EVALUATING THE BEHAVIOR OF MSE WALLS UNDER SURCHARGE LOADING USING A PARAMETRIC FINITE ELEMENT ANALYSIS

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Introduction and Background

The applicability of mechanically stabilized earth (MSE) walls for bridge abutments has become more apparent in recent years with multiple Departments of Transportation (DOTs) recognizing the significant time and cost savings these walls have in relation to other abutment designs. Along with simplifying construction, use of reinforced soil abutments reduces differential settlement and minimizes the “bump” at transition from bridge to embankment. The construction efficiency and functionality of MSE walls is motivating an increase in their use as bridge foundations as well the research into their performance in that capacity. The focus of this study is an investigation of MSE wall response to surcharge loading, both in terms of service-state conditions and ultimate capacity, with the goal of better understanding the behavior of these complex earth retention systems.

The finite-element modeling program, ABAQUS, was used to develop a 2D plane strain model of a geosynthetic reinforced retaining wall with modular block facing and polypropylene geogrid inclusions. This model was then calibrated and verified against other published numerical models and against full scale testing of instrumented geosynthetic reinforced walls. Once the model was considered representative, an extensive parametric study was carried out. The results from this study will help to illustrate the relationships between various wall parameters and the overall behavior of the reinforced soil system.

Numerical Model Details

- Plane strain, homogenous, isotropic solid soil and facing block elements
- Linear 2-D wire truss reinforcement elements
- Penalty friction with max slip and max shear interface between facing blocks to simulate shear key
- Tie constraint between reinforcement and backfill soil
- Rigid connection between reinforcement and facing
- Construction simulated with 0.5m lifts and 35kPa surcharge load to simulate compaction
- Calibration boundary conditions as shown below

Validation

Constitutive Model Calibration

The compacted backfill used in the full scale test wall was a clean, uniform, rounded beach sand (SP in USCS). The material properties from testing are shown in the table below. The constitutive model used in the numerical simulation involved the extended Drucker-Prager hyperbolic model for plasticity, which is capable of incorporating dilative hardening behavior and plastic flow, attached to linear elasticity. The stress-strain plot shown to the right compares experimental plane strain results to simulation results found in literature and those produced using the assigned Drucker-Prager constitutive model. The other numerical material model shown (Bathurst et al. 2000) is a nonlinear elastic-plastic material based on the Drucker-Chang stress-dependent hyperbolic model. The nonlinear elastic behavior (from the stress dependent tangent elastic modulus) of this model allows a close fit to triaxial test results at all confining pressures, but has less agreement with plane strain test results at higher confining pressures. The Drucker-Prager model used in this study produced an acceptable fit to the plane strain data with a small under-estimate of peak stress for higher confining pressures. Triaxial test results (not shown) were also used for calibration.

Wall Model Calibration

Once the constitutive model was verified, it was assigned into the wall model replicating the full scale test wall and the numerical model developed by Hatami and Bathurst (2000), which used the finite-difference program, FLAC. The results from the wall model were then compared and calibrated to the published results (Hatami and Bathurst 2000, 2006). The outputs used for comparison were the relative facing displacements at the end of construction (EOC) and at the end of surcharge loading (EUL) shown in the banded contour plots below, as well as the average vertical strain during surcharge and the strain in the reinforcement layers.

Approach failure surface in equivalent plastic strain at 70 kPa surcharge load (m)

Conclusions / Implications

Upon completion of the remaining work, a database will have been created containing all the results from each individual variable scenario. It is hoped that this study will be able to highlight some key relationships between design components of an MSE or GRS wall. After additional refinement of these results, based on the increased understanding gained from them, further work may lead to changes in the MSE/GRS design codes or improvements to the design recommendations for reinforced walls as bridge abutments. There will also be further evaluation of Limit Analysis as an alternative to Limit Equilibrium for design. Reinforced earth walls are complicated structural systems consisting of complex materials and strain incompatibilities. The challenge faced when designing these systems is in developing an accurate conception of all the relevant phenomena.

FLAC predicted
Measured
ABAQUS predicted

atabutment

Predicted relative facing displacement at EOC (mm)

Surcharge Footing

Measured
FLAC predicted
ABAQUS predicted

Relative facing displacement at 0.15m tension membrane surcharge load (mm)

Experimental and Simulated Plane Strain Results

Variables to Investigate

- Reinforcement Spacing
- Reinforcement Stiffness
- Placement of Surcharge Footing
- Size of Surcharge Footing
- Foundation Material
- Facing Type (block, wrap face)
- Wall Batten

Effects to Observe

- Lateral Deformation at the Facing
- Failure Mechanism / Location
- Location / Shape of Plasticity
- Ultimate Surcharge at Non-convergence
- Stress at Facing Toe
- Results from Strength Reduction Method

Compilation of the results from the parametric study is still in progress. A Python script has been developed to use in conjunction with ABAQUS so that many runs can be submitted in loops with each run automatically incorporating the desired alteration to a specific variable. The observed effects of changing the different variables in relation to the other parametric variables will provide insight into the interdependencies between the listed parameters and the wall’s behavior. Furthermore, the results from this study will be compared to those from traditional Limit Equilibrium and Limit Analysis (using the Discontinuity Layout Optimization) for the purpose of establishing the accuracy of these methods to fine-tuned failure criteria. The reinforcement spacing will be also be adjusted to include ranges associated with Geosynthetic Reinforced Soil walls. One of the observed effects is shown below as the plastic strain after a uniform load of 70kPa has been applied to the wall.