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Characterization of Frictional Interference in Closely-spaced Reinforcements in MSE Walls

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PROBLEM STATEMENT

The use of reinforced earth in the United States began in 1972; since then, Mechanically Stabilized Earth (MSE) walls have grown in popularity, and can be found along nearly every state and interstate highway corridor. Due to their inherent flexibility, MSE walls are being constructed to greater heights, in non-linear geometries, with multiple tiers and with very tight reinforcement spacing. For example, the four-tier West MSE wall at Sea-Tac International Airport (STIA see Fig. 1) was recently constructed to 46 m height, and is now the tallest wall in the Western Hemisphere (Stuedlein et al. 2010a). Tall walls (i.e., greater than 15 m in height) will proliferate due to increasing urbanization, right-of-way issues, and wetland mitigation; in other words, they offer a sustainable alternative to conventional grade separation, due to reduced mining and hauling of earth materials and reduced footprint. However, our **understanding** of the working stress behavior, including reinforcement strains and displacements, of tall, single and multi-tier walls **is unsatisfactory**. *The research proposed herein aims to address one of several knowledge gaps in the understanding of tall MSE wall behavior: prediction of reinforcement loads impacted by frictional interference of closely-spaced reinforcements associated with tall walls and/or walls in seismically active regions.*

Fig 1. Perspective aerial viewed from the northwest of the new third runway at Sea-Tac International Airport.

RESEARCH OBJECTIVES & APPROACH

The goal of this research is to characterize frictional interference in closely-spaced steel strip reinforcements used in MSE wall construction.

The research performed investigated the effect of soil-reinforcement interface behavior on the working stress behavior of tall, single and multi-tiered MSE walls. In order to substantiate the hypothesis of frictional interference, high-quality full-scale experimental data was required. The investigation required the following interrelated research tasks:

1. Characterization of the soil-reinforcement interface behavior of single steel strip reinforcements using instrumented pull-out tests;
2. Characterization of the effect of spacing on the shearing resistance of reinforcements using instrumented multi-strip pull-out tests; and
3. Assess the impact of potential efficiency effects on existing design methods for the observed STIA wall performance data.

The pull-out test program was conducted in the laboratories at Oregon State University using specially designed soil test boxes.

EXPERIMENTAL PROGRAM & RESULTS

In order to determine whether or not frictional interference contributes to increased loads in MSE walls, the frictional behavior of closely-spaced reinforcement strips must be compared to the frictional behavior of single reinforcement strips. The reinforcement strips used in this study were galvanized ribbed steel strips 50 mm (2 in.) wide by 6 mm (0.24 in.) thick, as shown in Figure 2. In order to properly evaluate tensile stress-strain behavior of these reinforcement strips, tension testing was performed on the actual steel strips used in the 3rd Runway Project, resulting in E = 208 GPa and f_y = 526 MPa.

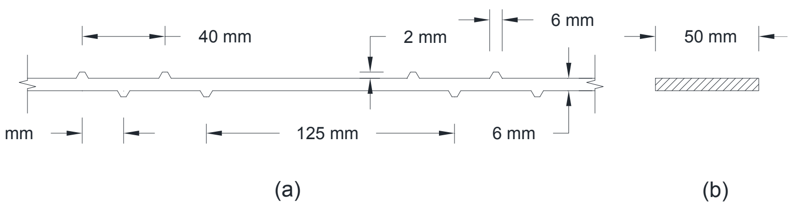

Fig. 2 Steel ribbed reinforcement dimensions (a) elevation view, and (b) cross-section.

The fill material used in this study was a well-graded sandy gravel, identical to the fill material used in the 3RD Runway Project at SeaTac International Airport. A comprehensive large-diameter triaxial test program was undertaken to determine the stiffness and strength of the fill material for comparison to the pullout test results. Figure 3a, 3b, and 3c shows typical stress-strain, principal stress ratio-strain, and volumetric strain-strain curves for the densely compacted fill material, respectively, whereas Figure 3d shows the variation of the friction angle with effective confining pressure for a range in relative densities of the fill material.

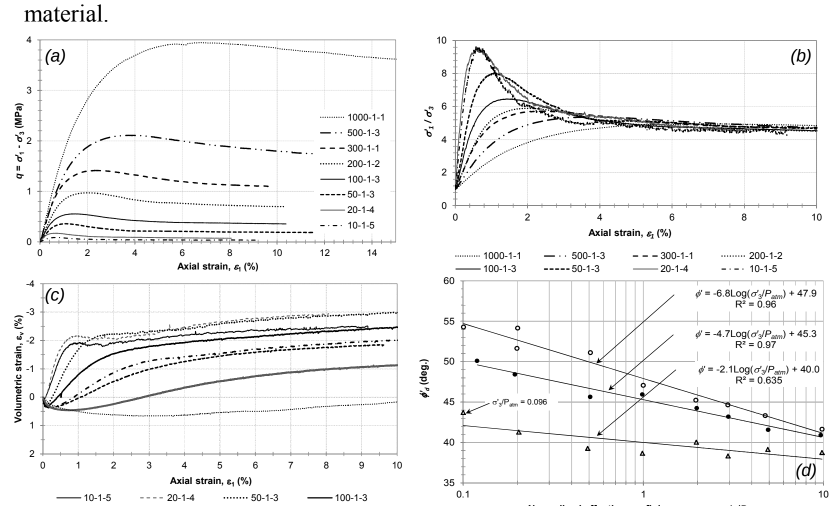

Fig. 3 Constitutive behavior of the sandy gravel fill material from large-diameter triaxial strength tests: (a) principal stress difference versus axial strain, (b) principal stress ratio versus axial strain, (c) volumetric strain versus axial strain, and (d) peak drained friction angle versus normalized confining stress.

Pullout tests on single and multiple strips were conducted in specially designed test boxes that could be pressurized to simulate walls up to 20 m (66 feet) in height. Six foot long single strips were placed within compacted fill in the single-strip pullout test box (Figure 4a and 4b) which measures 2.4 m long, and is 450 mm in height and width. Pullout tests were conducted by varying the soil pressure, which can be applied up to 250 kPa, and withdrawing the strip at a constant rate of 1 mm/min. Figure 5a presents the pullout load-displacement curves for reinforcement strips as a function of overburden pressure. The rate of increase in pullout resistance decreases with overburden pressure due to the suppression of dilation with increased overburden pressure (Figure 5b).

Fig. 4 Views of soil test boxes: (a) single strip pullout box and load frame, (b) view of instrumentation at the front of the single strip pullout box, (c) external view of large multi-strip pullout box, (d) internal view of the multi-strip pullout box, where up to nine strips can be tested simultaneously, (e) view of the partially filled large soil box, and (f) view at front of the large soil box.

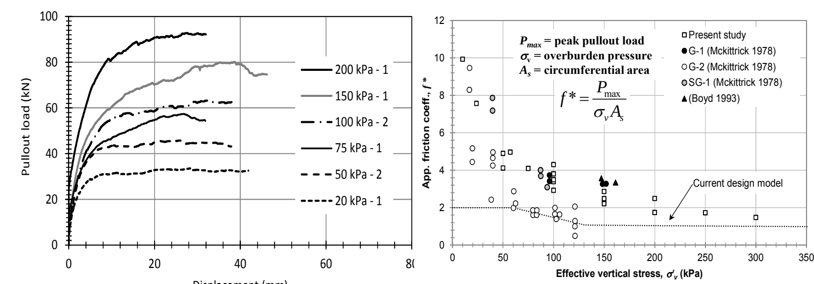

Fig. 5 Results of single-strip pullout tests: (a) load-displacement response for various overburden pressures, and (b) apparent friction coefficient as a function of overburden pressures deduced from this and other studies.

Multi-strip pullout tests were performed in a large, 4 m3 soil box (Fig. 4c – 4f) to evaluate the effect of spacing on frictional interference, and therefore load amplification, in reinforcement strips. A comparison of nine reinforcement strips spaced at 152 mm (6 in.) and tested at 100 kPa overburden pressure is shown in Fig. 6; here, it is observed that strips that are confined (strips 4 – 6) exhibit greater loads than those that are just partially confined. Additionally, the center strip (#5) is shown to exhibit 25% greater load than the single strip at the same overburden pressure (Fig. 5a). Load multipliers (Fig. 7) can be used to indicate the increase in load resulting from spacing effects, and are defined as the ratio of the load in a middle strip divided by the mean external strip loads in a row or column. The effect of horizontal spacing on load amplification is relatively constant for the spacings investigated, however, the load amplification is sensitive to the vertical spacing. Spacing greater than 300 mm (12 in.) appear to produce no load amplification. These findings will serve to inform future MSE wall designs.

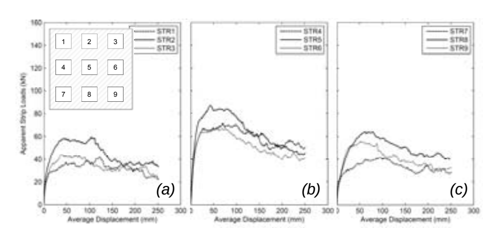

Fig. 6 Load-displacement responses for multi-strip pullout tests for square 152 mm (6 in.) spacing and at 100 kPa overburden pressure: (a) top row, (b) middle row, and (c) bottom row of strips. Note the larger pullout resistance for the middle row.

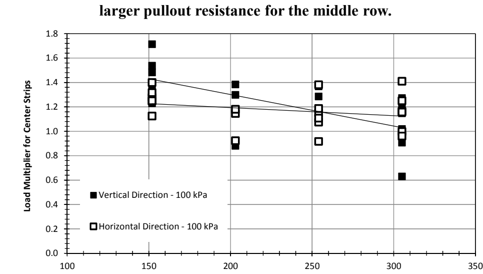

Fig. 7. Variation in load amplification with reinforcement strip spacing at 100 kPa overburden pressure.