ABSTRACT

Khasawneh, Yazen. Ph.D., Purdue University, May 2014. Long Term Performance of Integral Abutment Bridges. Major Professors: Antonio Bobet and Robert J. Frosch.

Elimination of the bearings and expansion joints in the superstructure of integral abutment bridges offers the advantage of reducing the initial and life cycle costs of the structure. However, such elimination may have an adverse effect on the displacement demand at the pile-abutment connection and on the earth pressures on the abutment wall due to the thermal expansion/contraction cycles of the bridge. These adverse effects have resulted in regulations that impose restrictions on the maximum length and skew angle of integral abutment bridges. This research consisted of a deep analysis of the problem by considering soil-structure interaction. The approach was multifaceted as it included experimental and numerical analysis. The experiments consisted of laboratory tests and large-scale filed tests, as well as monitoring of full-scale bridges already instrumented in Indiana. A new soil constitutive model was developed as part of the study. The model was validated and calibrated based on the laboratory and field experiments, and then used as part of a parametric analysis to provide recommendations for the design limits of integral abutment bridges.

The calibration and verification of the soil constitutive model showed that the model performed well under a wide range of stress levels and length scales. The increase of earth pressure behind the abutment with the number of cycles was well captured. The model performed well replicating the magnitude of the pile deformations and their inflection points.

During thermal loading of the bridge deck, the deck imposes displacement on the abutment wall, which in turns imposes displacements on the supporting piles. The magnitude of earth pressure developed behind the abutment wall and the displacement demand on the supporting piles is a function of several factors; one of the controlling factors is the abutment wall displacement amplitude and direction. The displacement amplitude and direction are controlled by the rigid body movement of the bridge superstructure, which is a function of the bridge length and skew. The superstructure displacement of skewed bridges will result in longitudinal, transverse and rotational movements of the abutment wall. During expansion of a skewed bridge, the superstructure expands and results on longitudinal displacement towards the backfill soils and rotation towards the obtuse corner. This mode of combined movements will result in non-uniform earth pressure distribution behind the abutment wall. In addition, successive expansion cycles will result in an escalation of earth pressure magnitude with annual cycles. It was found that the pressure distribution behind the wall is mostly uniform behind the abutment walls, except at the corners where local spikes of pressure were observed. In addition, it was observed that steady state earth pressure is reached after approximately five to seven cycles of thermal expansion of the bridge superstructure. During the contraction cycle, the skewed bridge superstructure movements are shortening in the longitudinal direction and rotation towards the acute corner. It was also found that active state earth pressure is reached after the first contraction cycle. The displacement demand on piles is a function of the abutment wall displacement. Larger displacement demand of the pile at the acute corner when compared to the obtuse corner was observed during expansion and contraction cycles. The inflection point of the piles deformed shape was found to be at relatively shallow depth (approximately at 18 to 20ft

below the ground surface). Concrete shrinkage and sequence of loading (starring with contraction cycle) affected significantly the displacement demand of the supporting piles, lower displacement demand of piles during the expansion cycle and much larger displacement demand during contraction cycles (three times larger for a 1000ft long bridge with 60^o skew).

The following parameters were investigated to develop recommendations for the design of integral abutment bridges: bridge length, skew angle, foundation stiffness, abutment wall stiffness, concrete shrinkage, and the sequence of loading. The parametric study results indicated that the maximum length and skew angle for integral abutment bridges with medium to stiff soils in the foundations could be 1000-ft and 60^o, respectively. The analyses indicated that the stiffness of the foundation had an adverse effect on the displacement demand on the piles for long bridges (>1000ft) on soft foundation soils.