Analytical Methodology to Evaluate the Basal Stability of Column-Supported Embankments

Danilo Botero Lopez, Civil and Environmental Engineering, University of Maine   Advisor: Ph.D. Aaron Gallant

Motivation

Column-supported embankments (CSE) are becoming more popular in infrastructure projects. Its main advantage is to accelerate construction by reducing the stresses in the soft soil foundations through arching, soil-column interface, and column tip transfer. The Current design methodology (FHWA) (Fig 1.) for assessing the global stability have some drawbacks:

- The unreinforced columns provided a resisting moment — Gallant & Botero 2020 showed that column fracturing does not trigger lateral spreading
- It assumes circular slip surface — Potential strain discontinuities and slip surface are developed in weaker materials
- There is no stress compatibility between the embankment fill, column, and soil — Ignoring reduction of the stresses in the soil due arching and soil-column interface

Then, a **physics-based** methodology is developed to evaluate the factor safety for basal stability of a CSEs and overcome these limitations.

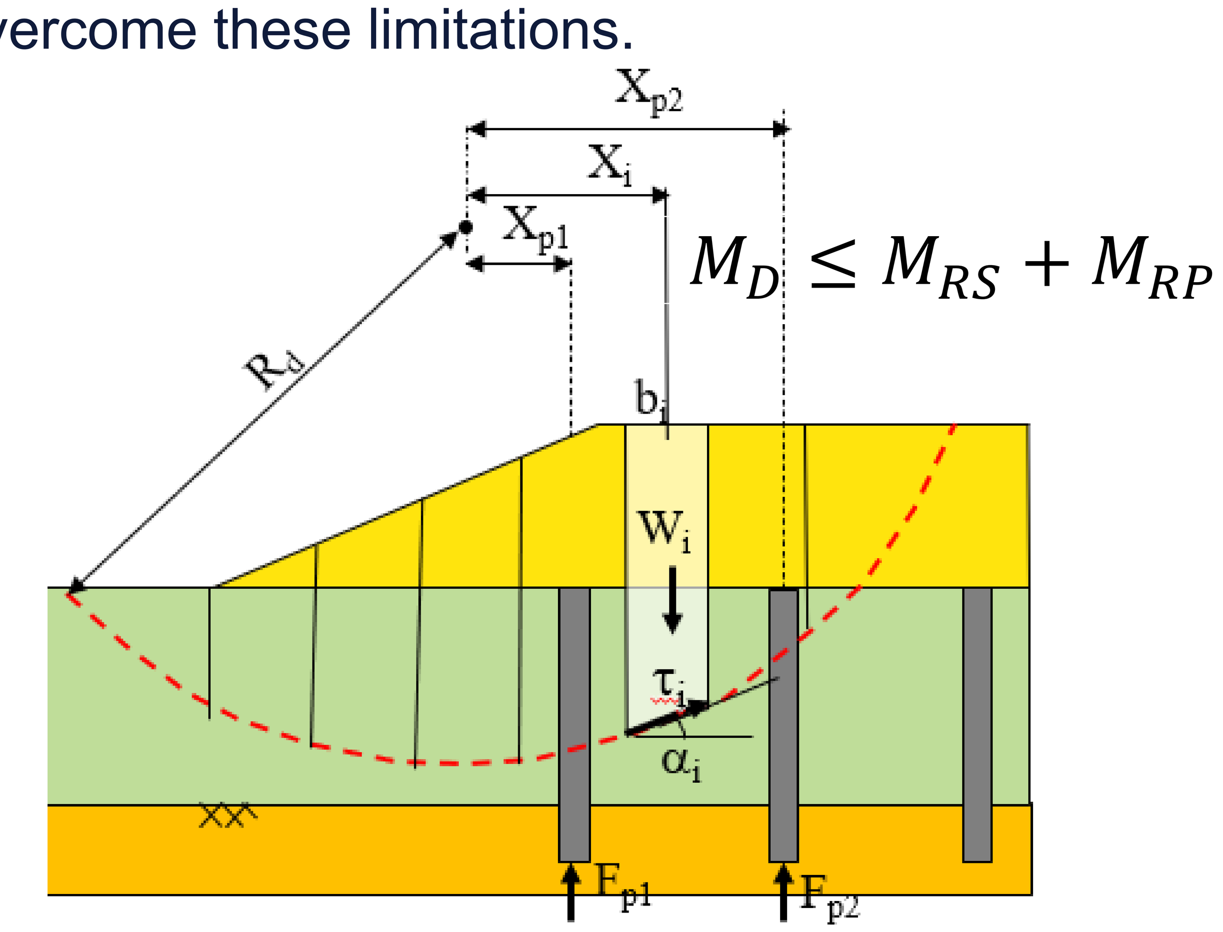
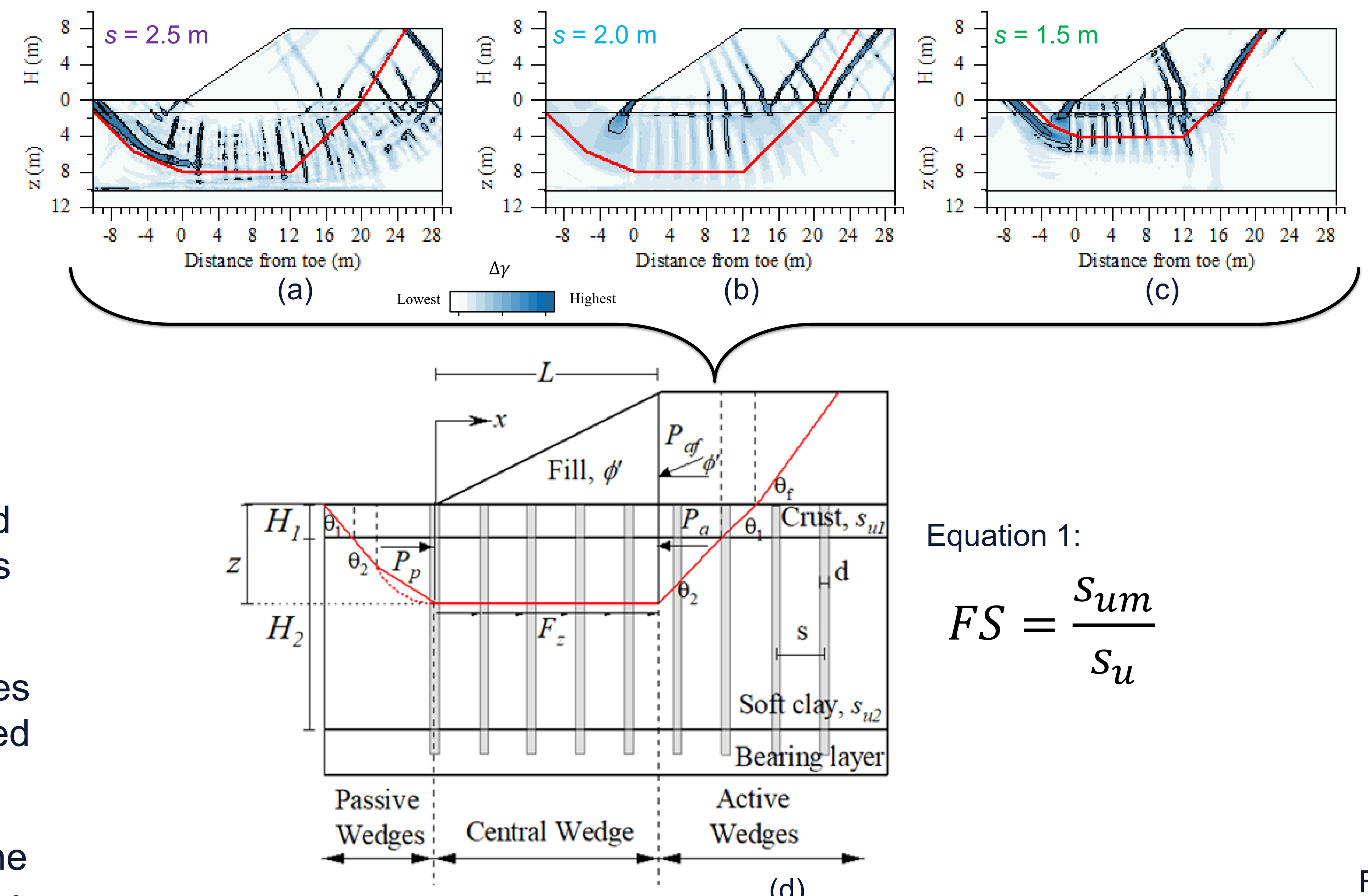


Fig 1. Design Methodology for Global Stability in the FHWA (Schaefer et al 2017).



Equation 1:

$$FS = \frac{s_{um}}{s_u}$$

Fig. 2. Shear Strains increments computed in the FEM for three different column spacings, s (a) 2.5 m, (b) 2.0 m, and (c) 1.5 m. (d) Force body diagram of the three wedge CSE, Red Line is the assumed failure slip surface in the analytical model

Methodology

3D parametric Finite Element (FEM) was performed and informed about the typical failure mechanism (see Fig. 2a.), the lateral pressure at the fill (Active pressure), the arching mechanism, the soil-column interaction, passive resistance. Although the finite element analysis is an excellent tool to estimate the factor of safety against basal stability of the CSE → it is very time consuming.

An analytical method to calculate the FS and the location of the critical slip surface is developed applying lateral equilibrium of the three-wedge system at a depth z (Fig 2.d). By proportional reducing the native shear parameters until the equilibrium is found (s_{um}). The factor of safety (FS) against basal stability at depth z is calculated using Eq. 1. (Fig 2.d). Finally, the FS correspond to lowest value when the slip surface's depth is varied throughout the entire soil profile.

Results

The numerical and analytical solutions show good agreement when comparing the location of the slip surface (Fig.3.a) and the factor of safety against basal stability (Fig.3.b).

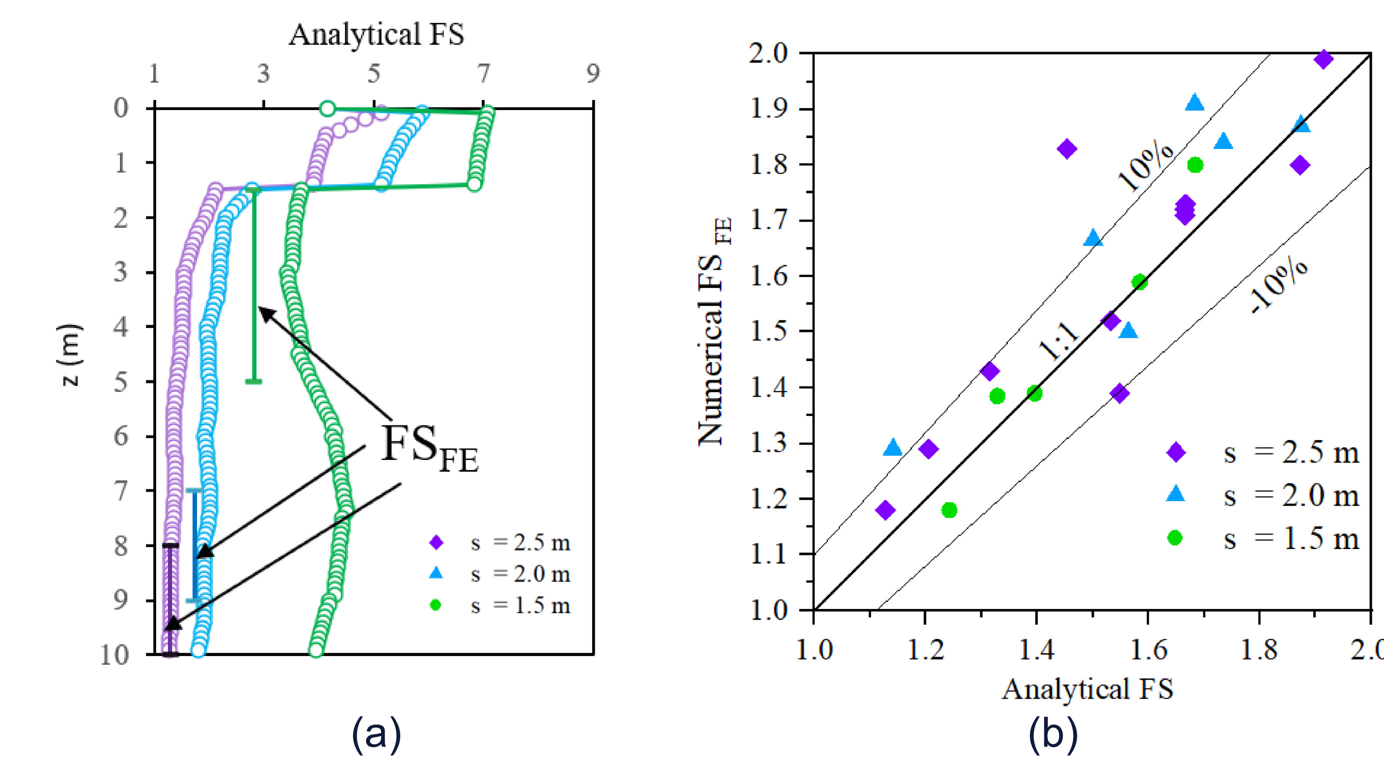
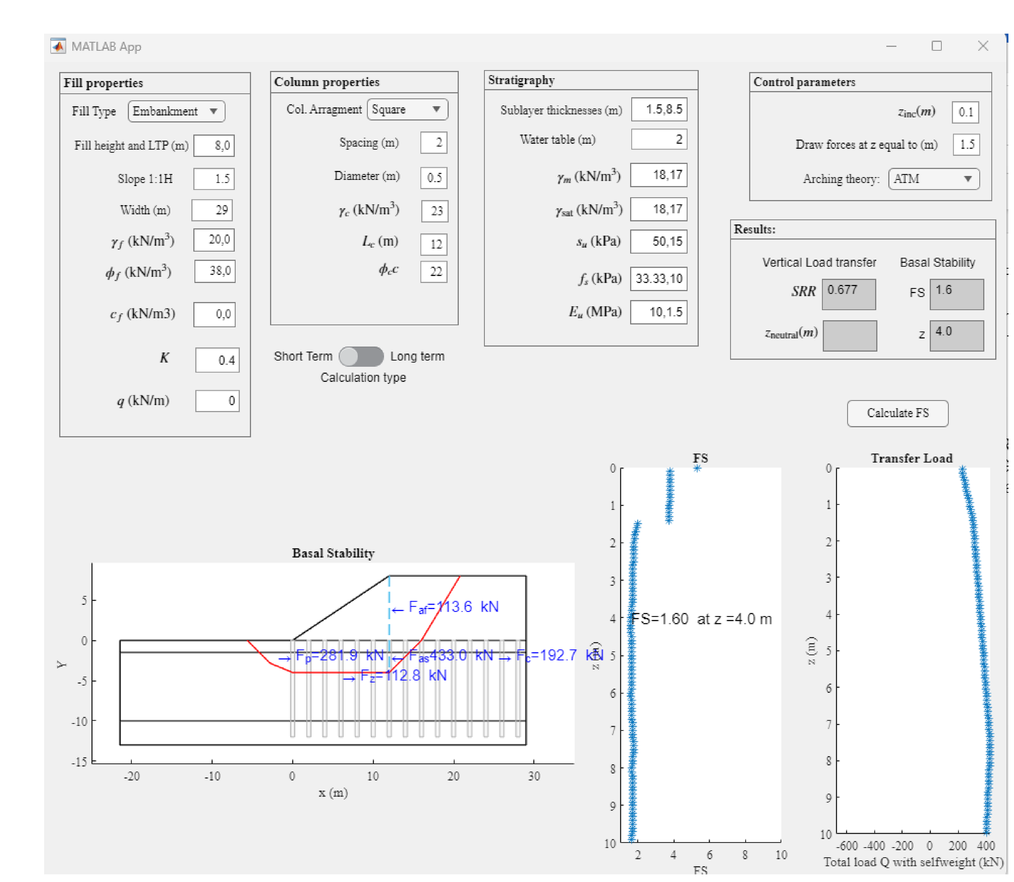


Fig. 3. Comparison of (a) analytical solution of FS at depth versus numerical for one subsoil conditions and three columns spacings and (b) Comparison of the numerical FS with the analytical for cases where FS<2 in the parametric study.



A MATLAB App is under development to calculate the FS of Basal Stability. This work will help practitioners in optimizing the column spacing of the system by determining a more accurate factor of safety against basal stability.

Acknowledgements: Funding for this research is provided by the Transportation Infrastructure Durability Center at the University of Maine under grant 69A3551847101 from the U.S. Department of Transportation's University Transportation Centers Program and the DFI.