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Reduction of Bridge Construction and Maintenance Costs through Coupled Geotechnical and Structural Design of Integral Abutment Bridges

Introduction

Eliminating bearings and expansion joints in the superstructure of integral abutment bridges has many advantages in reducing both initial and life cycle costs. However, elimination of these elements has an adverse effect on displacement demands at the pile-abutment connection and on the resulting earth pressure on the abutment wall due to thermal expansion/contraction cycles of the bridge. This effect on the displacement demand at the pile-abutment connection and on the earth pressure behind the abutment wall has resulted in imposed restrictions on the maximum length and skew angle of integral abutment bridges.

Several studies have been conducted to quantify these limitations. The studies focused primarily on the structural or soil component of the problem. This study utilized a coupled thermal-displacement analysis along with soil-structure interaction. An experimental-based numerical analysis approach was followed in this study. The experimental portion of the study consisted of laboratory-scale tests and large-scale tests. The laboratory-scale tests were conducted on sand using a specially designed apparatus that simulates the abutment movement with different skew angles and surface conditions. The large-scale tests were conducted on a 1/4-scale bridge of SR 18 over the Mississinewa River. The numerical simulation consisted of developing a soil constitutive model, verification and calibration of the model, and a parametric study to cover a range of bridge lengths and skew angles. The developed constitutive soil model was an elasto-

plastic model using the Drucker-Prager Yield criteria and an unloading/ reloading algorithm. The model was verified and calibrated using element tests from the literature, the results from the laboratory-scale tests conducted in this study, results from the large-scale test, and monitoring data of a full-scale bridge. Finally, a parametric study was conducted for eighteen cases and investigated bridge length, skew angle, foundation stiffness, abutment wall stiffness, existence of wing wall, and shrinkage and loading sequence effects.

Findings

The results from the large-scale tests showed that skew angle imposes transverse and rotational movements to the deck in addition to longitudinal movements expected

Research approach

from expansion/contraction due to thermal effects. The presence of backfill introduces friction between the soil and abutment which reduces the rotational and transverse movements during expansion cycles. Settlement in the backfill at the abutment wall is an indication of active wedge formation during the contraction phase and was observed during summer testing. Soil pressures at the obtuse corner of the abutment are larger than at the acute corner due to the larger degradation of the stiffness at the acute corner caused by rigid body rotation during expansion. During winter testing, frozen soil was observed which resulted in a gap during contraction cycles and subsequently the absence of soil pressure.

Calibration and verification of the soil constitutive model showed that the model performed well under a wide range of stress levels and various length scales. The model has acceptable predictive capabilities. Escalation of earth pressure behind the abutment with number of cycles was captured. The semi-linear response of earth pressure upon reloading under lateral loading was also captured. The model performed well replicating the magnitude of pile deformation and in calculating the inflection point.

The parametric study results indicate that shrinkage and loading sequence significantly affects the performance of integral abutment bridges. Furthermore, the effect of the abutment wall stiffness, for the range of practical wall thickness typically used on integral abutment bridges, is not significant. An integral abutment bridge of 500 ft with a 60° skew on soft to firm foundation soils resulted in displacement demands of the piles less than 2.0 in. For a 1000 ft bridge with a 60° skew, displacements greater than 2 in. are developed and reached 3 in. To achieve these larger displacements, confining reinforcement as recommended by Frosch et al. (2009) is required. The stiffness of the foundation may have an adverse effect on the displacement demand on piles in the case of long bridges (>1000 ft) on soft foundation soils. For this case, a full soil-structure analysis should be conducted.

Implementation

This study was a continuation of research conducted at Purdue University on integral abutment bridges (Frosch et al. (2006, 2009); Frosch & Lovell (2011)). This research

supports the conclusions provided by Frosch and Lovell (2011) and agrees with the recommendations already provided in the INDOT bridge design manual. This research indicates that it may be possible to increase the maximum bridge lengths for skew angles greater than 30°. For soft to very soft foundation soils and for long bridges (>1000 ft), bridge-specific analyses should be conducted utilizing soil-structure interaction.

References

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