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A parametric study and rating of steel I-girder bridges subjected to military load classification trucks

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ABSTRACT

This paper presents the flexural behavior and corresponding load rating of simply-supported steel I-girder bridges subjected to military truck loads. The military trucks are categorized by the Military Load Classification (MLC) system according to the North Atlantic Treaty Organization (NATO). A total of 144 load cases are studied for 6 different bridge models based on validated 3-dimensional finite element analysis (FEA) models to examine the deflection, lateral load distribution, and load rating of the bridges. The parameters examined include bridge characteristics (span length, girder spacing, and girder stiffness) and vehicular properties (wheel-line spacing, number of axles, and weight). The response of the bridges under the MLC trucks is compared with that under the standard HS20 trucks of the American Association of State Highway and Transportation Officials Load and Resistance Factor Design (AASHTO LRFD) specifications. Existing predictive models for load distribution factors are evaluated, including the applicability of bridge code provisions for the MLC trucks. The load rating methods based on the Load Factor Rating (LFR) and the Load and Resistance Factor Rating (LRFR) are studied.

1. Introduction

Rating of constructed bridges is necessary to determine the load-carrying capacity of bridge components to allow traffic loads. Inadequate load rating may cause the premature deterioration of bridge superstructure [1]. An adequate estimation of live load effects on a bridge is, thus, particularly important. Current standards for rating a bridge are heavily relying on lateral load distribution factors suggested by bridge codes to estimate live load effects on a bridge [2]. Simplified code equations may reasonably predict the lateral load distribution of live load at a reasonable cost compared to rigorous refined analysis methods, namely, grillage or finite element analysis (FEA). Given that the American Association of State Highway and Transportation Officials Load and Resistance Factor Design (AASHTO LRFD) equations have been calibrated using standard HS20 trucks, an accuracy issue may arise for the applicability of the empirical equations when a bridge is subject to nonstandard truck loads such as military vehicles or logging-industry trucks. The flexural behavior of bridges under such nonstandard truck loads may be different from that under the standard trucks in AASHTO LRFD because of their discerning characteristics, including the number of axles, wheel-line width, and weight [1,3]. The current practice of evaluation for existing bridges may ignore the contribution of nonstandard truck properties [1]. Therefore, adequate predictive methods for live load distribution of nonstandard trucks and corresponding load rating of existing bridges are required.

Extensive research has been conducted to predict the live load distribution of standard trucks on various bridge superstructures [4–8]. Limited effort, however, has been made on estimating the lateral load distribution of nonstandard trucks having different vehicular characteristics in comparison to that of HS20 [1,3]. Research related to military truck load is particularly rare. Military vehicles are categorized into the Military Load Classification (MLC) system (details are discussed later) in accordance with the North Atlantic Treaty Organization (NATO). Pinero [9] reported load distribution factor equations for MLC trucks using the harmonic decomposition method. Ortiz [10] completed the prediction of live load effects of MLC trucks by considering 7 most commonly-used military vehicles in the United States, including some field tests, and proposed 28 formulas for bending moment prediction. Despite these research endeavors, detailed flexural behavior of bridges subjected to MLC trucks and their contribution to load rating have not been examined at all.

This paper presents the flexural behavior of slab-on-girder bridges having various girder spacing, span length, and girder stiffness under selected MLC trucks, based on 3-dimensional FEA models representing 144 load cases on 6 different bridge

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superstructure models. Emphasis was given to the evaluation of predictive methods for the lateral distribution of MLC trucks and the rating of the bridges. Slab-on-girder bridges were studied in this research because such a bridge superstructure is the most common type in the United States [6].

2. Lateral load distribution of MLC load

2.1. Description of the MLC system

Military vehicles are classified according to the MLC system that consists of wheeled and tracked vehicles [11], except for vehicles having a gross weight of less than 3 tons. The configuration of MLC trucks is different from that of the AASHTO LRFD HS20 truck in terms of the number of axles, weight, wheel-line spacing, as shown in Fig. 1. Further details on the MLC loads are available in STANAG [11]. Similar to the posting of a bridge for civilian vehicles, a classified military vehicle can reasonably cross the bridge that includes a higher MLC classification number. The present study focused on the wheeled MLC trucks of three selected categories, namely, MLC20, MLC50, and MLC80 that represented light, medium, and heavy MLC trucks, respectively.

2.2. Code provisions

The lateral distribution of live load in a bridge superstructure (slab-on-girder) may be obtained using Eq. (1) [12].

$$LDF = \frac{M_{refined}}{M_{beamline}} \quad (1)$$

where LDF is the live load distribution factor; $M_{refined}$ is the maximum bending moment that a girder actually experiences; and $M_{beamline}$ is the bending moment obtained from one-dimensional beam-line analysis. Bridge codes provide a method to estimate the lateral load distribution of loaded vehicles, using empirical equations that have been calibrated based on the standard truck loads such as HS20 in AASHTO LRFD. The code equations are not shown here for brevity, but available elsewhere [13,14].

2.3. Predictive models for MLC load

Pinero [9] and Ortiz [10] proposed empirical equations for the lateral load distribution of MLC trucks (Tables 1 and 2), based on a modification of the AASHTO LRFD equations [14]. The Pinero model was calibrated using the harmonic decomposition method that predicted the maximum load effect of MLC trucks on slab-on-girder bridges. The Ortiz model was based on a simple finite element method to determine the lateral load distribution of MLC trucks, using frame elements and quadrilateral shell elements to represent the girders and slabs of bridges, respectively. A regression analysis was then conducted to generate distribution factor equations for the MLC loads. Ortiz [10] noted that the developed equations were for rating purposes, rather than design applications.

Table 1
Live load distribution factors for moment proposed by Pinero [9].

Girder	Loaded lane	Distribution factor[a]
Interior	Single	$0.3 + \left(\frac{S}{18.2}\right)\left(\frac{S}{L}\right)^{0.41}\left(\frac{nI}{12Lt_s^3}\right)^{0.28}$
	Multiple	$0.05 + \left(\frac{S}{11}\right)^{0.56}\left(\frac{S}{L}\right)^{0.14}\left(\frac{nI}{12Lt_s^3}\right)^{0.068}$
Exterior	Single	$-0.11 + \left(\frac{S}{19.6}\right)^{0.43}\left(\frac{S}{L}\right)^{0.01}\left(\frac{nI}{12Lt_s^3}\right)^{0.005}$
	Multiple	$-0.03 + \left(\frac{S}{16.84}\right)^{0.7}\left(\frac{S}{L}\right)^{-0.047}\left(\frac{nI}{12Lt_s^3}\right)^{-0.034}$

S = girder spacing; L = span length; n = modular ratio of girder to slab; I = girder moment of inertia; t_s = slab thickness.
[a] US customary unit.

3. Bridge rating methods

Army Regulation 420-72 [15] recommends that the load rating of vehicular bridges be conducted using the *Manual for Condition Evaluation of Bridges* [16] to determine the maximum safe MLC of constructed bridges. The Manual typically includes two rating categories, namely, *inventory rating* and *operating rating*. To examine the load effect of MLC trucks, operating rating may be recommended to account for the maximum permissible live load, rather than inventory rating that indicates the safety of a bridge under MLC trucks for an infinite period of time. For this study, the Load Factor Rating (LFR) method was adopted as shown in Eq. (2) [16], rather than the working stress method.

$$RF = \frac{C - A_1 D}{A_2 L(1+I)} \quad (2)$$

where RF is the rating factor; C is the present load-carrying capacity of the member; D is the dead load effect; L is the live load effect; I is the dynamic load allowance (or impact factor), and A_1 and A_2 are the multiplication factors for the dead and live loads, respectively (A_1 = 1.3 and A_2 = 1.3 are recommended by AASHTO [16] for operating rating). The calculated rating factor, RF, is multiplied by the rating truck to determine the rating of the bridge. The present structural condition of the bridge to be rated should be adequately included in the rating equation through a site inspection. The live load effect for rating may be obtained from lateral load distribution factors using the bridge specifications explained in the previous section or from a refined analysis such as finite element modeling. Although this rating method has broadly been adopted in the bridge community, its applicability may be reduced because the load factor design method is no longer used in most agencies.

The Manual [16] permits an alternative rating method based on the concept of reliability for the rating of existing bridges using the Load and Resistance Factor Rating method (LRFR), as shown in Eq. (3) [17,18].

Weight and wheel-line spacing

Truck	Weight (kN)	Wheel-line (mm)
HS20	325	1800
MLC20	214	2150
MLC50	516	2050
MLC80	819	2260

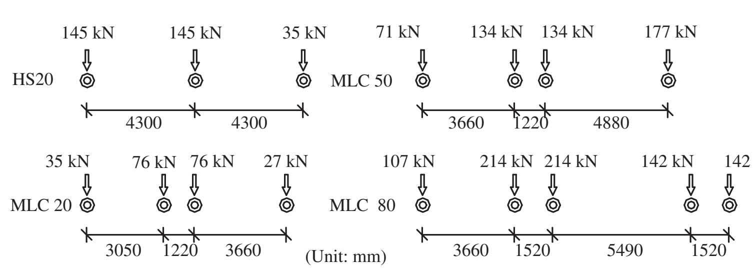

Fig. 1. Details of selected MLC load configuration.