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Numerical investigations into the behavior of light rail bridges

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ABSTRACT

This paper presents various technical aspects related to bridges under light rail gravity loadings, including flexural and shear responses, deflection, serviceability, and dynamic load allowance. Unlike highway and conventional rail bridges, the behavior of light rail bridges has scarcely been reported; thus, limited information is available. Five types of benchmark bridges are designed with steel plate girders, prestressed concrete boxes, reinforced concrete T-girders, prestressed concrete I-girders, and closed steel box girders. Three-dimensional finite element models are developed to predict the behavior of these bridges when loaded by four representative light rail trains operated in the United States (Colorado, Massachusetts, Minnesota, and Utah), which results in 4,932 cases. Parameters for investigations involve structural configurations (simply-supported and continuous spans), geometries (girder spacing, span length, curvature, and skew), and loading characteristics (one-track-loaded and two-track-loaded with one to four articulated trains). A comparative study is conducted to evaluate the applicability of existing design specifications (highway and heavy-haul train loadings) that are frequently referenced in light rail bridge design. The flexural moment of the bridges is controlled by span length, the number of loaded tracks, and the axle spacing of the articulated trains. Contrary to the implications of horizontal curvature, those of skew angles are significant in altering the responses of the bridges concerning moments and fundamental frequencies. The deflection criteria of the existing specifications are not applicable to the light rail bridges; consequently, an alternative approach is suggested. Regarding dynamic load allowance, the predicted values are generally lower than those used in practice.

1. Introduction

Light rail systems in the United States cover more than 23 major cities and transport over 1.6 million passengers weekly [1,2]. Direct fixation tracks with continuous welded rails are broadly employed in the design of modern light rail bridges (ballasted tracks may not be preferred owing to self-weight and the needs for maintenance). The configuration of light rail trains differs from those of both traditional heavy-haul trains (e.g., wheel diameters and track gages) and highway vehicles (e.g., load magnitudes with multiple axles). As a result, the behavior of bridges carrying these transportation modes varies. Unlike the case of bridges carrying highway and heavy-haul train loadings, information on bridge responses under light rail loadings is scarce, which may restrict the efficient design of light rail bridges. Further information is available in TRB [1], which provides a comprehensive review of light rail trains and their background.

The present practice of light rail bridges is largely reliant upon the experience gained from field observations/testing and the adoption of existing provisions stipulated in specifications for highway vehicles and heavy-haul trains. This is attributed to a dearth of technical investigations into the behavior of bridges carrying light rail transit (in other words, the load responses of light rail bridges are known only on a limited basis, and insufficient data have been reported previously). It is also recognized that capital investment in rail bridges is relatively limited compared with highway bridges [3]. Albeit scant, a few papers discussed preliminary results related to light rail bridges. Yuan et al. [4] carried out in-situ monitoring for bridges under light rail trains and variable environments. The effects of thermal loading were presented along with bridge deflections. Khan et al. [5] instrumented a prestressed concrete girder bridge for light rail transit and measured strains. Findings including the dynamic load allowance and load distribution factors obtained from field measurements were not in conformance with those of existing design specifications. Wang et al. [6] developed a dynamic model to study the safety and stability of a three-span bridge loaded by light rail trains. The deflection of the bridge and operating speed affected the safety and passenger comfort of the trains.

By identifying the specific gap between the current experience-based practice and the actual response of bridges subjected to light rail loadings, an improvement in design can be made. Among the many aspects to be explored, the following are crucial elements that require

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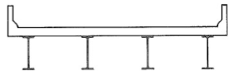
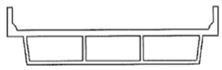
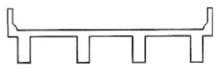
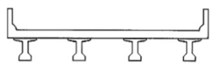
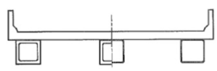
Table 1
Model matrix.

Superstructure	Schematic[a]	Span length	Girder spacing	Number of span	Skew angle	Radius of curvature
Steel plate girder		24 m	1.2 m	1	0°	150 m
		30 m	1.8 m	2	20°	300 m
		43 m	2.4 m	3	40°	450 m
		49 m	3.0 m		60°	∞
Prestressed concrete box		24 m	2.4 m	123	0°	150 m
		30 m	3.0 m		20°	300 m
		43 m	3.6 m		40°	450 m
					60°	∞
Cast-in-place concrete tee beam		9 m	1.2 m	1	0°	N/A
		15 m	1.8 m	2	20°	
		21 m	2.4 m	3	40°	
			3.0 m		60°	
Precast concrete I or bulb-tee		24 m	1.2 m	1	0°	N/A
		30 m	1.8 m		20°	
		43 m	2.4 m		40°	
			3.0 m		60°	
Closed steel boxes		24 m	1.8 m	1	0°	150 m
		30 m	2.4 m	2	20°	300 m
		43 m	3.0 m	3	40°	450 m
					60°	∞

[a] Schematic based on AASHTO LRFD BDS [7].

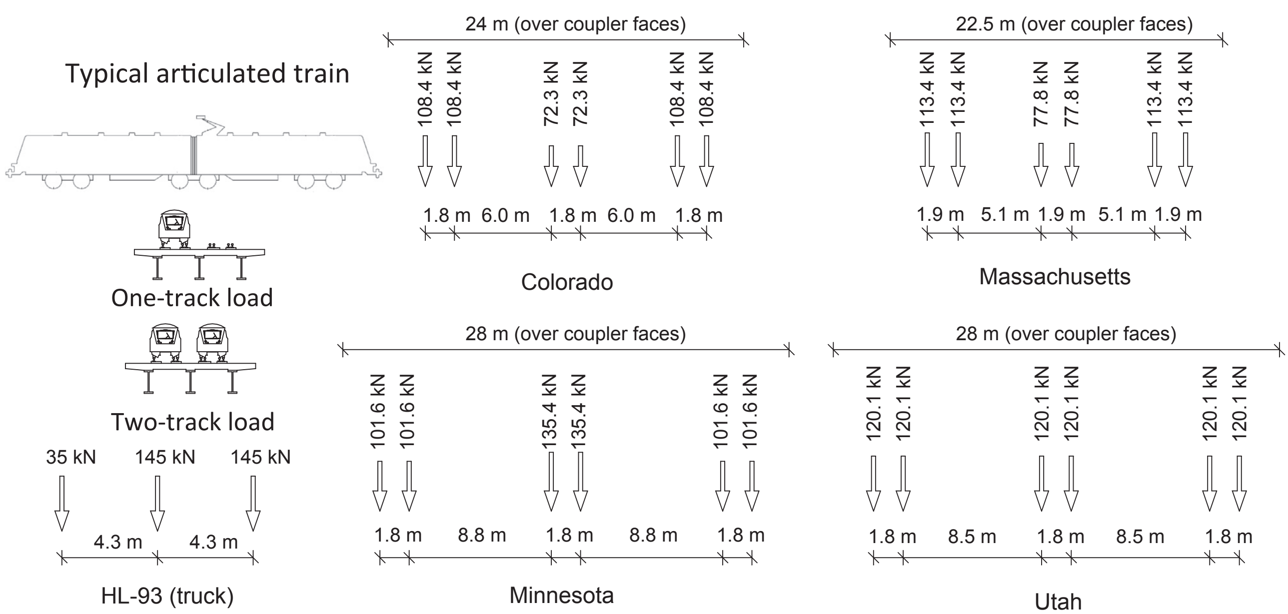


Fig. 1. Selected live load models representing light rail train and highway design loads in the United States.

attention to establish the foundation of light rail bridge design: moment and shear, deflection, and dynamic characteristics such as fundamental frequencies and dynamic load allowance. A comparative assessment of published specifications is another worthy task for examining their relevance to light rail loadings. The objectives of this paper are to investigate the behavior of bridges loaded with light rail gravity loadings, to characterize their static and dynamic responses, and to appraise the applicability of existing design provisions. An extensive parametric study was undertaken with 4932 finite element models to achieve these objectives. Although the development of new design provisions is outside the scope of the current study, technical findings are valuable to elucidate the response of light rail bridges, which will be useful when developing design guidelines.

2. Research significance

One of the most significant problems in the design of light rail bridges is that there are no unified specifications in the United States. That is, design approaches vary by transit agency and the same level of performance reliability cannot be accomplished in constructed light rail bridges (different from highway bridges). It is inappropriate to implement design requirements in practice (and to propose empirical recommendations or revise existing design information) without comprehending the behavior of bridges subjected to light rail loadings. To address this challenge, the physical response of light rail bridges should first be understood. The present research describes the results of an extensive parametric study with various bridge configurations subjected to representative light rail trains, which contributes to enhancing existing knowledge on light rail bridges. It is important to note that a