New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

High capacity geostrap reinforcement for MSE structures

M.J. Grien
The Reinforced Earth Company, Dallas, Texas, USA

J.E. Sankey
The Reinforced Earth Company, Vienna, Virginia, USA

ABSTRACT: High capacity geostraps, combined with new methods for connecting reinforcing elements to facing panels, have offered durable design solutions for mechanically stabilized earth (MSE) structures in sea water and aggressive environments. Analysis of the internal stability of the MSE structure is required to verify that the maximum tension applied to the reinforcing element does not exceed the long-term allowable tension and that the reinforcing length is sufficient to prevent pullout of the strip. Although physical considerations (i.e. material type, failure surface, coefficient of friction and lateral earth pressure coefficients) vary between reinforcement types, the internal design approach for MSE walls using high capacity geostraps has been found to be similar in many ways to discrete steel strips. The focus of this paper is to evaluate internal design considerations for a high strength polyester geostrap based upon results of a field test study, laboratory tests and numerical analysis.

1 INTRODUCTION

Recent developments in high strength polyester-based geostraps for use as reinforcing elements in MSE walls offer a cost-efficient design solution in marine and aggressive environments. The synthetic geostraps are noted for their high resistance to both chemical and biological degradation. When attached with a fully-synthetic connection to a reinforced concrete facing panel, as shown in Figure 1, reliable information on the geostrap's long-term design strength can be assessed considering design life and ambient temperature of the MSE wall.

Both laboratory and field test studies were conducted to select the parameters necessary for internal design of a MSE wall using the geostraps. From these studies, results were developed using geostraps for the line of maximum tension, lateral earth pressure coefficients and apparent coefficient of friction in MSE wall applications with width to height ratio of 0.7 and no heavily loaded structures. A design application was then developed using AASHTO Specifications (2002) for MSE walls, which were compared in turn to numerical analysis results for accuracy.

Figure 1. Construction of an MSE wall with geostraps.

1.1 *Tensile strength design*

The required allowable tension to prevent rupture of the geostrap may be checked against the maximum applied tension based on the lateral earth pressure from externally imposed loads. Studies of lateral earth pressure at different geostrap levels were used to back calculate the ratio for the coefficient of lateral earth pressure, K vs. K_a (active earth pressure coefficient). These results were then compared to values given in AASHTO Specifications for MSE walls, as shown in Figure 2, were referenced to determine a conservative design approach using geostrap reinforcement.

1.2 *Pullout resistance design*

For pullout prevention, the frictional properties and delineated line of maximum tension for the geostraps contribute to internal stability verification. The selection of design considerations for a MSE wall depend on the extensibility of the reinforcing element. Figures 3 and 4 from AASHTO Specifications define the

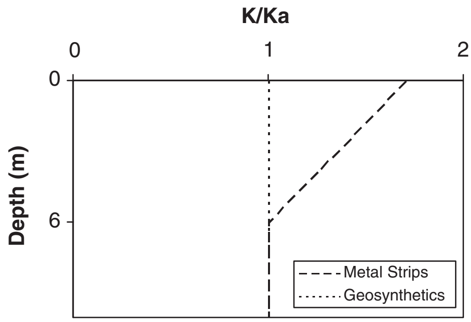

Figure 2. Ratio of lateral earth pressure coefficient, K/K_a.

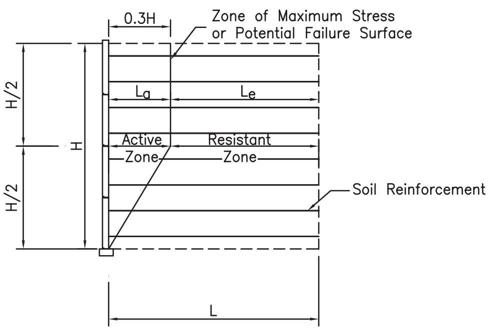

Figure 3. Inextensible failure surface.

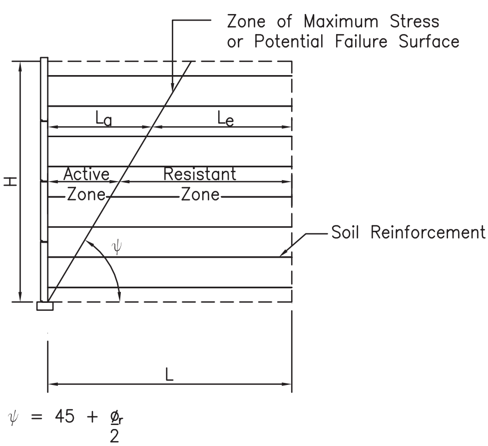

Figure 4. Extensible failure surface.

failure surface (line of maximum tension) based on reinforcing elements being either inextensible (steel) or extensible (geotextiles and geogrids). For the purpose of this paper, the actual values from the field study and numerical analysis were compared to AASHTO Specifications.

Default values from AASHTO for coefficient of friction (f*) between the reinforcing strip and soil

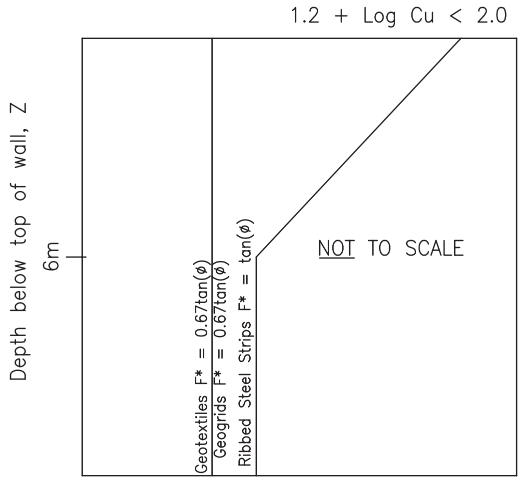

Figure 5. Default values of f*.

are shown in Figure 5. The actual values found from laboratory testing are compared to values in Figure 5.

2 DESCRIPTION OF GEOSTRAP AND CASE STUDIES

2.1 *Description of geostrap*

The geostrap reinforcing strip used in the study consisted of high tenacity polyester fibers (HTPET) encased in a polyethylene sheath. The high tenacity polyester is the load bearing element, while the sheath protects the yarns from installation damage and degradation. The durability of the geostrap has been increased by the polymerization process and is only for use in soil environments characterized by $3 < pH < 9$, with no detrimental affect on the strip due to low resistivity backfill or from backfills with high chloride or sulfate content. Ambient temperatures of the retaining wall site and design life are considered in the determination of the long-term allowable reinforcement tension.

Material Properties:
Tension = 22 kN with Strain; $\varepsilon = 4\%$
Strip Width; $b = 2 \times 50$ mm.

2.2 *Field study of MSE wall with geostrap*

A 6.4 m high MSE wall, located in St. Remy Les Chevreuse, France, was instrumented with 560 strain gauges on the geostraps and 176 strain gauges on the connections to the precast facing panels (Hoteit, Price and Schlosser, November 1993).

Properties of Backfill Material:
Average Dry Density; $\gamma = 15.3\ kN/m^3$

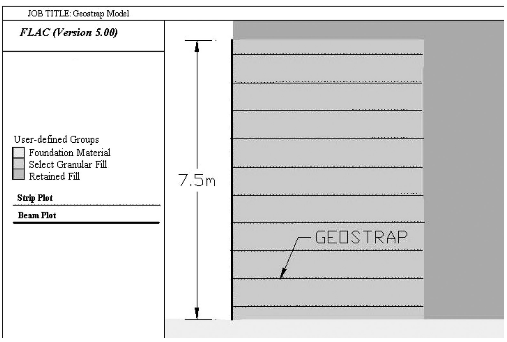

Figure 6. FLAC model.

Internal angle of friction; Ø = 37°
Cohesion; c = 5 kPa.

2.3 *Numerical analysis of MSE wall with geostrap*

The numerical analysis study was carried out using a finite difference program, Fast Lagrangian Analysis of Continua (FLAC) version 5.0, a 2D geotechnical program developed by the consulting company Itasca in the USA. The model was built using a sequential wall construction: first placing a 1.5 m high facing panel, followed by placement of level geostraps (5.5 m long) spaced uniformly at 750 mm, followed by reinforcing backfill and repeated up to a maximum design height of 7.5 m, as shown in Figure 6. After construction of the wall, a live load surcharge of 10 kPa was added. Maximum tensile forces (per linear meter) over the entire length of each strip were used to locate the line of maximum tension and to calculate actual lateral earth pressure coefficients.

Properties of Select Granular Fill Material:
Mohr-Coulomb Model
Density; $\gamma = 1900\,\text{kg/m}^3$
Internal angle of friction; Ø = 34°
Cohesion; c = 0 kPa
Young's Modulus; E = 80,000 kPa
Poisson's ratio; $\upsilon = 0.33$

Properties of Foundation Material:
Mohr-Coulomb Model
Density; $\gamma = 1900\,\text{kg/m}^3$
Internal angle of friction; Ø = 30°
Cohesion; c = 0 kPa
Young's Modulus; E = 40,000 kPa
Poisson's ratio; $\upsilon = 0.33$.

3 RESULTS

3.1 *Line of maximum tension*

Numerical analysis results show the maximum tension for the geostrap (per linear meter) close to the back of the panel facing then becoming unloaded on all strip levels beyond 4.5 m of reinforcement length. Geostrap tensions from the numerical analysis in levels 3 and 10, at depths of 1.875 m and 7.125 m, respectively, are shown in Figure 7. For the upper reinforcing levels, it is noted that the length of tensile forces over the entire length of the strip is greater than the lower strip levels.

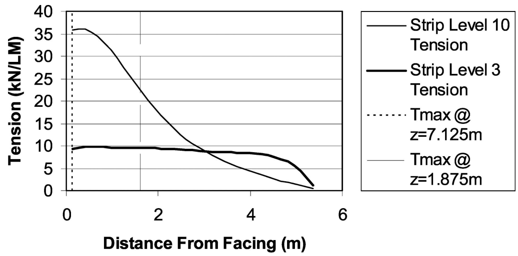

Figure 7. Numerical analysis results of tension throughout two geostrap levels.

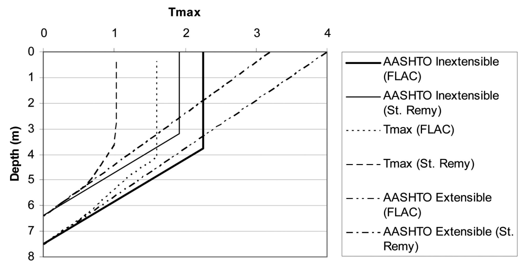

Figure 8. Actual T_{max} vs. Theoretical T_{max}.

Field study and numerical analysis results for lines of maximum tension (T_{max}) in the geostrap (per linear meter), shown in Figure 8, are both within 0.3H (wall design height), 0.16H and 0.2H, respectively. These lines for the geostrap were more closely represented in Figure 3 rather than Figure 4. This has a significant affect on the effective length (L_e) of the reinforcing strip, especially at the top of the structure. For example, the top level (z = 0.375 m) would have an effective length for resistance to pullout of the geostrap of 3.25 m, using the resistant zone shown in Figure 3, and approximately 1.51 m, using Figure 4.

3.2 *Lateral earth coefficients*

Actual values for maximum geostrap tension were compared in Figures 9 and 10 to calculate maximum tension using known values in Equation 4 for lateral earth coefficients, K_o (Equation 2) and K_a (Equation 1). T_{max} over the top 5 m of the field study wall was greater than calculated values, using K_a. Below 5 m, T_{max} was less than values obtained using K_a.

$$K_a = \tan^2(45 - \tfrac{\phi}{2}) \tag{1}$$

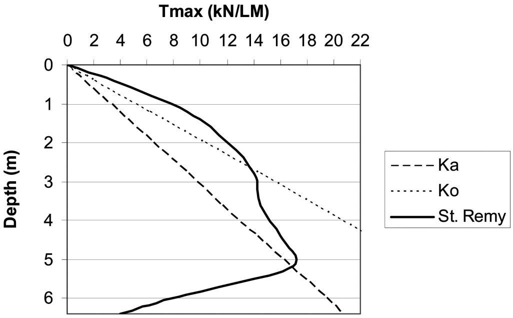

Figure 9. Field study values of T_{max} vs. K_a and K_o.

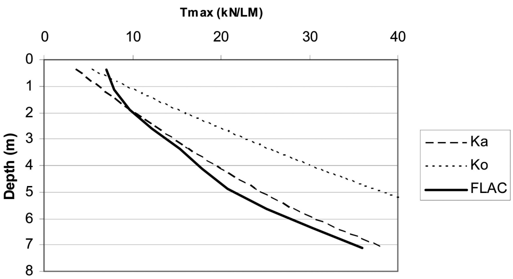

Figure 10. Finite difference analysis values of T_{max} vs. K_a and K_o.

$$K_o = 1 - \sin(\phi)^{2} \tag{2}$$

$$\textit{Tributary Area, } A = \textit{Vertical Strip Spacing} \times \textit{Horizontal Strip Spacing} \tag{3}$$

$$T_{\max} = K * \sigma_v * A \tag{4}$$

Similar to the field study, the finite analysis results of T_{max} over the top 2 m of the wall was greater than calculated values using K_a. Below 2 m, T_{max} was less than values obtained using K_a.

In a comparison between AASHTO and both studies, more than 20% percent of the top portion of the overall wall had a K/K_a ratio greater than what is required for geotextiles. Below 5.5 m, this ratio was less than 1.0 for both structures. Therefore in determining the applied tensile forces to the geostrap, simply using the line for a geotextile would not be sufficient.

3.3 *Apparent coefficient of friction*

Coefficient of Friction based on laboratory testing; f*

$$f^* = T_{\max} / 2bL\sigma_v \tag{5}$$

where:
T_{max} = maximum pullout load
L = embedment length of geostrap
σ_v = total vertical stress.

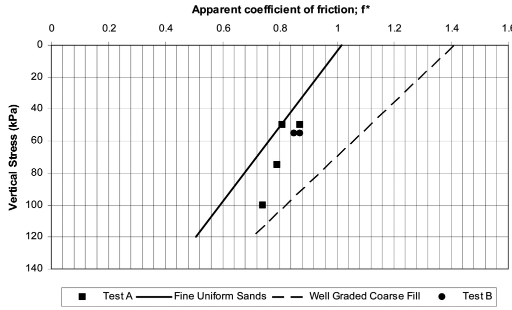

Figure 11. Coefficient of friction; f*.

The lab results show the coefficient of friction between the geostrap and soil was between the values for a ribbed steel strip and a geotextile, as shown in Figure 11. Internal stability analysis for pullout of the geostrap using the results for the coefficient of friction and effective length of the geostrap were more similar to a ribbed steel strip, as shown previously in Figures 3 and 5, respectively.

4 CONCLUSIONS

Field testing, laboratory testing and numerical analysis results were used in this paper to evaluate a MSE wall design using geostrap reinforcing elements. The evaluation showed some differences between the AASHTO design standards and actual test results. A possible reason for the differences could be that the geostrap used in the evaluation were of higher strength and less extensible than standard geotextiles originally considered by AASHTO. Additional design development is needed in AASHTO to account for higher strength polymeric reinforcing elements with closer behavior to steel reinforced structures.

Overall, high strength geostraps exhibit greater tensile capacity and lesser extensibility than other geosynthetic reinforcing elements used in MSE wall applications. At the same time, the frictional interaction is more akin to discrete reinforcement elements than the planar elements typical of geogrids and geotextiles. Therefore, where aggressive backfill conditions limit consideration for steel reinforcements, a cost-effective and more durable alternative is a high strength geostrap MSE wall application.

REFERENCES

AASHTO, "Standard Specifications for Highway Bridges," seventeenth edition, 2002.

Hoteit, N, Price, D. I., Schlosser, F., "Instrumented Full Scale Freyssisol-Websol Reinforced Soil Wall," technical article presented at the Conference for Soil Reinforcement – Full Scale Experiments of the 80's, November 1993.