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Live Load Distribution on Concrete Bridges: Design, Evaluation, Construction, Innovation

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Editors:
Nur Yazdani and Benjamin Z. Dymond

American Concrete Institute
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In recent years, both researchers and practicing engineers worldwide have been investigating the effect of live load distribution on concrete bridges during design, evaluation, and construction. Papers discussing live load distribution issues and innovation for concrete bridge decks and/or supporting girders were considered for inclusion in this Special Publication. Papers in the following areas of interest were sought: AASHTO methodology, other available codes/specification provisions, simplification of the AASHTO methodology, traffic non-parallel to girders, construction stage issues, partial composite deck-girder systems, long-span girders, slab-span structures, and bridges with missing as-built plans.

To exchange international experiences among a global group of researchers, ACI Committees 343 and 342 organized two sessions entitled “Live Load Distribution on Concrete Bridges: Design, Evaluation, Construction and Innovation” at the Fall 2021 ACI Virtual Convention. This Special Publication contains the technical papers from experts who presented their work at these sessions. The first session was focused on girder bridges and the second session was focused on non-girder bridges. The technical papers in this Special Publication are organized in the order in which they were presented at the ACI Convention.

Overall, in this Special Publication, authors from different backgrounds and geographical locations share their experiences and perspectives on how live load distribution affects concrete bridges during design, evaluation, and construction. Contributions were made from different regions of the world, and the technical papers were authored by experts at universities, government agencies, and private companies.

The co-editors, Dr. Nur Yazdani and Dr. Benjamin Dymond, are grateful for the contributions from the Special Publication authors and sincerely value the time and effort of the authors in preparing the papers in this volume. Furthermore, the Special Publication would not have been possible without the effort expended by the experts who peer reviewed the papers in this volume.

Nur Yazdani and Ben Dymond
Co-Editors

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Live Load Distribution in a Slab-on-Girder Bridge Subjected to Corrosion and Differential Settlement

Jun Wang and Yail J. Kim

Synopsis: This paper presents the structural performance of bridge decks reinforced with steel and glass fiber-reinforced polymer (GFRP) bars subjected to corrosion and differential settlement. The superstructure system of the bridge comprises a deck slab and prestressed concrete girders, which is modeled using a finite element program. In compliance with the American Association of State Highway Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (BDS), live loads are applied and the implications of various load combinations are examined. Emphasis is placed on determining stress distributions and corresponding live load distribution factors when subjected to the external distress. The calculated load distribution factors are compared against those obtained from AASHTO LRFD BDS. The stress levels and load distributions in the steel- and GFRP-reinforced concrete decks are found to be similar.

Keywords: corrosion; fiber reinforced polymer (FRP); live load distribution factor; settlement

INTRODUCTION

Live load distribution factors (LDF) are used to determine how vehicular loadings affect the behavior of a slab-on-girder bridge. The factors may be obtained by logging strain gage readings in the field, while simplified equations given in the American Association of State Highway Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (BDS) are often taken for design convenience [1]. Several parameters control LDF, including superstructure stiffness, deck thickness, span length, and girder spacing [1], and it is generally acknowledged that the empirical AASHTO LRFD distribution factor equations produce conservative results [2]. Transportation agencies frequently spread deicing chemicals during the winter for the safety of motorists; however, those chemicals deteriorate bridge decks, expedite the occurrence of chloride-induced corrosion damage, and result in a noticeable economic impact [3,4]. From an operational point of view, deteriorated decks with reduced flexural stiffness in a bridge lead to unacceptable deflections and stress redistributions [5]. Glass fiber-reinforced polymer (GFRP) reinforcing bars have become a promising solution to the corrosion of bridge decks, considering several benefits such as their noncorrosive nature, good strength to weight ratio, and fatigue resistance [6]. Nonetheless, among other reasons, practitioners are reluctant to adopt GFRP composites because of their low elastic modulus, which may influence the distribution of live loads and serviceability of highway bridges. In addition to corrosion problems, differential settlement is deemed a critical issue for constructed bridges. A case study reports that more than 90% of examined bridges had a settlement of less than 4 in. (100 mm) [7]. Once a differential settlement occurs, the load distribution mechanisms of a bridge structure change and some members may carry excessive bending moments and shear forces [8,9]. Although the weakened flexural stiffness of bridge members owing to corrosion may provide adverse synergies when combined with differential settlement, insufficient endeavors have been expended thus far. This preliminary study documents the ramifications of such multihazards on the load distribution of a four-span bridge, including the potential of GFRP reinforcement.

RESEARCH SIGNIFICANCE

Notwithstanding the popularity of the AASHTO LRFD distribution factors, little is known about their applicability to a situation where corrosion and differential settlement take place simultaneously. Furthermore, the use of low modulus GFRP reinforcement in a bridge deck under these circumstances has not been explored previously. The present research evaluates the load distribution in a slab-on-girder bridge subjected to corrosion, settlement, and vehicular loads.

MODELING PROCEDURE

Finite Element Modeling

Finite element analysis was conducted with CSiBridge to predict the behavior of the four-span prestressed concrete girder bridge shown in Fig. 1(a). The four spans were 110 ft (33.5 m) each, which sum to a total structure length of 440 ft (134 m). The bridge structure, designed per an FHWA report [10], included AASHTO Type VI girders and an 8-in. (200-mm)-thick deck slab as shown in Fig. 1(b); the deck was reinforced with No. 5 bars (diameter = 0.625 in. (16 mm)) at spacings of 8 in. (200 mm) and 7 in. (175 mm), as shown in Fig. 1(c). The compressive strength of concrete for the girder and deck was 6 ksi (40 MPa) and 4 ksi (28 MPa), respectively, and their elastic moduli were 4,696 ksi (32.4 GPa) and 3,834 ksi (26.4 GPa), respectively. The Poisson's ratio of the concrete was 0.2. The elastic modulus and yield strength of the steel bar were 29,000 ksi (200 GPa) and 60 ksi (414 MPa), respectively. An alternative reinforcing scheme was considered using GFRP bars with an elastic modulus of 5,920 ksi (41 GPa) and a tensile strength of 100 ksi (690 MPa). Grade 270 steel prestressing strands with a diameter of 0.5 in. (13 mm) were placed in the girders. Rollers were located at both abutments, and a hinge and rollers were assigned to the piers. The girders and piers were connected with link elements. The standard live load, HL-93 (the HS-20 truck or design tandem with the lane load), was generated near the right exterior girder to represent a single-lane-loaded scenario.

Validation

Two reference bridges were selected to validate the modeling approach [10,11]. As summarized in Table 1, the first bridge consisted of two spans (110 ft (33.5 m) + 110 ft (33.5 m) = 220 ft (67 m)), while the second bridge was composed of three spans (37 ft (11.3 m) + 65 ft (19.8 m) + 42 ft (12.8 m) = 144 ft (43.9 m)). The two-span bridge shown in Fig. 2(a) was loaded with HL-93 to focus on live load effects, and the three-span bridge shown in Fig. 2(b) was subjected to settlement. Figures 3(a) and (b) compare the live load- and settlement-induced moments taken from