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Numerical analysis method for long-term behavior of integral abutment bridges

WooSeok Kim [a,*], Jeffrey A. Laman [b,1]

[a] PB Americas Inc., One Penn Plaza, New York, NY, United States
[b] Department of Civil and Environmental Engineering, Pennsylvania State University, University Park, PA, United States

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ABSTRACT

Many engineering uncertainties exist in the prediction of integral abutment bridge (IAB) long-term behavior. This paper reports on the development of numerical modeling methodologies formulated on the basis of an extensive field monitoring program and results obtained from four IABs on I-99 in central Pennsylvania. The proposed numerical modeling methodologies allow long-term bridge response prediction, recognizing that an IAB has significant time-dependent response changes as a result of irreversible soil–structure interaction and time-dependent effects of the superstructure in the case of prestressed concrete girders. Both measured and numerical responses indicate that soil–structure interaction and time-dependent effects significantly influence long-term IAB behavior. In addition, relatively low rotational stiffness and nonlinear behavior of common abutment-to-backwall connections influence long-term response. The proposed numerical modeling methodologies are practical and reasonably predict long-term IAB behavior and response under thermal loading.

1. Introduction

Measured integral abutment bridge (IAB) responses demonstrate distinctly nonlinear characteristics with certain displacements and rotations accumulating over time. As time progresses, behavior predictions based on models that do not account for this accumulating, nonlinear behavior become relatively inaccurate. IAB numerical modeling protocols, therefore, must be established so as to form the basis for practical nonlinear, long-term numerical analysis. IAB behavior is difficult to predict generally, prohibiting the use of conventional bridge analysis methods due to complex boundary conditions, uncertainties and nonlinearities related to ambient temperature changes, soil–structure interaction, and concrete creep and shrinkage. Practical analytical tools to predict IAB behavior and response are, therefore, called for. The present study develops a practical, nonlinear, time-dependent numerical modeling methodology to accurately simulate long-term behavior of IABs and to form a basis of a nominal numerical model for future stochastic analyses.

The established IAB numerical analyses [1–4] are limited to an application of unidirectional, extreme temperature load as per AASHTO LRFD [5] without time-dependent effects and an abutment displacement prediction based on superstructure free expansion. These limitations result in a less accurate and conservative response prediction because the actual IAB behavior is not reflected. Field measurements [1,6–10] demonstrate that the superstructure expands during summer and contracts during winter. Abutments also move back and forth due to daily and seasonal temperature fluctuations, but do not fully return to the original position due to concrete time-dependent effects and nonlinear soil–structure interaction, experiencing an accumulated, residual abutment displacement toward the bridge. Therefore, a numerical analysis that incorporates a time-history analysis for a 75-year AASHTO bridge life is needed to accurately simulate this irreversible IAB behavior.

Presented herein are techniques to model critical IAB components in the overall numerical model and prediction results compared to measured response. Of the several commercially available structural analysis tools available, ANSYS Release 11.0 [11] has been used in the present study. The numerical description of the bridge includes material properties, environmental and time-dependent loads, and boundary conditions. The measured IAB material properties and dimensions have been utilized wherever possible to increase the accuracy of the predictions [8–10]. The definitions of IAB environmental loads and boundary conditions have been performed based on AASHTO [5], LRFD [12] and PCI Bridge Manual [13] recommendations. In a companion study, an extensive parametric study was performed and can be found in [14].

* Corresponding author. Tel.: +1 212 631 3869.
E-mail addresses: wooseok.k@gmail.com (W. Kim), jlaman@psu.edu (J.A. Laman).
1 Tel.: +1 814 863 0523; fax: +1 814 863 7304.

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Table 1
Field monitored IAB description.

Bridge no.	Girder type (see notes)	Integral abutment	Abutment height (H) (m)	Spans (m)	Length (L) (m)
109	PennDOT 28/78	Both	3.5	26.8-37.2-37.2-26.8	128.0
203	AASHTO V	North only south fixed	5.8	14.3-26.8-11.3	52.4
211	PennDOT 28/78	Both	4.3	34.7	34.7
222	PennDOT 24/48	Both	4.0	18.9	18.9

Notes: All bridges are right bridges. Girder dimensions can be found in [15]. No restraints at intermediate piers.

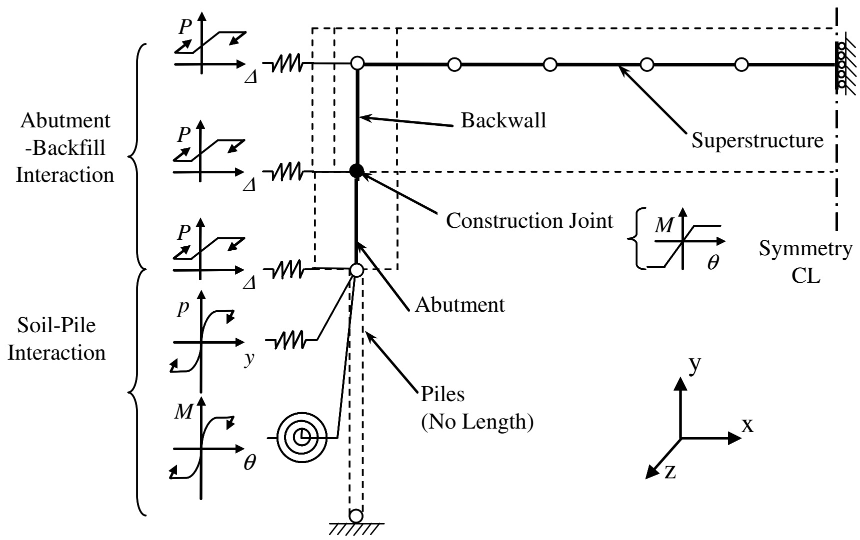

Fig. 1. Schematic of 2D numerical model.

The numerical model was built in 2D considering superstructure symmetry about the bridge mid-length only when applicable. A 2D numerical model, rather then 3D, is required due to the overwhelming requirements of computing time (several days) and data storage (many gigabytes) for a 3D time-history analysis of several years. Previous studies [2,4,16,17] have demonstrated that 2D models are able to simulate IAB behavior and response with a high degree of accuracy. While reducing the model size to accommodate long-term simulations, a 2D nominal numerical model is capable of incorporating key component behaviors of IABs. With certain limitations, 3D numerical models for long-term analysis have been developed with results presented in [8–10,16].

Two IAB behaviors of high interest are: (1) soil–structure interaction; and (2) nonlinear behavior of the construction joint between the abutment and backwall. Soil–structure interaction is categorized into two parts: (1) abutment–backfill interaction; and (2) soil–pile interaction. The Winkler spring model was adopted for abutment–backfill interaction based on classical Rankine active and passive pressure theory. Soil–pile interaction was modeled utilizing nonlinear p–y curves derived on the basis of American Petroleum Institute [18] recommendations. The construction joint between the backwall and abutments located below the girder bearing was modeled based on joint moment–rotation characteristics [19].

Loads applied to the numerical models are: (1) backfill pressure on abutments; (2) time-dependent effects of the concrete superstructure; (3) ambient temperature variation; and (4) temperature gradient along the superstructure depth. Backfill pressure applied to abutments was modeled as a linearly varying stress distribution with depth [20]. Time-dependent effects due to prestressing steel relaxation and concrete creep and shrinkage were also incorporated utilizing both the equivalent temperature method [21] and the age-adjusted elastic modulus method (AEMM) [13]. The superstructure temperature gradient was modeled as an equivalent, linear variation along the superstructure depth rather than a multilinear variation recommended by AASHTO LRFD [5] due to program element limitations.

2. Field monitoring

Field instrumentation and monitoring was conducted to measure actual IAB responses to environmental loads. Data collection occurred at four selected IABs and one weather station on I-99 near Port Matilda, PA. General descriptions of the four IABs are presented in Table 1. The instrumented IABs are similarly configured with a cast-in-place deck on four precast, prestressed concrete girders with no skew and a single row of weak axis oriented HP310 × 110 (HP12 × 74) piles. Each bridge was instrumented during construction with backfill pressure cells, abutment displacement extensometers, girder strain gages, girder tiltmeters, abutment tiltmeters, pile strain gages, and sisterbar gages in approach slabs [7–10].

3. Nominal numerical model component development

A schematic, 2D, numerical model, developed for use in the present study, is presented in Fig. 1 [22]. Half of the bridge structure is modeled, utilizing symmetry. The structure mid-length node is restrained against x-axis translation (longitudinal) and z-axis rotation. The single row of weak axis oriented steel H piles is assumed to be rigidly connected to the abutment. The y-axis (vertical) pile displacement is insignificant and, therefore, the pile is restrained in the y-axis direction with a roller support. The participation of the supporting piles is modeled as an equivalent lateral and rotational nonlinear spring at the base of the abutment. The nonlinear properties of the construction joint between the backwall and abutment are modeled based on calculated moment–curvature properties.