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A framework for statistical distribution factor threshold determination of steel–concrete composite bridges under farm traffic

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ABSTRACT

This paper presents a novel statistical framework to determine distribution factors (DFs) for steel–concrete composite girder bridges subjected to agricultural vehicles. The framework consists of multiple parts including live load field testing, finite element simulations, and statistical analyses. For field testing, strain sensors are installed at critical locations to monitor strain data resulting from passes of test agricultural vehicles. Measured strains are utilized to determine experimental DFs and also used to calibrate finite element models. As part of the model simulation, a number of vehicles of interest are selected and applied to the models to compute analytical DFs. Statistical thresholds for each group of interior and exterior girders are calculated by performing a statistical analysis of the computed data. To demonstrate this procedure, a sample application of interest is discussed. Findings indicate that the proposed framework is capable of reasonably estimate lateral live-load DFs for interior and exterior girders of the particular rural bridge under the effect of varying agricultural loads. The proposed framework is anticipated to provide a more sophisticated live load distribution characteristics' estimate on such bridges loaded.

1. Introduction

Using appropriate lateral live-load distribution factors (DFs) is a key process for reliable design and structural safety assessment of bridges. DFs have been sometimes used to evaluate individual girder damage in a bridge system [1]. Many bridges in the US are in service on secondary roadways where heavy agricultural vehicles travel often; these vehicles have quite different characteristics from traditional highway-type vehicles resulting in rather unique bridge responses [2–5]. Specifically, Seo et al. [2] demonstrated that the single front axle of the agricultural vehicle led to greater loads being carried by the center girder, resulting in a greater field response compared to the highway vehicles. In the United States, the structural adequacy of bridges has typically been evaluated using DFs calculated based upon the American Association of State Highway and Transportation Officials (AASHTO) specifications [6,7]. Unfortunately, the AASHTO specifications do not address farm vehicles. In addition to the specifications, limited studies relating the impacts of agricultural implements on the structural adequacy of bridges exist [1–5], resulting in few good resources for bridge engineers. Most available technical documents include the examination of these effects on roads and pavements [8–11]. Therefore, a framework for determining agricultural vehicle-induced DFs in an efficient manner is needed.

Most literature related to bridge load distribution focuses on computing DFs for traditional road vehicles. The AASHTO specifications [6,7] provide the DF formulas that were primarily derived from computational parametric studies for bridges subjected to conventional trucks [12]. The AASHTO code DFs have been experimentally evaluated by performing field tests on existing bridges loaded by several test trucks [13–15]. These studies showed that, in most cases, the AASHTO values were conservatively adequate. Fortunately, this tendency is consistent with other studies [16–18] comparing DFs determined from field testing, computational models, and codified procedures. Cai [19] proposed new DF formulas to better calculate the DFs than the AASHTO formulas, yet was still conservative. The conservative nature of the AASHTO formulas raised concerns for bridge designers and rating engineers. These concerns led to the initiation of NCHRP project 12–62 [20] where the goal was to develop a simplified DF determination framework, accounting for a broad range of bridge and diaphragm configurations along with transverse truck positions. Although the framework developed from the project was capable of efficiently

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estimating DFs for most US highway bridges [20–22], various farm implements, which have vastly different geometries, suspensions, and other attributes [1–5], have not been considered. In the meantime, a recent study [2] has showed that the AASHTO formulas overestimated DFs for the bridges under most two axle wheel farm vehicles, but the AASHTO DFs were *just permissive* for the terrerator with a front single wheel system. In the European Union, simplified DF formulas have not been introduced in Eurocode [23] for designing bridges because they may be too conservative or permissive to be put in practice [24]. In lieu of the DF formulas, a linear elastic analysis has been predominantly adopted to determine live load girder distribution that can be of practical interest in the bridge design and assessment [23,25]. The effects of farm vehicles on live load distribution characteristics of bridges have not been addressed in European practice [23–25].

Recent studies have been conducted to examine live load DFs of bridges subjected to non-conventional highway vehicles such as military trucks [26,27] and special overload vehicles [28]. Kim et al. [26,27] investigated the flexural live load distribution characteristics and corresponding load rating of composite steel–concrete bridges loaded with military trucks. Over one hundred military loading scenarios combining axle spacing, axle number, and weight were considered to investigate their effects on the load distribution of representative bridges. It was concluded that the load distribution was dominated by the weight and spacing of the military trucks and the AASHTO LRFD formulas conservatively predicted DFs of the bridges. Later a simplified formula was also proposed for assessing the critical weight of military trucks on such bridges [27]. Bae and Oliva [28] established a framework to identify flexural load DFs for multi-girder bridges under overload vehicles, including single-lane and dual-lane/trailer vehicles, by means of a linear elastic analysis. It was reported that DF formulas involving vehicle configurations and bridge characteristics were developed to examine their effects on the bridges. In addition to the non-highway vehicles, other recent DF studies for different bridge types, including posttensioned box-girder [29], reinforced concrete T-beam [30], steel I-girder [31–33] have been carried out using typical highway trucks. As stated above, significant efforts have been made to modify and implement design guidelines and specifications related to DFs considering various vehicle configurations and bridge types. However, technical information specific to evaluation of bridges under farm traffic loads is scarce.

The objective of this work is to develop a framework for the statistical DF threshold determination of steel–concrete composite bridges loaded by various agricultural vehicles and to study its application to an actual bridge for substantiating its feasibility. The framework includes carrying out multiple field tests, rigorous finite element simulations, and statistical analyses. To demonstrate the proposed framework, a rural composite steel–concrete bridge was used in this study. Strain data collected as various vehicles crossed the structure were used to calculate experimental DFs and calibrate a finite element model. Utilizing different configurations of farm vehicles commonly used in the United States, model simulations were conducted using the calibrated model to determine an ensemble of analytical DFs. Thresholds for each group of exterior and interior girders were calculated by performing a statistical analysis of the analytical DFs. To verify the validity of the statistical thresholds for the select bridge, these thresholds were compared to those from the field tests and the AASHTO specifications. It is anticipated that the proposed and validated framework is capable of more accurately and efficiently computing DFs for the bridges subjected to agricultural vehicles with different configurations and weights. Further, the framework can be used for reliable design and structural integrity evaluation on such bridges.

2. Proposed statistical distribution factor threshold determination framework

The proposed framework for the statistical determination of steel–concrete composite bridge DF thresholds is discussed herein and is illustrated in Fig. 1. Step 1 is to perform multiple field tests on a selected bridge using full-scale farm vehicles with known characteristics. The goal of the field tests is to collect actual data which can be used for both experimental DF calculation and analytical model calibration. Several factors should be considered and evaluated prior to performing field tests on the target bridge. These factors include the selection of rural steel–concrete composite bridges, development of instrumentation plan, selection of test vehicles, and determination of loading paths. Representative composite girder bridges located on secondary roadways where farm vehicles travel frequently should be selected through the consideration of their accessibility and proximity to bridge engineers performing field testing. The field tests also require a detailed instrumentation plan so that accurate model calibration may be achieved. As part of developing the plan, sensor type, sensor number, and sensor location should be determined for collection of information. Typical agricultural vehicles frequently found on secondary roadways should be selected and then their paths should be determined prior to field tests. During field tests, field response (e.g., strain time histories) resulting from each vehicle pass is obtained and used for model calibration.

Step 2 in Fig. 1 is the calibration of analytical models based upon the field collected data. Calibrating analytical models with field data is a vital process in the overall framework of determining statistical DF thresholds of rural bridges. Model calibration can be made through an iterative process of minimizing errors between field and analytical data by systematically altering the model until little further improvement can be made. The calibration process consists of three major sub-steps: selection of calibration parameters, adjustment of parameters' values, and statistical comparison. Calibration parameters affecting structural behavior of rural bridges should be initially selected. A past study of a typical girder bridge for its model calibration [34] indicated that model properties, which include moments of inertia for critical bridge components, moduli of elasticity for materials, and restraints at supports, were considered critical to model calibration. These calibration parameters are used in this framework. Their initial values for the parameters are described using information obtained from bridge plans, inspection history records, and/or field measured geometries. These values for each calibration parameter can be adjusted, within reasonable upper and lower limits, until the

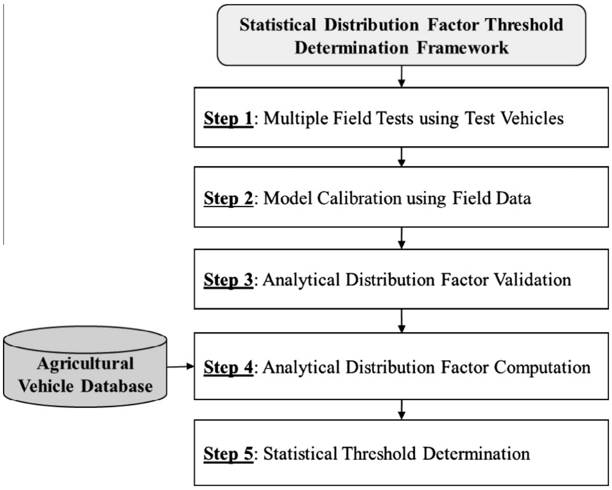

Fig. 1. A flowchart of rural bridge distribution factor determination.