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A new live load model for bridges carrying light rail transit

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ABSTRACT

This paper presents the development of a standard live load model for light rail bridges. It is recognized that the absence of a standard load model causes design outcomes varying from agency to agency, which is problematic from performance and reliability standpoints. A blend of deterministic and probabilistic approaches is employed to propose a new load model. Pursuant to light rail transit guidelines, benchmark bridges are designed (steel plate, prestressed concrete multicell box, reinforced concrete tee-beam, prestressed concrete I and bulb-tee, and steel box girder bridges). Finite element analysis is conducted to examine the response of the bridges when loaded by representative light rail trains operated in the United States (Colorado, Massachusetts, Minnesota, and Utah). Parametric investigations in conjunction with numerous loading configurations (48,256 model cases) characterize light rail train loadings, and corresponding results are exploited to determine the extreme bending moments and shear forces of the bridges at four probability levels (the average, upper 20%, 99.9%, and 75-year categories). The upper 20% model shows load effects similar to the standard live load model (HL-93) of the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (BDS). The 99.9% and 75-year models envelop the moments and shear forces resulting from the representative light rail trains. These candidate load models are further assessed against site-based load inference. The 75-year model is selected and proposed to be the standard live load model entitled LRT-16 (a uniformly distributed load of 14 kN/m plus three axles of 150 kN at a spacing of 4.3 m, which is configured similarly to those of HL-93 in AASHTO LRFD BDS). The applicability of the standard load model is evaluated using 33 light rail tra.

1. Introduction

The design of bridges subjected to light rail transit has frequently been conducted using the American Association of State Highway and Transportation Officials (AASHTO) Specifications. TRB [1] mentions that old transit systems, such as Chicago and New York, were designed using the American Railway Engineering and Maintenance-of-Way Association (AREMA) manual, whereas new systems, such as Atlanta and Baltimore, were designed in accordance with the AASHTO Specifications. Some state agencies permit the Allowable Stress Design (ASD) method for light rail structures [2]. In 2007, the Federal Highway Administration mandated that light rail bridges be designed as per the AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications (BDS) [1]. TCRP 155 states that there is no design code for light rail transit in the United States [1]. It also discusses that the AASHTO Specifications and the AREMA manual cannot fully address the need for designing light rail bridges because most light rail trains are heavier than HL-93/HS-20 [3], but lighter than Cooper E80 [4]. Several transit agencies have developed their own design specifications for bridges carrying light rail transit loading (agency-specific loading substantially varies from 578 kN to 720 kN per train, for example, as detailed in a subsequent section).

The most critical concern in light rail bridge design is the absence of a standard live load model. Current practice is based on the historical engineering judgment and experience of individual transit agencies. As a result, there is a dearth of uniformity in the level of safety or reliability for bridges designed to resist loadings from light rail transit trains across the United States. Probability investigations are imperative when a load model is developed, because the effects of live load are controlled by numerous random variables (e.g., vehicle weight, loading position, traffic volume, and bridge configuration). The AASHTO LRFD live load model (HL-93) was developed in 1993 [5], and was assessed using 22 exclusion trucks (load-enveloping). It is likely fair to state that the development of the HL-93 loading was a blend of what could be termed “traditional methods (load-enveloping)” and more “modern methods (probability-based methods)”. The quantification and management of uncertainty provides structural engineers with a much better measure of how safe a structure is or what the true level of safety is. At the same

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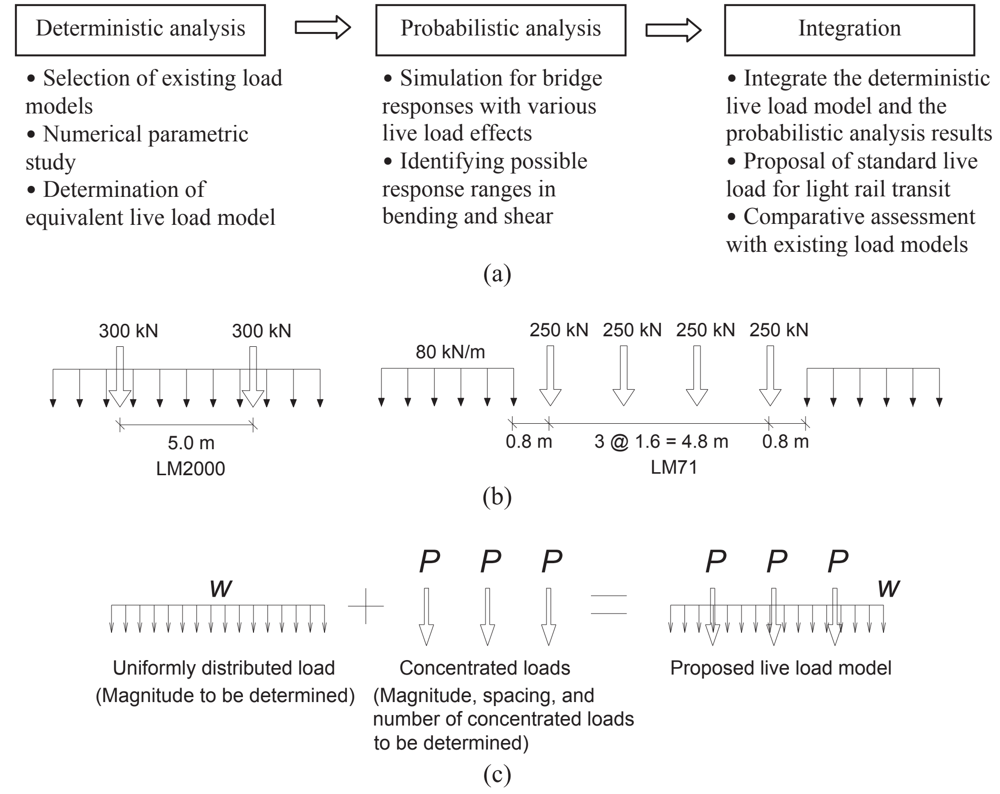

Fig. 1. Background of model development: (a) schematic of procedures for determining the standard live load model of light rail transit; (b) European train load models; (c) proposed standard live load format.

time, though, it is probable that not as much time, effort, and monies have been expended on research and development efforts over the years on railway bridge engineering as compared with highway bridge engineering. Thus, the highway bridge engineering community likely had much more technical data (e.g., in-situ responses) to work with than is available for light rail transit. As such, the blend of traditional methods and modern methods had to lean more toward emphasizing the modern methods. All possible known vehicle configurations are not technically available, unless significant dollars and time are invested as is the case for highway bridges which possess a substantially long history and abundant technical data. Probability-based modeling is, therefore, an inevitable (and robust) technical option in determining a load model for light rail bridges.

This paper presents a new live load model for light rail bridges based on finite element modeling using various bridge configurations along with representative light rail trains in the United States (48,256 cases). Predictions are probabilistically interpreted to ensure the load effects generated by the light rail trains are reasonably conservative and reliable. Because information on light rail loading is extremely rare, a rigorous and careful evaluation is important. The load effects (moment and shear) induced by probability-based candidate load models are compared with those generated by existing train loads (load-enveloping with 33 light rail trains), and further assessed using site-data-based probability prediction to justify the use of the proposed standard live load model, which comprises a combination of concentrated and uniform loadings at set spacings, which will quantify and encompass (or envelope) loading effects. The proposed standard live load model is flexible enough that it can address potential increases in axle loads and modified train configurations in the future. It is emphasized that the objective of using a notional live load model for bridge design (either highway bridges or rail bridges) is to conveniently predict the behavior of bridges subjected to certain types of loadings. As long as the model generates reliable bridge responses from design perspectives, its configuration does not matter and there is no need for alteration. For example, the European train models [6] completely differ from the Cooper E80 of AREMA [4]; however, the models generate reliable structural responses and are used in practice.

2. Background

The AASHTO Specifications and the AREMA manual do not provide accurate loading information when designing light rail bridges [1]. The conservative bridge design required by the AREMA manual may not be applicable to light rail bridges. The types and configurations of light rail trains operated in the United States vary depending upon manufacturers. Consequently, the loadings actually experienced by structures entail a certain level of uncertainty or a lack of surety with regard to actual axle load magnitude and axle spacing (these loadings and spacings are not deterministic). Probability-based live load calibration is a tool that allows for the quantification and management of uncertainty. A blend of deterministic and probabilistic approaches may be used in the development of a live load model for light rail train gravity loadings. This dual-faceted methodology maximizes the utility and information garnered from each approach (i.e., rapid development of a base or benchmark load model using the results from deterministic finite element models and then subsequently addressing uncertainty by conducting probability analyses with the data produced by the models). Another important aspect of developing a standard live load model is its practical convenience for bridge designers who are familiar with AASHTO LRFD BDS and its similarity to highway traffic gravity loadings (HL-93). With this in mind, the standard light rail load model should be as close as possible to the HL-93 in configuration (e.g., number of axles) and application. The standard live load model for light rail train loadings should consider the following aspects:

- Integration and consideration of existing light rail train load models used by various transit agencies
- Similarity with the live load model of AASHTO LRFD BDS