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Effect of soil–bridge interaction on the magnitude of internal forces in integral abutment bridge components due to live load effects

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ABSTRACT

In this study, the effect of soil–bridge interaction on the magnitude of the internal forces in integral abutment bridge (IAB) components due to live load effects is studied. For this purpose, structural models of typical IABs are built by including and excluding the effect of backfill and foundation soil. Analyses of the models are then conducted under an AASHTO live load. In the analyses, the effects of the backfill and foundation soil on the magnitude of the internal forces in IAB components are studied for various structural, geometric and geotechnical parameters such as bridge size, abutment height and thickness, pile size and orientation, number of spans and foundation soil stiffness.

The analysis results revealed that soil–bridge interaction has a significant effect on the magnitude of the live load moments in the components of IABs. Including the effect of backfill behind the abutments in the structural model is generally found to result in larger superstructure support and abutment moments and smaller superstructure span and pile moments. The difference between the live load moments for the cases with and without soil–bridge interaction effects is found to be a function of the foundation soil stiffness. However, the soil–bridge interaction is found to have only a negligible effect on live load shear in the superstructure. Furthermore, the equivalent cantilever concept used for modeling of the abutment piles is found to inconsistently yield either conservative or unconservative estimates of the internal forces in the components of IABs except for the superstructure shear.

1. Introduction

An integral abutment bridge (IAB) is one in which the continuous superstructure, the abutments and the single row of steel H piles supporting the abutments are built monolithically to form a rigid frame structure. Typical single and multi span IABs and their details at the abutments are illustrated in Fig. 1(a)–(d).

In bridge design, most bridge engineers prefer using simplified two dimensional (2-D) structural models and live load distribution factors available in current design codes to determine live load effects in bridge components. Although the monolithic construction of IABs forces the substructures to interact with the backfill and foundation soil under thermal and gravitational load effects [1,2], the current state of design practice in North America and Europe normally neglects soil–bridge interaction effects in live load analyses of IABs. That is, the backfill behind the abutments is not considered in the 2-D structural models of IABs for live load analysis and the piles are usually modeled as simple equivalent cantilevers fixed at some distance below the ground surface. For instance, the IAB In-house Design Guidelines of Ontario Ministry of Transportation of Canada recommends a structural model where the backfill stiffness is totally neglected and an equivalent cantilever approach is used for modeling of the steel H-piles [3].

Recently, many transportation agencies in most parts of USA and Canada routinely prefer IABs in the construction of their infrastructure network due to their many economical and functional advantages [1,4–8]. Consequently, several transportation agencies such as New York, Iowa and Virginia Departments of Transportation in the USA [9–11] as well as Ontario [3] and Alberta [12] Ministry of Transportations in Canada have developed in-house design guidelines and reports concerning the design and performance of IABs. Special design guidelines and reports for IABs have also been developed by some research institutions [13,14] as well as bridge engineers and researchers [1,5–7]. However, these design guidelines and reports generally contain information about the geometric limits (e.g. maximum length and skew angle limits), pile types and orientations, abutment design, wing-wall configuration and abutment–backfill interaction in IABs especially under thermal and seismic loading. Moreover, many research studies have been conducted on the effect of backfill and foundation soil on the performance of IABs under thermal effects [15–21]. However, research studies concerning the effect of soil–bridge interaction on the performance of IABs under live loads are scarce. Accordingly, in this study, the effect of soil–bridge interaction on the magnitude of

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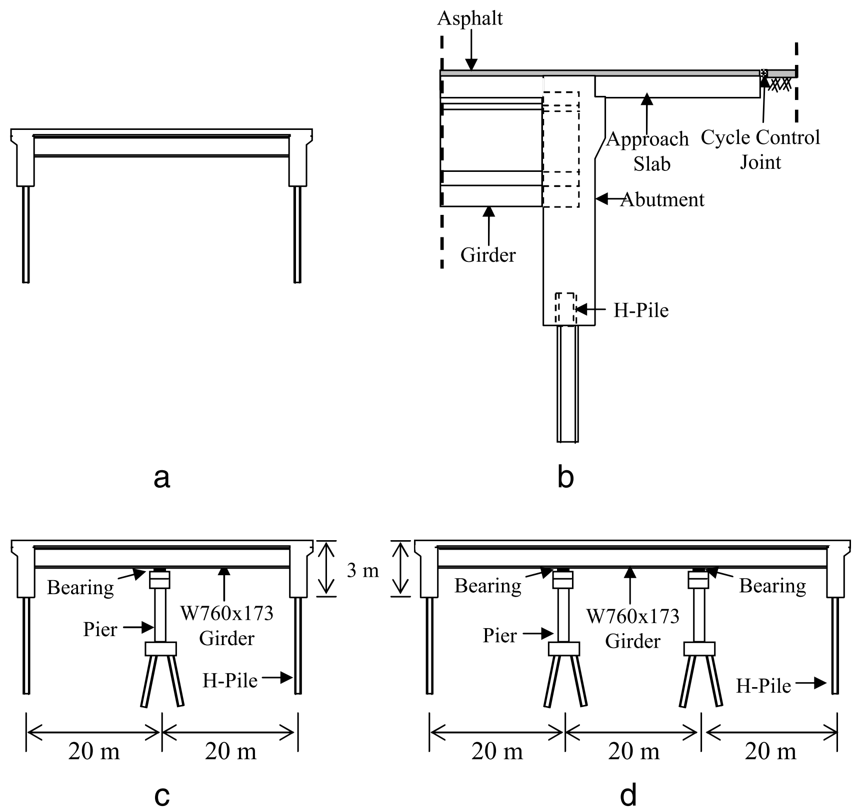

Fig. 1. (a) A typical single span IAB, (b) details of a typical IAB at the abutment, (c) two-span version of the small bridge used in the analyses (d) three-span version of the small bridge used in the analyses.

internal forces in IAB components (superstructure, abutment and piles) due to live loads is studied. The results from this research study is then used to present design recommendations to the engineering community at large for building simplified 2-D structural models of IABs for estimating live load effects in IAB components using distribution factors.

2. Research objective, scope and outline

The main objective of this research study is to investigate the effect of the backfill and foundation soil on the magnitude of the internal forces in IAB components under live load effects.

The presented research study is limited to symmetrical IABs with no skew. The abutments are assumed as supported by end-bearing steel H-piles. A moment connection is assumed between the piles and abutment as well as between the superstructure and abutment. A typical moment connection detail for the pile–abutment and superstructure–abutment joints and connection details over the middle supports of continuous IABs is illustrated in Fig. 2(a) and (b). These connection details have been used successfully by the Ontario Ministry of Transportation over the last two decades [3]. Granular uncompacted material typically used for IAB construction is assumed for the backfill behind the abutments while cohesive soil (clay) is assumed for the pile foundations. However, the findings of this research study could be extrapolated to cohesionless foundation soil as well. The water behind the abutment is assumed to be properly drained through the granular material and perforated pipes wrapped with geotextile typically used at the abutment bottom in bridge construction. Moreover, the scope of this research study is limited to short to medium length IABs where the superimposed dead load (SDL) and thermal effects are assumed to be less significant compared to live load effects. Consequently, yielding of the piles is not anticipated under total load effects and the behavior of the backfill and foundation soil is assumed to be within the linear elastic range since small lateral displacements of the abutments and piles are expected under live load effects. This also ensures that potential formation of a gap behind the abutment due to cyclic thermal movements is negligible.

To reach the above stated objective, 2-D structural models of IABs are built including and excluding the effect of backfill and foundation soil. In the 2-D structural models studied, several geometric, structural and geotechnical parameters are varied to cover a wide range of possible IAB configurations. This resulted in 200 different IAB structural models. The structural models are then analyzed under current AASHTO (American Association of State Highway Transportation Officials) LRFD Bridge Design Specifications' [22] live loads using the finite element based program SAP2000 [23]. Furthermore, to verify the assumption of linear elastic behavior for the backfill and foundation soil, a typical IAB is analyzed under thermal, SDL and live load effects and the results from each individual load case and their combination are compared with the ultimate soil resistance. The results from these analyses are then summarized and the conclusions are outlined.

3. Parameters considered in the analyses

A parametric study is conducted to investigate the effects of backfill and foundation soil on the magnitude of internal forces in IAB components due to live loads for various geometric, structural and geotechnical properties of IABs. The stiffness of the foundation soil (clay) is anticipated to affect the magnitude of the internal forces in IAB components due to live loads. Thus, an equivalent pile length neglecting the effect of the foundation soil and four values of clay stiffness are considered in the analyses. Furthermore, to cover a wide range of possible IAB configurations, the bridge size,