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Finite Element Modeling of Soil-Structure Interaction and Backfill Sequencing in Buried Arch Bridges

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The University of Maine has developed a composite buried arch bridge system that uses concrete-filled fiber-reinforced polymer (FRP) tubular arches (CFFTs) as the main structural members [1]. During construction arches are cast into concrete footings and filled with concrete. A concrete or FRP deck is installed over the arches and the structure is backfilled with granular soil, which results in an environmentally durable, buried bridge structure.

The soil performs three major functions in these structures: it is a construction dead load, it restrains arches from moving and thus reducing bending stress in the arches, and it dissipates live load from vehicular loading. Bridges built to this point have been designed using a finite-element (FE) beam code developed at UMaine that models the backfill process to capture dead load effects. As soil is applied to the arch nonlinear elastic soil springs are connected to the arch and decking elements to provide lateral restraint. Spring force is based on the overburden pressure (dead and live) and the relative displacement of the arch and the soil. Live load distribution in the completed bridge is based on the Boussinesq analytical model for subsurface pressure under a patch load. However, this approach does not take arch geometry into account when determining the effect of surcharge pressures. Initial 2D continuum FE analyses and results from large-scale laboratory tests indicate that the beam FE models are likely conservative due to their crude approximation of soil-structure interaction during both backfilling and live loading. Critical design values that are sensitive to the simulation of soil-structure interaction include arch bending stresses and footing thrusts.

Present research focuses on soil-structure interaction between the overburden soil and the arch structural system through laboratory studies and FE analysis. The laboratory study considers four half-scale bridges comprised of 3-arch systems with 6.1 m spans, including 8:3 and 5:1 span-to-rise ratios. The scaled lab tests were designed to replicate field installation with the soil applied in lifts alternating up each side of the arch until a soil depth 0.6 m above the arch decking. The arch systems are then loaded with a series of line loads representative of the AASHTO design tandem.

In parallel with the laboratory testing, more sophisticated FE models have been developed with Abaqus to help explain experimental results and to establish sensitivity to soil parameters crucial to design. The model uses continuum elements for the soil with a Mohr-Coulomb material model for elastic-plastic behaviour, which has been used effectively by other researchers to simulate the effect of live loads [2] and backfilling [3, 4]. The Abaqus Explicit solver was used to allow the use of a nearly tensionless soil material, which is representative of the granular backfill used in the experiments and actual construction. The structural arches are modelled with beam elements, and the steel arches use an elastic-perfectly plastic material. As with the beam model, the Abaqus model simulates the backfill process and then allows live loads to be applied to the structure after the soil has developed locked-in stresses from backfilling. Figure 1 shows a short rise arch model during backfilling.

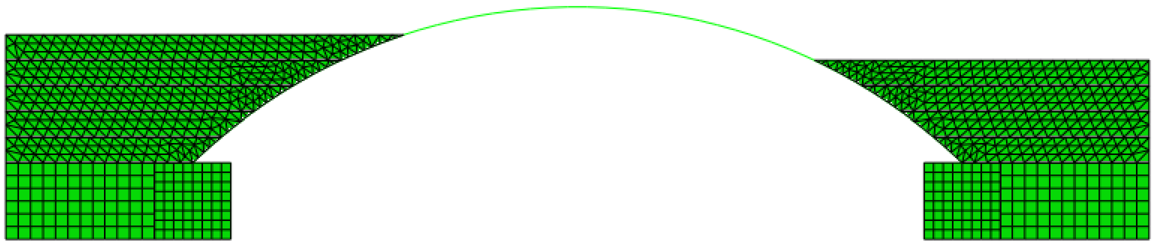

Figure 1. Short arch with 1.1 m backfill on left, 0.9 m on right.

Soil-structure interaction is simulated with frictional contact between the arch and the decking using friction coefficients that dependent on decking material. Critical parameters that are considered using this model are apex deflection, pressure, and moment response versus apex load as well as the footing thrust forces during construction loading and live loading.

This presentation will overview the development and essential features of the FE models, and give a critical comparison between the simulated and measured response of the soil and structure to backfilling and surcharge load effects.

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