Retaining Walls

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An overview of the characteristics and design of Gravity, Mechanically Stabilized Earth (MSE) and Geosynthetic Reinforced Soil (GRS) retaining walls

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1.0 Introduction

Retaining walls are not a new concept. Walls used to retain masses of soil have been around for thousands of years and were used in virtually every civilization in history. Geotechnical engineering is a branch of civil engineering that deals with soils as engineering materials; a retaining wall is any geotechnical structure which is used to retain a mass of soil that would otherwise tend to move down slope due to gravity and stresses acting within the soil (Terzaghi et al, 1996). There are generally two classifications of retaining walls: externally stabilized walls which use heavy materials on the outside of the soil mass to resist soil movement, and internally stabilized walls which utilize artificial reinforcements placed in the soil to carry tensile loads and stabilize the soil mass (Khan and Sikder, 2004). Retaining walls have many different uses. Walls are often used to achieve desired changes in ground elevation which exceed the natural slope. Walls can be used to stabilize ground slopes, for example if removing the lower part of a hillside for a road would create an unstable slope, a retaining wall could be constructed to provide resistance to soil movement. Walls can be used to prevent erosion and ground sloughing by creating a barrier to soil particles moving down the slope. And certain types of soil retention systems also have unique applications such as bridge abutments and stream crossings. Retaining walls can be found everywhere from urban centers to rural farm lands, and across almost every resource and industrial sector.

The objective of this essay is to provide a general overview of three types of retaining walls through review of current literature. The scope of this essay encompasses basic retaining wall theory and design. There are three common types of retaining walls that will be discussed in this essay. The first type is gravity retaining walls. This is a general term for walls that use the self-weight of the wall to support the soil behind the wall, called backfill which may be undistirubed natural soil or disturbed soil that is placed and compacted behind the wall. Gravity walls are a classic example of the externally stabilized wall system. The walls are constructed using heavy materials that must be sufficient to resist the vertical and lateral stresses imposed on the wall from the soil mass (Criag, 1992). Mechanically Stabilized Earth (MSE) walls are the second type of retaining walls to be discussed. MSE walls consist of a rigid face tied-back with reinforcements to elements embedded behind the wall with the purpose of "mechanically" stabilizing the soil mass (VanBuskirk, 2010). The horizontal reinforcements are spaced and connected to the rigid face throughout the height of the wall, with the primary design considerations being vertical distance between layers of reinforcement, strength of the reinforcements themselves, and connection strength between the reinforcements and the rigid face (Elias et al, 2001). Triaxial test results show that the addition of reinforcement results in increased peak strength, larger axial strain at failure, and reduced or limited post-peak loss of strength (Elton and Patawaran, 2005).Although MSE walls use reinforcements within the soil mass, MSE walls are technically classified as externally stabilized walls because the explicit purpose of the reinforcements is to prevent deformation of the wall face and current design standards ignore the soil-reinforcement interaction (Wu, 2001). The third type of retaining wall is a relatively new technology called Geosynethic Reinforced Soil (GRS); GRS walls are an example of internally stabilized walls and are different than MSE walls. The concept of reinforced soil is not new; evidence of reinforcing soil for stability can traced back as early as the construction of the Great Wall of China (Bradley and VanBuskirk, 2009). Although the theory of reinforcing soil remains the same, GRS uses new technology that provides improvements over other reinforced soil walls such as MSE walls. GRS walls are constructed using well-compacted soil between closely spaced reinforcement layers (VanBuskirk, 2010). The close spacing between reinforcement layers allows the face of GRS walls to be flexible, non-rigid and non-load bearing (Wu, 2007). This essay will display the similarities and differences of gravity, MSE and GRS walls.

2.0 Gravity Retaining Walls

2.1 Overview

Gravity retaining walls are earth retaining structures that use the mass (self-weight) of the wall to resist and stabilize soil (Figure 1). The vertical walls are typically constructed with stone, concrete or other heavy materials. The mass of the wall must be sufficiently large to withstand the stresses distributed within the retained soil. Stresses in the soil develop from dead and live loads, as well as porewater pressure. The term batter refers to the angle of the face relative to the vertical direction; the walls often have a slight positive batter to improve stability, where the wall tilts slightly in the direction of the retained soil mass. Gravity walls have the advantage of simple design and construction, but have the disadvantage of being significantly uneconomical as they rely completely on the weight of the wall to resist the soil mass, and have higher construction costs when compared with internally stabilized soil systems (Khan and Sikder, 2004).

2.2 Design

2.2.1 Face

Gravity retaining walls use external stabilization to retain masses of soil. This method of soil stabilization employs external resistance to counterbalance the stresses developed within the soil. As outlined in Craig (1992), the design of retaining structures has traditionally been based on the specification of a factor of safety in terms of moments, i.e. the ratio of the resisting (or restoring) moment to the disturbing (or overturning) moment. Moments occur when the wall tends to rotate (typically about the base) due to stresses imposed from the soil. The wall is constructed using heavy materials such as stone or concrete. The mass of the wall provides the resistance to moments and stresses that develop in the backfill. In general, the stress imposed on the wall increases with depth of soil thus the mass required in the wall is proportional to wall height. Lateral earth pressure which acts in the horizontal plane in the backfill soil is the primary design consideration; the retaining wall must be designed to account for expected lateral earth pressures (See Sections 2.3.3 and 2.3.4). The wall face is simple to construct, but is labour intensive in construction and requires abundant materials.

2.2.2 Backfill Soil

Granular, course-grained soils are highly permeable and are the preferred backfill soils of gravity walls. The course grains and large void spaces allows the excess porewater pressure to dissipate quickly, which results in the drained condition and decreases the stresses imposed on the retaining wall. The drained condition arises when water within the soil is able to dissipate and only the soil particles support loads; conversely, soils in the undrained condition retain water within the soil and both soil particles and water must contribute to supporting stresses. The existence of either the drained or undrained conditions depends on soil type, grain size distribution, geological formation, rate of loading and artificial drainage systems within the soil (Budhu, 2007). Artificial drainage systems are often installed in the backfill to further facilitate drainage. Locally derived materials are typically used as backfill if suitable granular soils are present onsite.

2.2.3 Lateral Earth Pressure

A gravity retaining wall must resist stresses in both the vertical and horizontal directions. Soil masses exist in three directions or planes: x, y and z (Figure 2). On each of these planes, the normal and shear stresses and strains can be evaluated. However, situations exist where not all three planes need be analyzed. A condition known as “plane strain” develops where the normal strain in one direction is zero, and only the stresses and strains in the other two directions are important for analysis. With respect to the x, y, and z planes in Figure 2, the stress and strain in the y direction (σ_y and ε_y) tend to zero because the displacement in the y direction is very small compared to the width of the wall (Craig, 1992).

Lateral earth pressure acts in the horizontal plane in the backfill. Because a retaining wall prevents movement of a soil mass, the wall must provide equal and opposite stresses to counteract the stresses from the soil. In the plane strain condition only the vertical effective stress (σ_v') and horizontal effective stress (σ_h') are considered. The horizontal stress is known as lateral earth pressure and is defined as the magnitude of stresses between the soil mass and the adjoining retaining wall in the horizontal plane (Craig, 1992). The Lateral Earth Pressure Coefficient, K, is used in calculation of lateral earth pressure and can be applied in three categories: at-rest, passive, and active. Active refers to the wall tilting out away from the soil mass and passive refers to the wall tilting in toward the soil mass (Craig, 1992). Because lateral earth pressure acts in the horizontal plane, the magnitude of the normal stress is imposed on the retaining wall face and "pushes" the wall outward creating a moment. The purpose of knowing lateral earth pressures is so the retaining wall can be designed to accommodate those pressures and prevent failure during its service life.

2.2.4 Rankine and Coulomb Earth Pressure Theories

Earth pressure theories are used to calculate the expected lateral earth pressure on a retaining wall. Determining exact values of stresses and strains within a soil mass requires a rigorous analysis of the stress-strain relationship, solutions to the equations of equilibrium, and the boundary conditions must be known (Craig, 1992). Boundary conditions are a set of differential equations along with a set of restraints that define a region where the differential equation is valid (Polyanin and Zaitsev, 2003). An example would be differential equations defining horizontal and vertical displacements within a soil. In reality, a complete analysis of lateral pressures isn't possible because the solutions to the differential equations in the boundary conditions are rarely known. Because an exact solution to lateral earth pressures cannot be known with any reasonable degree of accuracy, engineers use earth pressure theories to estimate lateral earth pressure acting on gravity retaining walls.

The two commonly accepted theories for calculating lateral earth pressure are the Rankine theory developed in 1857 and the Coulomb theory developed in 1776. Craig (1992) presents the theories and formulae for calculating lateral earth pressure which are shown in Tables 1 and 2. The theories are based on five primary assumptions. The first assumption is the backfill soil is granular and cohesionless, and contains no or very little fine-grained soil particles such as clay and silt. The second assumption is the soil is homogenous and not a varying mixture of materials. The third assumption is the soil is isotropic, where the soil has similar stress-strain properties in all directions and the soil is not artificially reinforced. The fourth assumption is the soil and wall are semi-finite where the wall is very long and the soil mass is undisturbed with no bends or other boundary conditions. The final assumption is the soil is well-drained so that porewater pressure may be neglected. Although there have been many advances in geotechnical engineering since these theories were developed, both remain the basis for present day earth pressure calculations for gravity retaining walls.

The Rankine Earth Pressure Theory was developed by William Rankine (1820-1872). Rankine's theory is a set of equations based on properties of the soil which predict at-rest, active and passive pressures when shear failure is at the point of occurring throughout the soil mass (Craig, 1992). Consider an element of soil behind a smooth, frictionless wall surface. The active and passive states develop in a wedge of soil between the wall and the failure plane, and are produced through a rotational movement of the wall about the base (Craig, 1992). The active state occurs when the wall is allowed to relax outward. Active pressure is considered a minimum value because as the wall moves and the soil laterally expands, lateral stress decreases to a minimum value reaching the limiting tensile strength of the soil.

The passive pressure state occurs when the wall moves in toward the backfill. In the passive state, soil is laterally compressed until lateral pressure reaches a maximum value. The active and passive pressure states occur through uniform strain within the soil which pushes or pulls the retaining wall. Lateral strain must occur near the top of wall and there must be sufficient deformation to reach the active and passive states. The fulcrum of the rotating wall must be at the base; if rotation were to occur about the top of the wall, lateral strain at the top may be approximated to zero. If lateral strain is zero, the at-rest pressure applies. The Rankine theory formulae are presented in Table 1.

The Coulomb theory was developed by Charles-Augustin de Coulomb (1736-1806) who was the first to study earth pressure problems on retaining structures. The Coulomb theory is similar to the Rankine theory with some key differences. The Coulomb theory does not estimate at-rest pressure. The Rankine Theory assumes a smooth, frictionless wall whereas the Coulomb theory accounts for and quantifies wall friction through a direct shear test. When wall friction is zero, results will be the same as the Rankine theory. The lateral earth coefficients, K_a and K_p for lateral expansion and compression respectively are calculated using limit equilibrium theory to determine the limiting horizontal pressure at failure (Craig, 1992). Many failure planes are possible so numerous potential planes must be identified and analyzed. In general, the Coulomb theory underestimates active pressure and overestimates passive pressure (ie. upper bounds to true collapse loads). The Coulomb theory formulae are presented in Table 2.

State	Lateral Earth Pressure Coefficient	Pressure
Active	$K_a = \frac{\cos\beta - \sqrt{(cos^2\beta - cos^2\phi)}}{\cos\beta + \sqrt{(cos^2\beta - cos^2\phi)}}$	$P_a = K_a\gamma z\cos\beta$
Passive	$K_p = \frac{\cos\beta + \sqrt{(cos^2\beta - cos^2\phi)}}{\cos\beta - \sqrt{(cos^2\beta - cos^2\phi)}}$	$P_p = K_p\gamma z\cos\beta$
At-rest	K_o is determined experimentally through a triaxial test.	$P_o = K_o\gamma' z$

Table 1: Rankine Theory Formulae from Craig (1992) where β = angle of inclination, ϕ= internal angle of friction of soil, z = depth below surface, γ = unit weight of soil and γ' = effective unit weight of soil.

State	Lateral Earth Pressure Coefficient	Pressure
Active	$K_a = \left(\frac{\sin(\alpha-\phi)/\sin\alpha}{\left(\sqrt{\sin(\alpha+\delta)}\right) + \sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\beta)}}}\right)^2$	$P_a = \frac{1}{2}K_a\gamma H^2$
Passive	$K_a = \left(\frac{\sin(\alpha+\phi)/\sin\alpha}{\left(\sqrt{\sin(\alpha-\delta)}\right) - \sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\beta)}}}\right)^2$	$P_a = \frac{1}{2}K_p\gamma H^2$

Table 2: Coulomb theory formulae from Craig (1992) where α = angle of dilation, δ = wall friction, γ = unit weight of soil, ϕ = angle of internal friction of soil, and H = height of the wall.

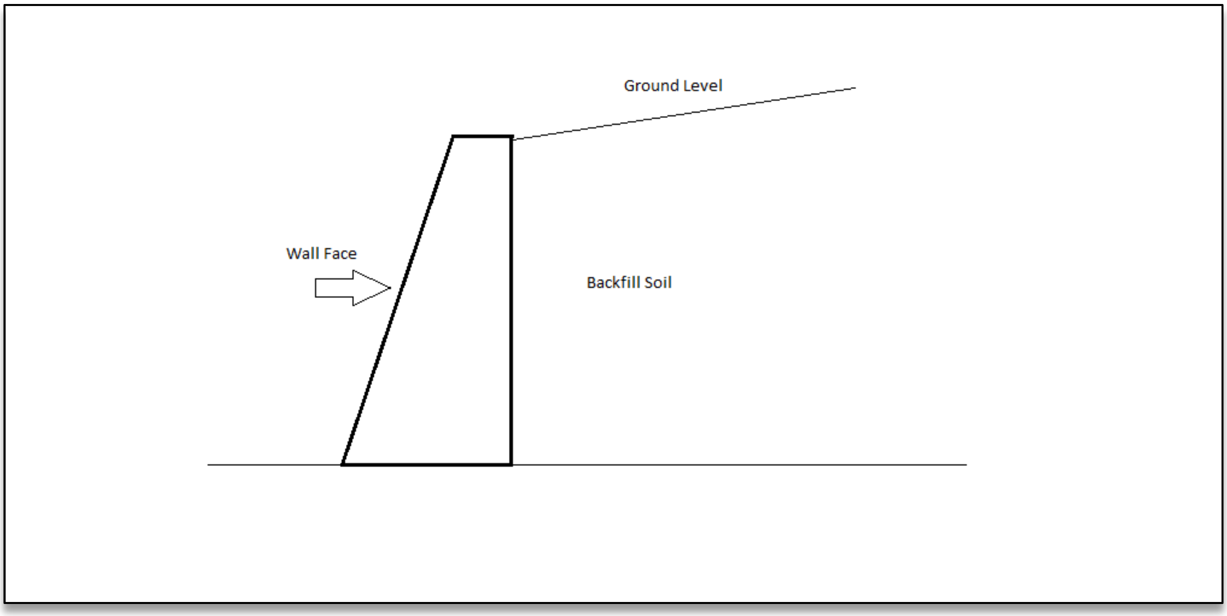

Figure 1: Gravity retaining wall schematic

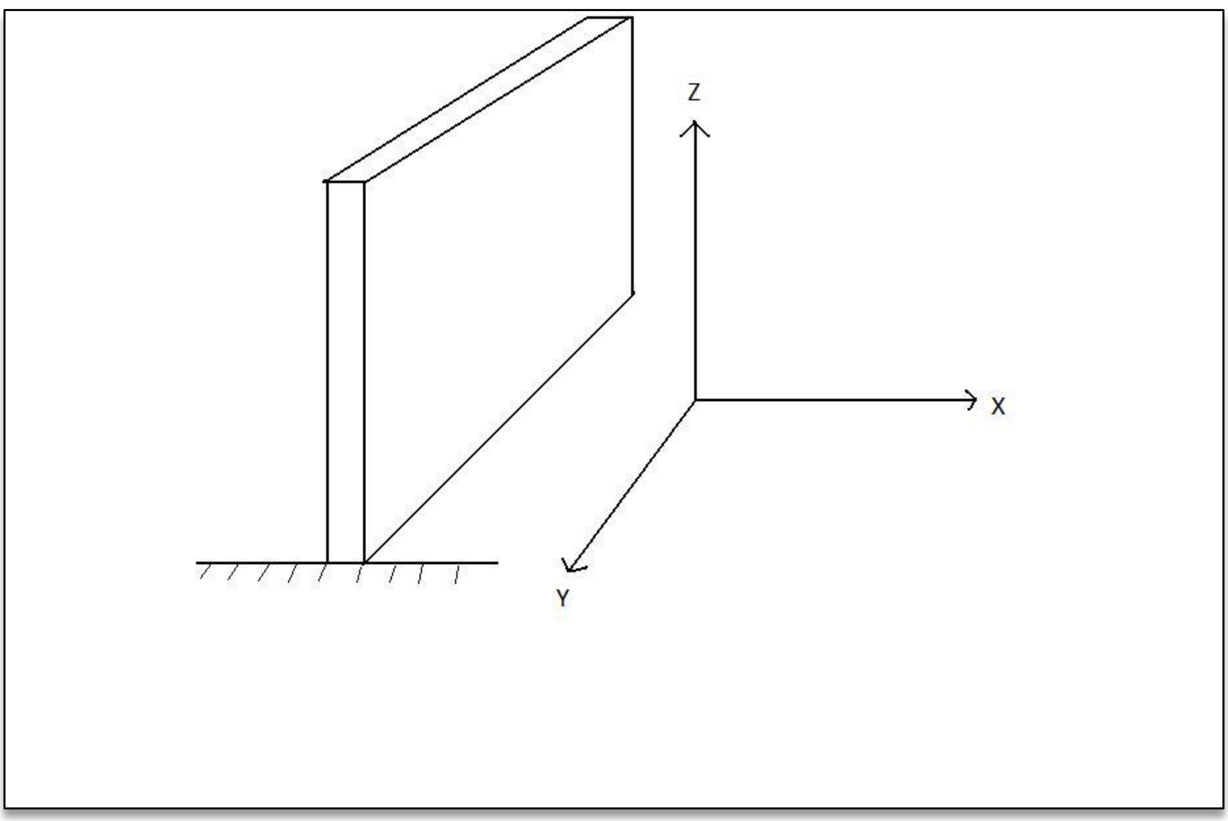

Figure 2: Plane (x,y,z) directions in backfill soil behind a gravity retaining wall

3.0 Mechanically Stabilized Earth (MSE) walls

3.1 Overview

Mechanically Stabilized Earth (MSE) is a generic term used to describe externally stabilized soil retention systems that use reinforcements within the soil that tie-back the face (VanBuskirk, 2010). These systems consist of alternating horizontal layers of reinforcement that connect to a vertical, rigid face (Figure 3). MSE walls are gravity-like structures, but the primary difference to gravity retaining walls is the use of reinforcements within the backfill soil. Reinforcements can be metallic or strong geosynthetics, and may be strips, grids or sheets (Elias et al, 2001). MSE walls utilize the tie-back approach in which reinforcements tie-back the rigid face to elements behind the wall, and add tensile strength to the soil thus preventing the soil from deforming under soil stresses (Elton and Patawaran, 2005). Together, the rigid face and reinforcement composite unit provide stronger retaining walls than gravity walls. The backfill soil within the layers of reinforcement is known as reinforced soil and is stronger than unreinforced soil; the preferred backfill soils for MSE walls are granular soils with good drainage (Elias et al, 2001). The vertical length between horizontal layers, known as reinforcement spacing, is an important consideration in design as reinforcements influence soil strength within the reinforced soil region (Wu, 2001). However, MSE wall design places more emphasis on reinforcement strength than reinforcement spacing (VanBuskirk, 2010). Soils have high compressive strength but lack tensile strength, thus MSE walls are a popular alternative to gravity retaining walls because of the additional resistance to lateral earth pressures provided by the reinforcements.

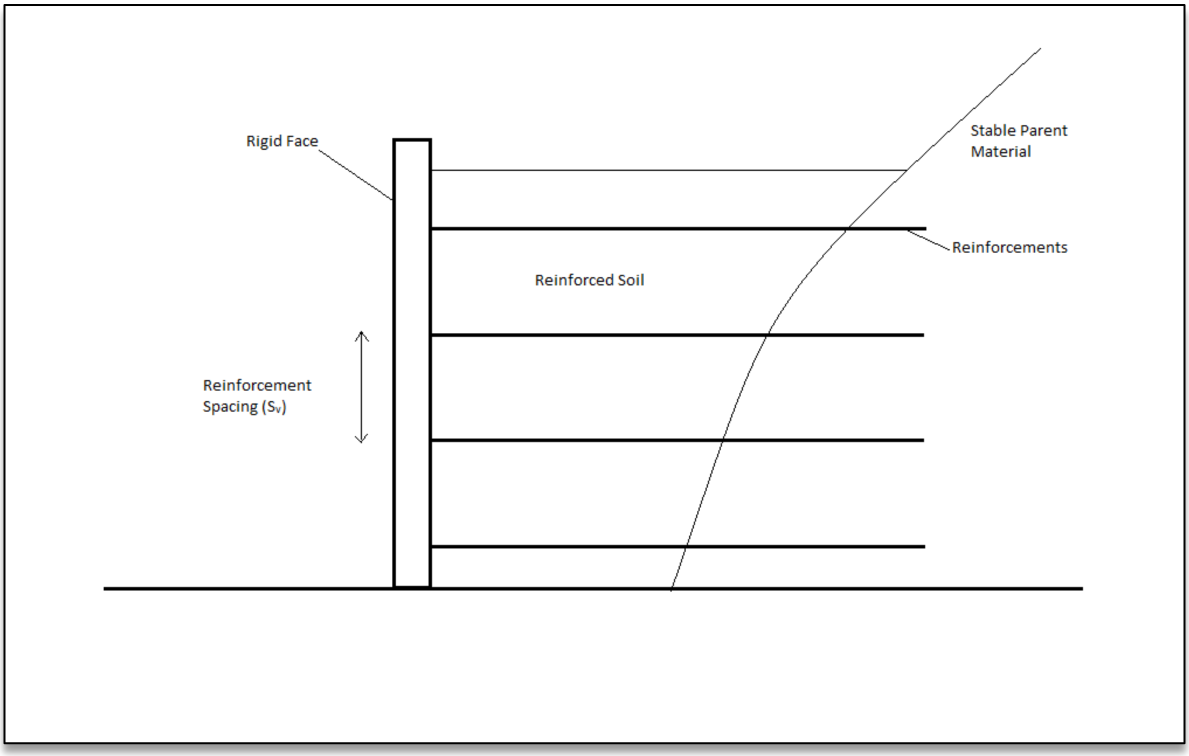

Figure 3: MSE wall schematic

3.2 Design

3.2.1 Face

The rigid face of an MSE wall is important for two reasons: aesthetics and soil retention. The wall face is the only part of system which is visible. Therefore, in some applications the face must be aesthetically pleasing. In addition to aesthetics, the face is also functional as the strong reinforcements tie-back and stabilize the face which retains the soil and prevents deformation (Bradley and VanBuskirk, 2009). As in gravity retaining walls, stresses on the face are assumed to increase linearly with height. Although the reinforcements support some of the stress within the backfill, the mass of the face is generally proportional to wall height; current design standards require that an increase in wall height requires an increase in face mass (Elias et al, 2001). The major types of faces used in MSE walls include segmental precast concrete panels and drycast modular blocks. The facing also provides protection against backfill sloughing and erosion (Elias et al, 2001).

3.2.2 Reinforcement Types

Reinforcements are placed horizontally in the backfill to tie-back the rigid face and compensate for the soil's lack of tensile strength. By placing tensile reinforcements in the soil, the strength can be improved significantly (Elias et al, 2001). Stresses are transferred to the reinforcements through friction; however, MSE design standards ignore the actual soil-reinforcement interaction and reinforcements are designed purely as a means to tie-back the face (VanBuskirk, 2010). Reinforcements can be geometrically categorized in 3 groups: strips, grids or sheets. Typically, reinforcements are comprised of steel or strong geosynethics. Types of steel include stainless, galvanized, or coated. Other reinforcements may include polymers, aluminum, and copper (Elias et al, 2001).

3.2.3 Reinforcement Spacing

The vertical distance between horizontal layers of reinforcement is referred to as reinforcement spacing (Figure 3). There is an inverse relationship between reinforcement spacing and load bearing capacity of soil. An increase in load bearing capacity of an MSE wall generally increases with more layers of reinforcement spaced closer together (Elias et al, 2001). However, MSE walls are typically designed to maximize reinforcement spacing to reduce materials and labour costs. MSE design standards utilize an active earth pressure approach and a Rankine failure wedge to analyze the soil mass, which and assumes a linear relationship between reinforcement strength and reinforcement spacing (VanBuskirk, 2010). Wu (2001) demonstrated that spacing plays a much larger role than reinforcement strength in the overall performance of reinforced soil walls; however, current MSE design standards such as AASHTO do not recognize the full influence of reinforcement spacing. MSE walls continue to be designed with the paradigm of heavy wall faces with strong reinforcements at wide spacing.

3.2.4 Backfill Soil

The selection of backfill soil is crucial because the backfill is the primary source of stresses that the MSE wall must resist. In theory, any soil may be used as nature of adding reinforcement to the backfill increases the strength of the overall soil-reinforcement composite unit (Elton and Patawaran, 2005). However, as in gravity retaining walls, granular soils are the preferred backfill of MSE walls because granular soils are typically well drained and can exclude the consideration of porewater pressure. Initially, the soil itself contributes to the strength of the structure but as the soil beings to fail, stresses are transferred to the reinforcements and wall face. Therefore, the ideal properties of MSE backfill soil are parallel with the backfill soil of gravity walls. The NCMA Manual (NCMA, 1996) lists the advantages granular soils which are easy compaction, good drainage, high strength under loading, and less susceptible to creep. Creep is tendency for soil to slowly deform permanently under the influence of stresses (Kirkby, 1967). The increase in strength of reinforced soil compared to unreinforced soil is as much as four times under drained conditions (Ashmawy and Bourdeau, 1998).

3.3 Cost

MSE walls are considerably more economical than gravity retaining walls, where economic benefit increases with height of the wall (Khan and Sikder, 2004). MSE walls utilize shear strength within the reinforced soil region to support soil stresses, which decreases the mass needed in the rigid face. A smaller face provides cost savings for both materials and construction. Additional cost savings compared to gravity retaining walls results from the following: relatively simple and quick construction, suitable backfill material available on or near the site, and elimination of rigid, deep foundations because MSE walls can accommodate relatively large total and differential settlements (Elias et al, 2001). Thus, MSE walls offer cost savings over gravity retaining walls, if onsite conditions permit the application of MSE.

The cost of an MSE retaining wall is a function of the height of the wall, type of reinforcement, and transportation cost of select backfill (Elias et al, 2001). The total cost of an MSE wall is sum of the costs of materials and construction of each of its principle components. FHWA (Elias et al, 2001) accounts for estimated costs of each component relative to total cost of a precast concrete faced MSE wall as: erection of panels and contractors profit ~ 25-30%, reinforcing materials ~ 20-30%, facing system ~ 25-30% and backfill materials ~ 35-40% where cost of backfill materials is highly dependent on proximity of suitable select granular material to the construction site. Figure 4 from Elias et al (2001) shows a cost comparison of different retaining walls. Reinforced concrete (R/C) Cantilever walls are similar in geometry and construction to gravity retaining walls, and we see the cost savings are significant when compared to MSE walls using both metal and geosynthetic reinforcements. R/C Cantilever walls range from \$450 to \$750 USD per m^2 of face, and rapidly increases with height. The costs of MSE walls are not as height dependent, and range from \$200 to \$400 USD per m^2.

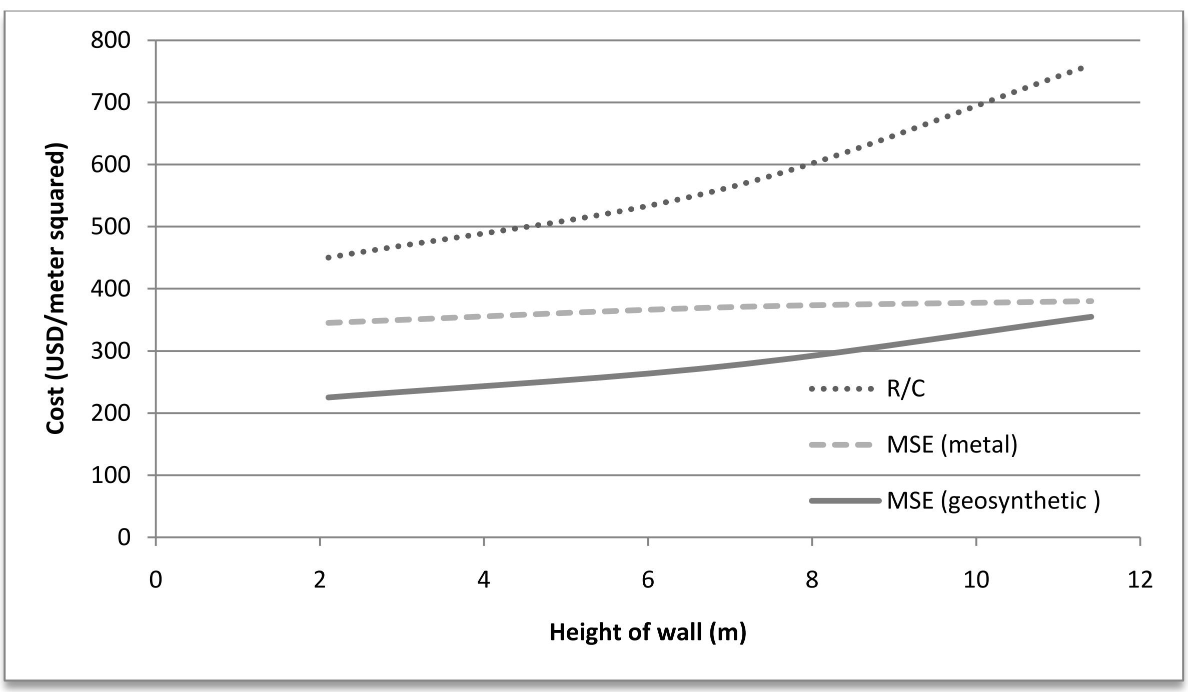

Figure 4: Cost comparison of Reinforced Concrete (R/C) gravity retaining walls with MSE walls

4.0 Geosynthetic Reinforced Soil (GRS) walls

4.1 Overview

GRS retaining walls are different than MSE walls in design and construction. GRS walls consist of alternating horizontal layers of geotextile reinforcement and compacted backfill (Figure 5). MSE walls use a tie-back approach where the reinforcements are “attached to” to the rigid face and the function of the reinforcements is to keep the face and soil mass together; reinforcements in GRS walls are “placed in” to internally stabilize the soil by carrying tensile loads (VanBuskirk, 2010). GRS and MSE walls are similar in that both walls ideally use well-compacted, granular backfill soil with good drainage, however, there are more differences than similarities. The geotextile fabric surrounds and confines each layer of compacted soil preventing movement of soil particles and the reinforcement-soil interaction increases tensile strength of the soil (Bradley and VanBuskirk, 2009). The MSE tie-back approach does not account for the confining quality of the reinforcement-soil interaction (Barrett and Ruckman, 2007). MSE walls place emphasis on strong reinforcements at wide spacing but Wu (2001) showed that reinforcement spacing is much more important than reinforcement strength. The spacing between layers of reinforcements is smaller than MSE walls (VanBuskirk, 2010). In GRS walls, spacing is small enough to place all soil between reinforcement layers into the zone of influence (soil adjacent to the reinforcement which is stabilized) thus stabilizing the entire reinforced soil composite block (Bradley and VanBuskirk, 2009). Closely spaced layers of well-compacted granular fill are superior to MSE walls in resisting both static and live loads (Barrett and Ruckman, 2007). MSE wall faces are rigid whereas GRS wall faces are flexible wire frames which do not need to be heavy and rigid as they are not load-bearing. The construction of GRS walls is simple and repetitive: install wire frame face, place fabric over previous layer, place and compact backfill, and repeat. Unlike MSE walls where multiple layers of facing elements are placed between layers of reinforcement, reinforcements in GRS walls are placed at every layer of the wire frame face thus construction can be less confusing to construction crews. GRS walls can offer significant cost savings if site conditions permit use and two case studies are presented in Section 4.5 to illustrate the cost-effective nature of GRS. The primary difference to MSE walls is that GRS walls are internally stabilized and are constructed with soil, not to resist soil.

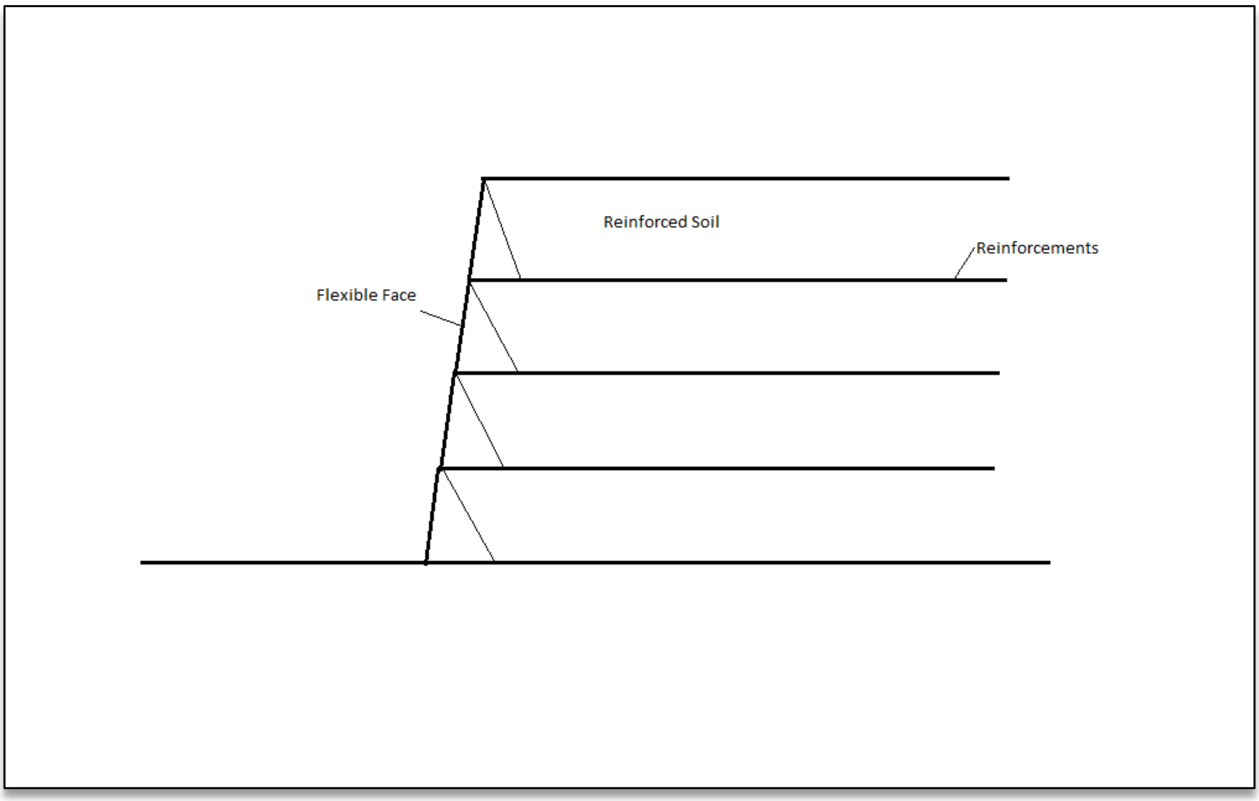

Figure 5: GRS wall schematic

4.2 Design

4.2.1 Face

GRS wall faces consist of flexible wire frames and struts. The wire frames have a slight positive batter and can come in either 0.46 m or 0.56 m height (Bradley, 2009). One of the differences between GRS and MSE walls is the lack of rigid face. Because MSE walls are designed using a tie-back approach, the face needs to be rigid and heavy to resist lateral earth pressure; GRS walls on the other hand, use internal stabilization and do not require a rigid, load-bearing face. The advantage of wire frames is that they can be cut to length and design can be easily modified in the field if needed.

GRS walls are internally supported and thus the wall face carries little to no load (Bradley and VanBuskirk, 2009). GRS walls use smaller reinforcement spacing and the resulting pressures on the wall face are considerably less. Pressures on the wall face are confined within each compacted layer of fill and Wu (2001) found that smaller reinforcement spacing results in significant reduction in lateral earth pressures on the face. Of the entire GRS wall system including the reinforced soil region, lateral earth pressure is the actually the smallest on the face and is practically constant with depth (Chou and Wu, 1993). Current design methods use Rankine or Coulomb earth pressure theories which assume pressure on the face increases linearly with depth which has historically resulted in use of heavy blocks for the face as to resist the calculated earth pressures. However, the faces in true GRS walls are not load-bearing and Wu (2007) demonstrated that lateral earth pressure on the face is merely the pressure between adjacent reinforcement layers called bin pressure. A flexible face and small reinforcement spacing reduces bin pressure which is independent of wall height (Wu, 2007). The flexible wire frames and struts in GRS wall faces assist the geotextile in confining compacted soil layers but do not contribute to supporting dead and live loads.

4.2.2 Reinforcement Types

GRS walls use geosynthetic reinforcements which are permeable, polymeric fabrics which are specifically designed for use in soil, hence the prefix “geo”. Geosynthetic reinforcements used in GRS walls typically are geotextiles which are large fabric mats. Landslide Solutions Inc. (2008) recommends woven geotextiles with a tensile strength rating of at least 28.5 kN/m. However, unlike MSE walls geotextile strength is of secondary importance; reinforcement spacing is more important for performance of GRS walls (Bradley and VanBuskirk, 2009). Nevertheless, reinforcement strength cannot be neglected in design. Triaxial test results show that the addition of reinforcement results in increased peak strength, larger axial strain at failure, and reduced or limited post-peak loss of strength (Elton and Patawaran, 2005). Current design standards place more emphasis on reinforcement strength than reinforcement spacing because MSE design philosophies are still prevalent. True GRS walls do not require very strong reinforcements because the soil-reinforcement interaction, which is the key element in the performance of internally stabilized walls, is not a function of reinforcement strength (Wu, 2001). GRS walls use smaller spacing than MSE walls thus do not require very strong reinforcements.

4.2.3 Reinforcement Spacing

Reinforcement spacing plays a more important role in performance of a GRS wall than reinforcement strength (Wu, 2001). Each level of wire frames on the face consists of two layers of reinforced compacted fill (Bradley, 2009). The wire frames are either 0.46 m or 0.56 m in height; the reinforcement spacing is maximum 0.28 m in height (Bradley, 2009). The imposed horizontal planes of reinforcement that surround the closely spaced compacted layers confine the soil which resists dilation (soil particles motioning past other soil particles) and shearing in response to dead and live loads (Bradley and VanBuskirk, 2009). Initially, the compacted soil provides strength but as slippage occurs it causes the reinforcement tensile strength to be mobilized. GRS walls use smaller spacing than MSE walls where the goal is to have the zones of influence from the reinforcements at the top and bottom of a compacted layer to overlap. The result is a very stable and strong layer of compacted fill without the need for very strong reinforcements or a rigid, heavy wall face. GRS walls with tight reinforcement spacing require less reinforcement per meter of wall height than MSE wall design (VanBuskirk, 2010).

4.2.4 Backfill Soil

The backfill soil within a GRS wall consists of the compacted fill between the layers of reinforcements. As in gravity and MSE walls, the preferred backfill soils are granular, course-grained soils that promote adequate drainage. Drainage is promoted by matching permeability of the geotextile with that of the backfill soil, sloping the geotextile layers, and incorporating artificial drains in the structure (Bradley and VanBuskirk, 2009). Well compacted fill between the layers of reinforcement is vitally important for the performance of GRS (and MSE) walls. Many MSE wall failures can be attributed to lack of adequate and uniform compaction (Mooney et al, 2008). Compaction during construction of a GRS wall is achieved through hand compactors. Because of the shallow layers of compacted fill, the wall is strong enough that the compactors can operate virtually right at the edge of the wall despite the absence of a rigid face. The keys to a successful and strong reinforced soil layer are use of granular fill and good compaction.

4.3 Cost

GRS walls can offer significant cost savings over other retaining walls if site conditions permit the use. The availability of suitable granular fill on or near the construction site is typically the limiting factor in implementing a GRS wall. Lengthy transportation of suitable fill soil severely increases the cost of a GRS wall; conversely, use of onsite materials as fill can significantly reduce cost if the material would otherwise have to be removed by end-hauling. The nature of internally stabilized walls utilizes strength of the soil and does not rely completely on the structure of the face to resist lateral earth pressure; internally stabilized walls are considerably more economical compared to externally stabilized walls such as gravity and MSE walls (Khan and Sikder, 2004). The components of the wall, including construction equipment, are generally small and modular which decreases transportation costs, and easily allows construction in very remote locations as all components and equipment can be transported using a light pick-up truck. Figure 6 from Khan and Sikder (2004) clearly shows that GRS walls are the most cost effective option compared to the other retaining walls presented in this essay.

Two case studies are presented to illustrate the cost benefits of GRS walls. GRS retaining walls can be applied in a variety of applications including bridge abutments. In the fall of 2005, GRS bridge abutments were used for the Bowman Road Bridge in Defiance County, Ohio. The bridge consists of prestressed concrete box beams supported on GRS abutments without the use of a deep foundation to support the superstructure (Adams et al, 2007). The alternative to GRS abutments was to use pile-cap abutments where long piles would have been driven into the ground to support the bridge. The quoted cost of pile-cap abutments was $338,000 USD and cost of GRS abutments was $266,000 USD thus the use of GRS provided a 20% cost savings and post-construction performance of the GRS abutments has been excellent and well within AASHTO criteria for simple supported bridges (Adams et. al, 2007). The second case study also takes place in 2005. A GRS wall was used to cross a deep gulley on a forest service road near Holberg, BC on northern Vancouver Island. Western Forest Products contracted the design of the wall to Terratech Consulting Ltd, a Salmon Arm based geotechnical engineering firm and the project was monitored by FP Innovations, a forestry research institute at the University of British Columbia. The alternative to building the retaining wall was to use a full bench cut into the slope to cross the gulley. The full bench cut option was very expensive because of the extensive blasting, it created an undesirable road alignment, and it was operationally impracticable to construct because the fill slope would need to be extended 20 m down the gulley. The estimated cost of the full bench cut option was $83,000 CAD whereas the GRS wall with finished road cost $63,200 CAD, a roughly 24% cost savings (Bradley and VanBuskirk, 2009). As shown in the case studies, GRS walls can offer a significant cost savings if site conditions allow the use.

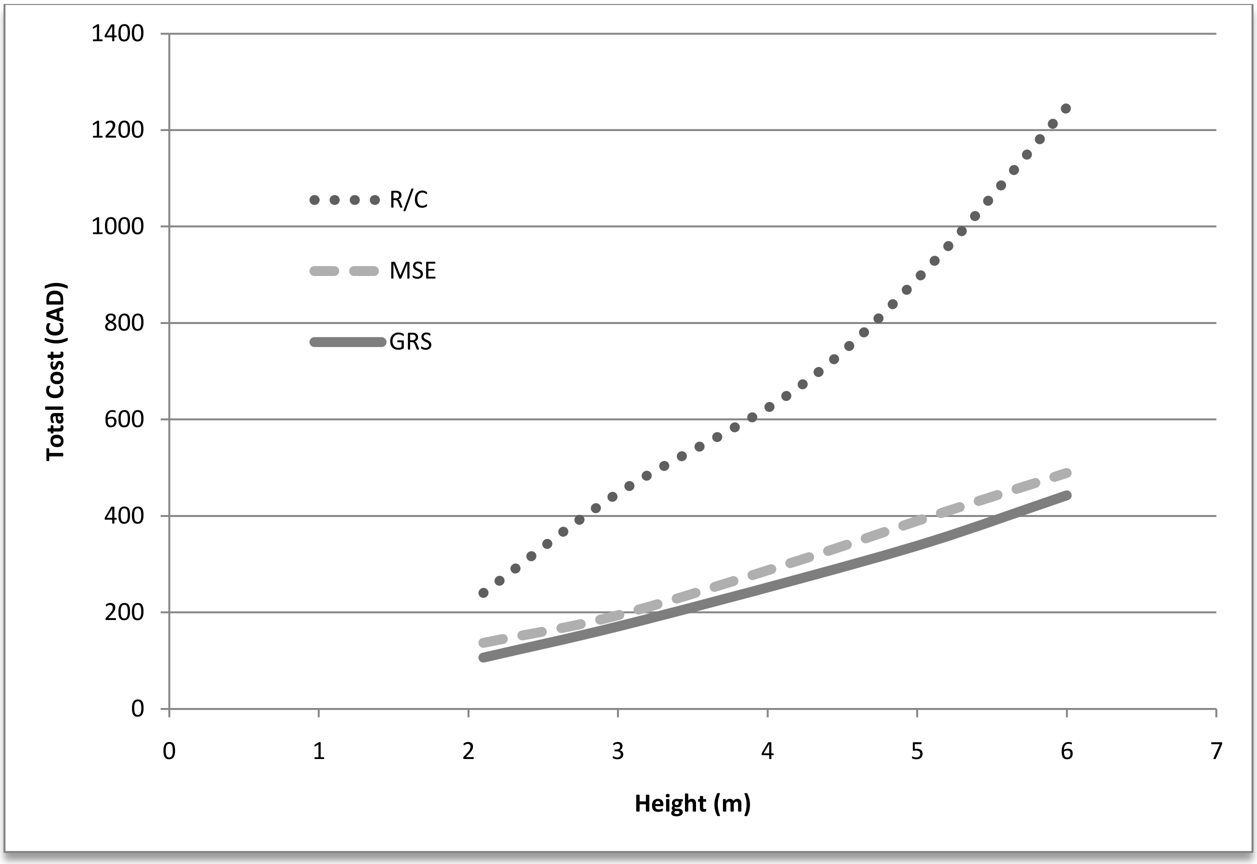

Figure 6: Cost comparison of R/C, MSE and GRS walls

5.0 Conclusion

This essay presented an overview of gravity, MSE and GRS retaining walls. Gravity and MSE walls are both externally stabilized walls; MSE walls are more economical than gravity walls because they utilize reinforcements that tie-back the face and provide additional resistance to lateral earth pressures. Internally stabilized walls such as GRS walls are the most economical because the nature of internal stabilization utilizes inherent strength within the soil, and does not rely completely on external stabilization. Gravity and MSE walls have a rigid face whereas GRS walls have a flexible, non-load bearing face. This is because the lateral earth pressures are confined within each layer of reinforcement in GRS walls, called bin pressure, therefore lateral earth pressure on the face does not increase with depth.

Lateral earth pressures are assumed to increase with depth for gravity and MSE walls thus the mass of the face must increase with an increase in wall height. MSE wall design uses a tie-back approach where the purpose of the reinforcements is to tie-back and stabilize the rigid face; MSE design ignores the interaction between soil and reinforcements. MSE walls use very strong reinforcements at wide reinforcement spacing. GRS walls account for the soil-reinforcement interaction in which the reinforcements confine and stabilize the soil adjacent to the reinforcement. It has been shown that not only is reinforcement spacing more important reinforcement strength, but the soil-reinforcement interaction is independent of reinforcement strength. Therefore, GRS walls do not require very strong reinforcements and spacing between reinforcement layers is much less than MSE walls. MSE walls can use either metal or geosynthetic reinforcements whereas GRS walls use only geosynthetic reinforcements; geosynthetics are less expensive as shown in Figure 4. The preferred backfill soils for all three walls are granular, course-grained soils that promote good drainage. For reinforced soil walls such as MSE and GRS, adequate compaction of the backfill is very important for the performance of the wall. GRS walls are the most cost effective and as the case studies showed can offer significant cost savings if site conditions permit use. Gravity walls are simplest to construct but are not economical, MSE walls are better than Gravity walls but GRS offer significant benefits over MSE and gravity walls in terms of design, construction and cost.

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