of interest to many researchers. Most of the studies performed on live load models were based on truck data obtained within programs carried out by the Ontario Ministry of Transportation since the early 1970s. This was the vastest database available until now. The maximum load effects for various time periods from one day to 75 years were derived from extrapolated distributions. Single and two lane bridges are considered. For one lane traffic a single truck governs for shorter spans, and two following trucks govern for longer spans. For two lanes of traffic, the maximum effect is obtained for two trucks with fully correlated weights, travelling side-by-side. It has also been concluded that the bias factor (ratio of the mean to nominal value) is larger for smaller spans.

The maximum observed truck weights were up to 250 kips, causing maximum moments two times larger than AASHTO load and resistance factor design values. Gindy and Nassif (2006) formulated a similar conclusion based on data from New Jersey. It was found out that maximum gross vehicle weight reaches a value of 225 kips and it shows a steady increase at an annual growth rate is 1.2%. It has been proved that WIM measurements show the unbiased truck weights, which are 30-50 percent larger than extreme values obtained at weight stations.

The WIM data is unbiased because the drivers are not aware of the measurements and they do not make an effort to avoid the scales. The WIM measurements from Michigan have also been used to study dynamic load, Nassif and Nowak (1995). It was found out that the dynamic load factor decreases with increased static loads, and that larger values of DLF are observed in exterior girders due to relatively smaller static load effect.

- Prior Investigations on Live Loading on Long Span Bridges

The most widely known researcher in the field of live loading on long span brides is Peter G. Buckland (1978, 1980, and 1991). He concluded that traffic loading on long span bridges can be accurately represented in the traditional manner, by one set of uniform and concentrated loads. One of his findings was that uniform load per foot reduces as the load length is increased. However, unlike many other studies he found out that concentrated load increases as the loaded length increases. Four uniform loading curves were developed for different loading cases.

The load cases were distinguished depending on the percentage of “heavy vehicles”: 2.4, 7.4, 30.0, or 100 percent, where “heavy vehicles” are defined as trucks and buses over 12000 lb. These loading curves were recommended by the ASCE Committee as vehicle loading of long-span bridges, in 1981.

They are known unofficially as the ASCE Loading. However, they have never been applied into the design codes. Peter G. Buckland had also made a valuable observation regarding several loaded lanes. He stated that if a single lane has a certain load on it, than the additional lanes would increase the load in the lane closer to the curb, as trucks gravitate towards it. However, load in the additional lanes can be reduced.

This approach can be successfully used for short and medium span bridges. However, its application to long spans can be questioned, since long span bridges cannot be constructed as simply supported beams. This method of deriving the equivalent load can be used exclusively for comparison of codes.

- Prior Investigations on Structural Reliability

For many years the random nature of various parameters influencing structural safety has been of interest to engineers. Until they gathered more knowledge about the laws of nature, they used to assure structural safety through ‘trial and error’ and intuition. Mathematical theories available nowadays describe material and structural behaviour sufficiently enough to give a rational basis for structural safety evaluations (Nowak and Collins, 2000). Early publications that quantified and presented a mathematical formulation of structural safety problems were published by Mayer (1926) and Wierzbicki (1936). They recognized that load and resistance parameters have random characteristics, and that each structure has a finite and limited probability of failure.

Their concept of a structural reliability problem has been subsequently adopted in the precursory publication for that field by Freudenthal (1956). In the 1960s, a new trend in using probabilistic concepts in the analysis of limit capacity and structural resistance was developed. The extensive development of practical tools and efficient methods for evaluating the probability of structural failure has been made in the last 30 decades. Initially, the probability of failure was defined by multidimensional integral functions of distributions and it was cumbersome to evaluate.

Bridges usually consist of a combination of series and parallel systems. Identification of collapse mode and degree of correlation between members is very difficult or often even impossible to evaluate. Moses (1982) proposed incremental load approach and suggested a procedure for identifying collapse mode for both ductile and brittle components.

IV. PROVISIONS FOR DYNAMIC LOAD FACTOR

There is considerable variation in the treatment of dynamic load effects by bridge design codes in different countries. The most common approach is to apply dynamic response as a fraction or multiple of the response that would be obtained if the same forces or loads were applied statically. The objective of this simple approach is to not increase complexity to the designer.

The American Association of State Highway and Transportation Officials Standard Specifications for Highway Bridges AASHTO LRFD [2007] define that dynamic load allowance shall be applied to static load effects of the truck or tandem, as a percentage specified in the table below. It shall not be applied to pedestrian loads or to the design lane load.

V. STANDARD VARIABLES AND PROBABILITY DISTRIBUTIONS

The key probabilistic characteristics of a random variable are described in terms of mean, variance and standard deviation. A distribution function would complete the description of the probabilistic characteristics of random variables, but sometimes it remains unknown. There are two types of random variables: discrete and continuous. A discrete random variable may take on only discrete values. Its probability is given by the probability mass function, ( ) *X i P x*. A continuous random variable can take on a continuous range of values, and its probability is defined by the probability density function (PDF), $f(x)$ *X*.

VI. LIMIT STATE FUNCTION

In most design codes, the structural design is based on the concept of limit states. The philosophy of limit state design assumes equilibrium between applied

loads and structural response of the structure (capacity, resistance). Therefore, a specified set of load and resistance factors is required for each limit state formulated for different possible scenarios of structural behaviour during construction as well as service life.
Three types of limit states are typically used with reference to structural reliability analysis:

1. Ultimate limit states (ULSs), which represents the loss of structural capacity.
2. Serviceability limit states (SLSs), which represents failure due to deterioration of functionality.
3. Fatigue limit states (FLSs), which represents the loss of strength for a structural component under the action of repeated loading.

The limit state defines the boundary between the desired and undesired performance of a structure, between situations when the structure is safe (a safety margin exists) and the structure is not safe (failure occurs). The probability of the desired performance of a structure is equal to the safety margin.
The concept of second-moment is often used in practical quantification of safety and reliability. It has been extensively used in calibrations of structural design codes. The FOSM approach can be put into several categories with regard to accuracy of results, required input data, computing cost, or simplicity of formulation.

VII. SUMMARY & CONCLUSIONS

In the study, a live load model for long span structures was derived. The live load model is valid for spans between 600 ft. and 5000 ft. and it is intended to reflect current traffic patterns, quantities of trucks and their weights. The developed live load model is recommended to be taken into consideration in the bridge design code. Preliminary study was performed by reviewing previous research and current provisions of international codes on the topic. Equivalent uniformly distributed load is calculated and compared.
The new live load was developed based on three models: an average 5-axle truck, legal load trucks and simulation of a traffic jam using WIM data. The newest available traffic database from a variety of sites within many different states was obtained. The magnitude of the database has to be underlined, because such an extensive actual weigh in motion database has never been used in the derivation of live load for any kind bridges.
A numerical procedure was developed to filtered out WIM data from erroneous readings and to simulate traffic jam situations. From the simulation the values of uniformly distributed load were derived for a variety of span lengths and site localizations. In the developed procedure, starting with the first truck, all consecutive trucks were added with a fixed clearance distance between them until the total length reached the span length.
Then, the total load of all trucks was calculated and divided by the span length to obtain the first value of the average uniformly distributed load. Next, the first truck was deleted, and one or more trucks were added so that the total length of trucks covers the full span length and the new value of the average uniformly distributed load was calculated. Trucks were kept in actual order, as recorded in the WIM surveys. Results of the simulations were plotted as a cumulative distribution function of uniformly distributed load for considered span lengths. The obtained mean value oscillates between values of 0.50 and 0.75 k/ft. Cumulative distribution functions were also plotted for maximum daily and maximum weekly combinations of trucks. For longer spans, uniformly distributed load decreases and is closer to the mean value.

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