MECHANICALLY STABILIZED EARTH (MSE) WALLS: SPECIAL SITUATIONS
Summary findings

CONSORTIUM FOR EDUCATION AND RESEARCH IN GEOENGINEERING PRACTICE

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BACKGROUND:

MSE walls have been used for many different purposes in civil engineering, however some design projects have encountered limited guidance in industry. The CERGEP members requested a literature review addressing special situations for MSE walls including MSE walls in slopes, MSE walls under flooding conditions, MSE walls on layered soils, back to back MSE walls, MSE walls under eccentric loading, the rigid block assumption for external stability analyses and economic optimization of the MSE walls shape.

WHAT THE RESEARCHER DID:

Information collected from a review of existing knowledge was completed covering the work of state agencies, federal agencies, global agencies, university research, and private contractor research. This information was summarized in a report. The reference is:

Bou Semaan S., Briaud J.-L., 2020, "Mechanically Stabilized Earth (MSE) Walls: Special Situations", CERGEP Report No.10 – SI/US units, Civil engineering, Texas A&M University.

WHAT THE RESEARCHER FOUND:

For MSE walls placed in slopes, AASHTO LRFD Bridge Design Specifications (2017) require that a minimum horizontal bench width of 4 feet (1.2 m) must be provided in front of these walls. Morrison et al. (2006) addressed the stability analysis of a Shored MSE (SMSE) wall perched in a slope. They identified the various types of stability failures for such walls. Guidelines for reinforced soil slopes are found in FHWA NHI-10-025 and are presented as an appendix in the report. Briaud (2013) provides guidance for calculating the factor of safety for a reinforced slope F_R where the failure circle goes through the reinforcement as:

$$F_R = [\, M_{Rmax\ (soil)} + M_{Rmax\ (reinforcement)}] / M_D,$$

where $M_{Rmax\ (soil)}$ is the maximum resisting moment provided by the soil along the failure circle considered, $M_{Rmax\ (reinforcement)}$ is the maximum resisting moment provided by the reinforcement, and M_D is the driving moment due to the soil weight and any other external loads. The moment arm involved in the moment $M_{Rmax\ (reinforcement)}$ for the reinforcement depends on the flexibility of the reinforcement and is critically important.

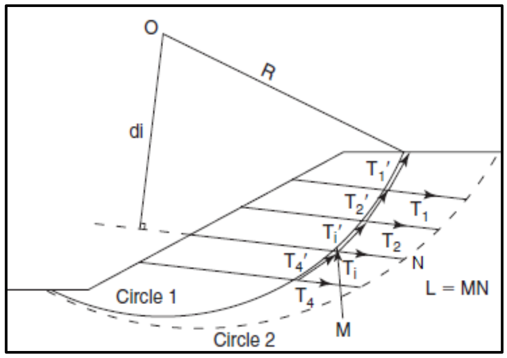

Fig. 1: Reinforced Slope (Briaud, 2013)

For MSE walls under flooding conditions, the most critical hydraulic condition for the MSE wall is the sudden drawdown condition after a long period of high water level (WL) in the channel. Aubeny et. al (2014) showed that there is no effect of rapid drawdown on the compound failure behavior of an MSE wall. There were two types of drawdown cases. Each case consisted of lowering the water level 3 ft (1 m) in front of a 20 ft (6 m) high wall while maintaining the WL constant on the reinforced soil side. In this study, the factor of safety (FS) dropped from 22% to 34% when rapid drawdown occurred compared to the same case with no drawdown. Miyata and his colleagues performed three full-scale tests to investigate the influence of cyclic flooding on the performance of multi anchor walls (MAW) (Miyata et. al, 2010) and steel strip reinforced soil walls (Miyata et. al, 2015). The results showed that the displacement of the facing panels during the flooding and draining cycles are acceptable and a FS equal to 3 on the anchors capacity resulted in a safe estimate of the anchors capacity.

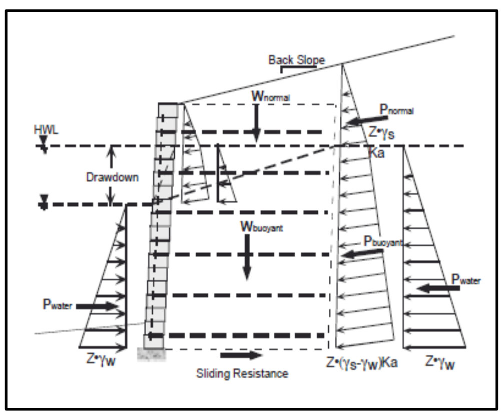

Fig. 2: Typical design section for sudden drawdown (http://www.mrkeystone.net)

The anchor capacities under flooded conditions were observed to be about 50% of the anchor capacities under drained conditions. The net lateral earth pressures acting against the back of the facing panels for MAW were observed to decrease during flooding and decrease or remain reasonably constant from the dry condition for steel strip reinforced walls. The peak tensile loads and connection loads in the steel strips below the flood level were observed to decrease from the dry condition. The comparison between the measured and predicted pullout capacities showed that a FS of 4.3 is required. The effects of corrosion should be taken into account when flooding conditions are present.

For MSE wall resting on a layered soil, the design consists of the ultimate bearing capacity of the soil under the foundation, and the tolerable settlement that the foundation can undergo without affecting the superstructure. Briaud (2013) presents a limit equilibrium method to calculate the ultimate bearing capacity of layered soils. The step-by-step process advances by assuming a reasonable failure mechanism, drawing a free body diagram of the failing body with the external forces and external moments applied to it, writing fundamental and constitutive equations and solving for the unknowns. For settlement, two approaches are presented. The elasticity method which is an approximation and the general approach which is valid in all cases (Briaud, 2013). The general approach consists of dividing the depth of influence into an appropriate number of layers i, finding the vertical strains corresponding to the vertical effective stress before loading and the vertical strains corresponding to the vertical effective stress after loading in the middle of each layer i. The difference in vertical strains corresponds to the relative compression of each layer.

For back to back MSE walls, FHWA guidance (Berg et. al, 2009) identifies two extreme cases: (1) the walls are far apart, and (2) reinforcements from both sides meet in the middle or overlap. The internal stresses within the inextensible reinforced soil of overlapping back to back MSE walls are conservatively modeled by using the at rest earth pressure coefficient Ko to the active coefficient Ka. The guidelines are valid for static load conditions or in areas where the seismic horizontal accelerations at the foundation level are less than 0.05g. In addition, the manual indicates that connecting reinforcements to both faces of back to back walls results in an increased earth pressure condition approaching Ko. Seismic loads in back to back walls were evaluated through a numerical study by Hardianto and Truong (2010). Deformation analyses were performed on a steel strip reinforced back to back walls 12 m (39.4 ft) high and having separations between wall faces of D= 0.4H and D= 1.0H. Results showed that under seismic conditions, back to back walls demonstrated similar displacements compared to single face MSE walls and reduced reinforcement loads. Widening existing facilities by building MSE walls in front of current faces with inadequate room was addressed by the NYSDOT (2012). The manual specifies that a minimum of two reinforcement layers, but no less than 3 ft (1 m) of reinforced soil, shall extend over the top of the existing structure or steep rock. The minimum length of these reinforcement layers should be 0.7H, or 5 ft (1.5 m) behind the face of the existing structure, or the minimum length required to resist the pullout forces applied to those layers, whichever results in the greatest reinforcement length. The minimum clearance between the top of the existing structure or rock face and the first reinforcement layer extended beyond the top of the existing structure should be 6 in (15 cm). A numerical analysis of a geosynthetic reinforced back to back MSE wall (Benmebarek et. al, 2016) presented an interaction distance less than that from the FHWA method. The lateral earth thrust from the study are compared with the FHWA Design guidelines (Rankine method) in Fig. 3. An in-depth numerical analysis of a 25 m (82 ft) tall MSE wall with a 15 m (49.1 ft) back to back portion (Truong et. al, 2007) along with field instrumentation validate the current standard practice for the load prediction in steel reinforcements. The results showed that in back to back walls where the reinforcements overlap more than 90% of their lengths the maximum tension in each reinforcement level occurs at the panel facing.

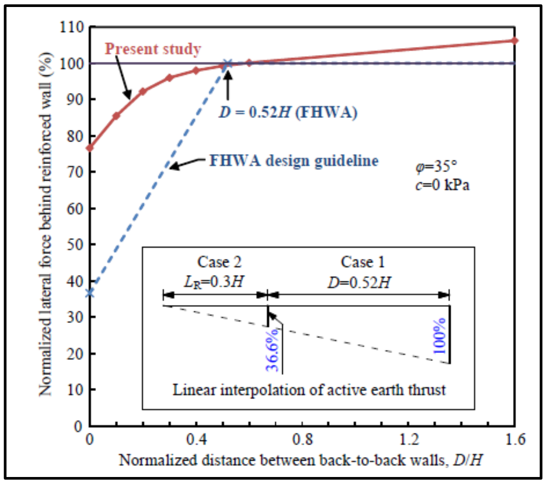

Fig. 3: Percentage of lateral thrust behind the reinforced wall (Benmebarak et. al, 2016)

<u>*For eccentrically loaded MSE walls*</u>, the effective foundation width can be evaluated using Meyerhof's effective area method where the effective width B' to be used in the general bearing capacity equation is ($B – 2e_b$) with e_b being the eccentricity due to a vertical load P and a moment M (e_b= M/P). Alternatively, the load eccentricity factor f_e used in the load settlement curve (LSC) method (Briaud, 2013) is: $f_e = 1 - 0.33\frac{e}{B}$ for the settlement at the center of the foundation and $f_e = 1 - \left(\frac{e}{B}\right)^{0.5}$ for the settlement at the edge of the foundation, with e being the eccentricity and B the foundation width.

<u>*The MSE Walls rigid block assumption*</u> used for sliding and overturning analyses is reasonable as shown by Aubeny et. al (2014). In this work, Aubeny et. al (2014) emphasize the importance of the unit weight and strength of the backfill soil and of the retained soil on the sliding and overturning results. For bearing capacity, Terzaghi's bearing capacity equation corresponds to a soil strength profile that increases linearly with depth. If the soil strength profile does not meet this requirement, then Terzaghi's equation should not be used. Instead, Briaud (2013) presented a set of direct strength equations that rely on the average value of the strength of the soil within the depth of influence of the foundation below the foundation level. The equations are generally of the form: $p_u = k\ s + \gamma\ D$, where k is the bearing capacity factor, γ is the effective unit weight of the soil, D is the embedment depth, and s is a measure of the soil strength averaged over the depth of influence. The k values are given in the report.

<u>*For MSE walls utilizing uneven reinforcement lengths*</u>, or non-rectangular geometry the guidelines in north America, in Asia and in the British Standard (2010) are similar. Such reinforcement geometry should only be considered if the base of the MSE wall is founded on rock or competent soil. For weak foundation materials, ground improvement prior to MSE construction may be necessary before allowing for nonstandard reinforcement geometries.

<u>*MSE walls current research*</u> includes MSE walls under flooding conditions with rapid drawdown for backfill materials that are within specifications, and back to back MSE walls. However, there is a lack of guidance for the design of MSE walls associated with the widening of existing highways.