Lateral Spreading Design of Geosynthetic-Reinforced Column-Supported Embankments

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Project Background

Geosynthetic-reinforced column-supported embankments (GRCSE) can be useful where project success is controlled by time constraints, where there is a need to protect adjacent facilities, or where a high-performance embankment is required. One design requirement of the GRCSE is to control lateral spreading, which is the lateral deformation that occurs in response to lateral earth pressures in the embankment and foundation. Excessive lateral spreading could lead to failure of the embankment fill, the geosynthetic reinforcement, the subsoil, and/or the columns. Lateral spreading could be resisted by the geosynthetic reinforcement in the load transfer platform, by the foundation columns, and by passive lateral earth pressures in the foundation soils at the embankment toe. The reinforcement develops tension in response to lateral earth pressures and vertical embankment loads. It must be designed to have adequate tensile capacity and a limit serviceability strain is typically applied. The columns develop bending moments under lateral earth pressures, thus they must also be designed with adequate capacity, which may be challenging for unreinforced cementitious columns commonly used for GRCSEs.

Project Objectives

Current GRCSE design procedures are limited by an incomplete understanding of the lateral spreading mechanism. Design uncertainties include:

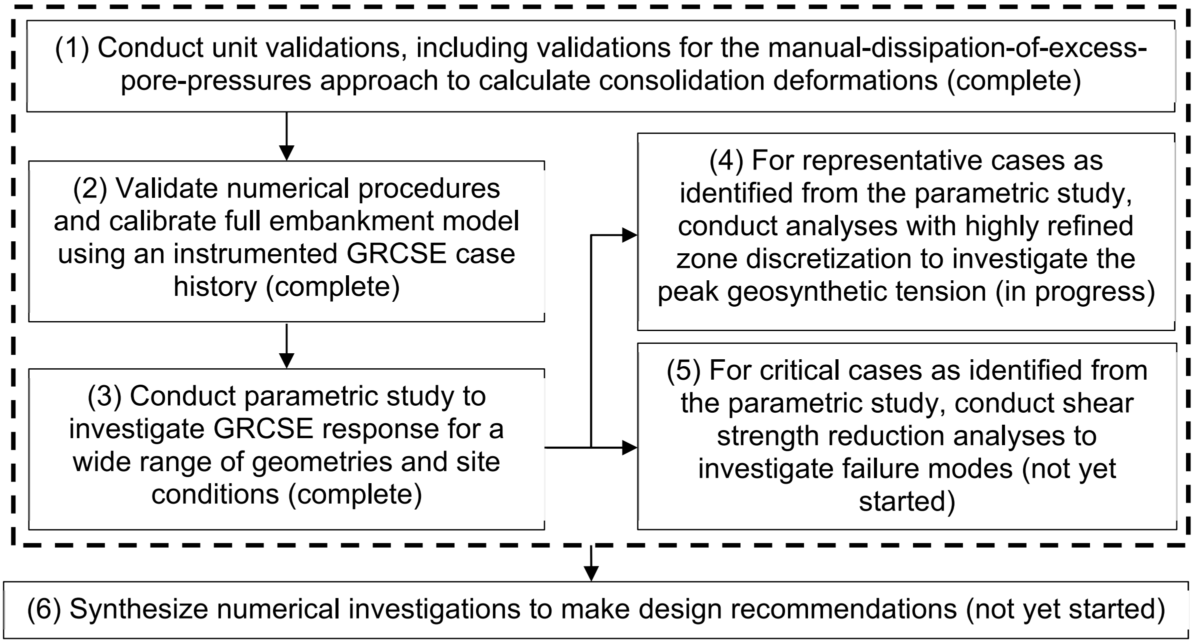
1. What is the lateral thrust that must be resisted by the geogrid? The lateral thrust comes from lateral earth pressures in the embankment and foundation. Lateral earth pressures are difficult to determine because they develop as a function of the vertical load distribution, which varies with time depending on the embankment construction rate, the foundation soil consolidation rate, and other system characteristics.
2. What is the geogrid tension that develops under the combined effects of vertical load transfer and lateral spreading? The current approach for calculating the required tensile capacity is to sum the tension from the vertical load transfer and lateral spreading effects. There is uncertainty on whether this approach is mechanically sound and conservative.
3. How should bending moments in the columns be calculated?

This project uses numerical analyses in FLAC3D to advance understanding of geosynthetic and column contributions to reducing lateral spreading. The goal is to develop design recommendations for calculating the lateral thrust distribution, the geosynthetic tension, and the column bending moments.

Research Tasks and Progress

Research tasks and progress are shown in the following flowchart.

Numerical Analyses in FLAC3D



Key Findings to Date

The limiting cases for lateral spreading analysis, as identified from case history evidence, are undrained end-of-construction and dissipated long-term. Accordingly, numerical analyses using a half-embankment geometry adopted an "undrained-dissipated" approach that involves: 1) undrained end-of-construction analysis with calculations of foundation excess pore pressures and undrained distortions; and 2) dissipated long-term analysis with calculation of consolidation deformations associated with the dissipation of excess pore pressures. The following results were obtained from "undrained-dissipated" analyses:

Lateral Thrust Distribution

1. Foundation lateral earth pressures are largest at undrained end-of-construction because vertical load distribution to columns is limited by incomplete subsoil consolidation and incomplete development of soil arching.
2. Analyses of 120 different embankments in the parametric study found the centerline lateral thrust in the undrained condition is approximately two times that in the dissipated condition. In addition, the centerline thrust in the undrained condition is approximately two times the passive resistance at the toe.
3. The lateral thrust resistance of the geosynthetic depends on its stiffness (J). For 1 to 3 layers of geosynthetic each having J=20,500 lb/ft, the maximum lateral thrust resisted is 2% in the undrained condition and 7% in the dissipated condition. For 1 to 3 layers of geosynthetic each having J=500,000 lb/ft, the maximum lateral thrust resisted is 15% in the undrained condition and 40% in the dissipated condition, for the range of conditions analyzed.

Column Bending Moments and Tensile Stresses

1. Column bending moments increase with distance from the embankment centerline, and the column tensile stress is largest in the peripheral columns due to the combination of larger bending moments and smaller axial compression.
2. In the parametric study, 117 scenarios modeled the columns as an unreinforced concrete material, and 111 of the 117 scenarios calculated zones of tensile failure due to bending in the columns. In the vast majority of cases, column bending failure did not result in embankment instability because columns that fail in bending can still support axial loads.