Protection of Reinforced Soil Structures using Geosynthetic Cementitious Composite Mats

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ABSTRACT

Geosynthetic cementitious composite mats (GCCMs) are a relatively new material technology in the world of geosynthetics. GCCMs consist of a flexible 3-dimensional fiber matrix filled with a high-early strength dry cementitious mix with a polymeric membrane (often PVC) laminated onto one side. They harden on hydration to form a durable, fiber reinforced cementitious layer. In this way they combine geotextile, geomembrane and concrete technology enabling geosynthetics to be used in completely new markets and applications. This paper considers the use of GCCM’s to protect Geosynthetic Reinforced Soil structures. It focusses on the three main applications where GCCMs can be used: a) the provision of a robust facing element to prevent UV degradation, vandalism and animal damage of geosynthetic reinforced wrap faced structures, b) the provision of top of wall drainage to collect surface water and prevent saturation of the reinforced soil block and c) the provision of toe drainage to prevent saturation and erosion of foundation soils. The characteristics and properties of GCCMs relevant for each application are reviewed and compared with traditional solutions to determine when they can be used to protect Reinforced Soil structures.

INTRODUCTION

The use of GCCMs in civil and geotechnical engineering has expanded considerably in recent years to provide erosion control solutions for a number of applications. Rather than replace existing erosion control geosynthetics such as Turf Reinforcement Mats (TRM’s) which improve the resistance of vegetation to erosion, GCCMs are used as an alternative to conventional concrete, such as poured, precast and sprayed solutions. They are used when higher levels of protection are required than TRM’s can offer, or when vegetation needs to be prevented from establishing in order to avoid long term maintenance issues. GCCMs are commonly being used in conjunction with conventional geosynthetics to provide a complete project solution, one such application is in the design of Mechanically Stabilized Earth (MSE) Walls and Reinforced Soil Slopes (RSS).

The National Highway Institute reports: FHWA NHI-10-024 FHWA GEC 011 Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes -Volume I and II include several references to the use of concrete in possible MSE Wall and RSS design, such as in external drainage (Section 5.3.2) and as a protective facing to Geosynthetic Wrap-Around
systems (Section 3.6.4). Here we will consider the properties of GCCMs that may enable them to be used as an alternative to conventional concrete in these applications.

**GCCM PROPERTIES**

The recently published ASTM D8058-17 defines GCCMs as ‘a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened when hydrated’.

As shown in Figure 1, they typically consist of 3 layers: - A fibrous top surface that wicks water into the central layer, which is composed of a dense, 3-dimensional fiber reinforced matrix filled with a cementitious blend that has a high early strength gain. The hardened central layer acts to protect a bottom waterproof polymeric layer.

The layers act to contain the cementitious blend during transport and installation, ensuring a consistent density of cement throughout the material and control of the water: cement ratio on hydration. Properly manufactured GCCMs cannot be over hydrated as they will fully set underwater, which greatly facilitates hydration on site by removing the need for careful water: cement ratio control. ASTM D8030-16 specifies the practice to prepare GCCM samples for testing of index properties by hydration of the GCCM through full immersion.

In the uncured state, GCCMs like other extensible reinforcing geosynthetics can be evaluated using tensile strength as one of the standard index tests. GCCM physical properties change with the addition of water and in service the GCCM becomes a thin rigid element. Once cured, GCCM’s performance is better evaluated by a flexural bending test, which considers flexural strength.

**Flexural strength.** Flexural strength is the primary characteristic considered when a GCCM is used as a facing element to a mechanically stabilized earth structure. As a suitable assessment of a GCCM’s tensile and compressive properties, ASTM D8058 sets out a 3-point bending test to assess and compare GCCM product performance. A typical stress/displacement graph is shown in Figure 2.
Figure 2. Typical stress-strain graph for a GCCM, data courtesy of Concrete Canvas Ltd.

Test results demonstrate a semi ductile failure in 3 phases. 1st, the initial elastic phase reaches up to about 4MPa before the initial crack of the material. The GCCM then ruptures in a saw tooth fashion of progressive concrete failure and fiber loading, and at final rupture the fibers themselves begin to fail. This semi ductile failure has practical benefits, particularly in areas of differential settlements or ground heave, as the GCCM can crack and deform locally. The PVC membrane is more elastic and is therefore still protected by the protective cover layers of the composite. The test is designed to demonstrate manufacturers quality control, as a higher initial breaking load at the 1st phase demonstrates a dense, high performance concrete that is well constrained in the GCCM. Poor quality cement blends and an inconsistent density would be reflected in lower initial breaking loads. Material with a lower initial break does not have the same resilience to differential ground movement and is more likely to disintegrate over time. A higher flexural strength before the first break is therefore preferable and ASTM D8058 3 point bending tests are used by GCCM manufacturers to check material quality. At 24 hours after curing, a minimum flexural strength of 4.0MPa before the initial crack is required.

**Abrasion resistance.** One of the most popular GCCM uses is to replace concrete in channel lining applications and is therefore subject to scour from sedimentation in water flow. Abrasion resistance is therefore an essential characteristic of a GCCM for use in channel lining, either at the top or toe of a mechanically stabilized earth structure. The fiber reinforced concrete component of GCCMs provides the primary scour protection and as such the materials need to be tested to standards outside the scope of geosynthetics. A simple abrasion test using a rotary platform abrader to ASTM C1353 quantifies the loss in GCCM thickness over a number of abrasive cycles. A low material loss (less than 8.0 x10^{-3} inches/1000 cycles) represents good abrasion resistance; a higher material loss represents poor resistance to abrasion. Testing on the Concrete Cloth GCCM demonstrates abrasion in two stages. Initially, the top surface fibers which contain some cement wears at a rate of 2.0 x 10^{-2} inches/1000 cycles, a similar rate to a 20MPa (2400psi) Quikcrete concrete as illustrated by the comparable gradient of the best fit lines.
in Figure 3 below. In the second stage of Concrete Cloth abrasion, the dense, high performance cement blend within the GCCM fiber matrix is worn. The abrasion resistance at this stage is much higher at 4.0 \times 10^{-3} \text{ inches/1000 cycles}. This is slightly better resistance than a high performance, 64MPa (9300 psi) self compacting Portland Cement concrete at 6 \times 10^{-6} \text{ inches/1000 cycles}, which is again illustrated by the slightly shallower gradient of the reinforced cement surface wearing best fit line in Figure 3. The test data demonstrates that GCCM fiber reinforced cementitious layers can provide excellent abrasion resistance similar to high performance concretes. Importantly, the fiber matrix in a GCCM ensures that when the GCCM is worn, the material remains intact and does not spall as in thin concrete samples. This is shown in the Quikcrete sample subject to 4700 abrasion cycles in Figure 4.

**Figure 3. Abrasion resistance behavior of typical GCCM. Data courtesy of Milliken Infrastructure.**

**Figure 4. Concrete and GCCM samples after abrasion cycles. Image courtesy of Milliken Infrastructure.**

**Permeability.** Permeability is an essential characteristic for channel lining. The permeability of a GCCM is typically governed by the polymeric PVC backing layer and the overlying fiber reinforced matrix can be considered to act as the protection layer. Typical coefficients of permeability for the polymeric backing layer range from $k = 10^{-8} \text{ m/s}$ for standard GCCM materials to $k=10^{-12} \text{ m/s}$ for specialist containment GCCM composites. Adjacent sheets of GCCM do not self adhere so the permeability of a GCCM structure is dependent on the method of joining the sheets together. For crest drainage applications with steep hydraulic gradients, which control surface water runoff from neighboring slopes, a shingled joint with screws installed to ASTM D8173 can suitably control flowing water and minimize ingress between layers, while providing sufficient permeability to release hydrostatic build up beneath. For shallow hydraulic gradients or where pooling of water is likely, permeability of the shingled
screwed joint can be reduced by combining with adhesive sealants, or by overlapping joints and heat bonding to provide a high impermeability, non-penetrative jointing method. The specification for jointing is dependent on the type of GCCM material, the application and required joint permeability based on ASTM D8173 and the GCCM Manufacturers guidance.

Other Considerations

Weed suppression. Unlike turf reinforcement mats and other erosion control geosynthetics that encourage and rely on vegetation growth to provide scour resistance, GCCMs act as a concrete sheet to resist erosion and provide continuous protection to underlying soils. The cementitious fiber matrix and waterproof backing layer blocks sunlight and provides a continual physical barrier, resulting in good weed suppression properties and therefore acts like conventional concrete solutions. Preventing vegetation growth can be beneficial in certain applications, for example when vegetation and subsequent silt build up over time can reduce crest drainage channel capacity, which will subsequently affect the channel performance in storm events. The cost of long term maintenance can influence a client’s decision to choose a low maintenance GCCM structure over vegetated solutions.

Installation. Conventional concrete installation practices for poured, precast and sprayed concrete can be time consuming due to preparatory works (e.g. shuttering steelwork), curing time and clean up. Independent Quantity Surveyor analysis by Engineers Incorporated Ltd., 2011 demonstrated that GCCM’s allow for faster installation rates, up to an order of magnitude of ten times.

Poured and sprayed concrete structures typically require specialist labor for suitable installation. GCCMs are supplied as a rolled geosynthetic that can simply be unrolled over a reinforced soil structure face and anchored at the crest and toe, thereby removing the need for specialist labor for deployment. This enables an MSE Wall and RSS contractor to install GCCMs as part of their contract package without the need to recruit a specialist labor force for concrete works.

GCCM material thicknesses typically range from 5mm to 13mm, which is considerably thinner than conventional concrete. The reduced volume of material results in fewer vehicle movements to and on site and also provides embodied carbon savings. A carbon footprint report on the Concrete Canvas GCCM (Mironov, 2017) compares an 8mm thick GCCM to a 150mm thick C20 in situ poured concrete channel and found by replacing the concrete with the GCCM, the embodied carbon is reduced by 55% in material alone, before installation reductions are considered.

The properties discussed in the sections above provide practical benefits when considered in MSE Wall and RSS design as reviewed in more detail below.

CREST DRAINAGE FOR SURFACE WATER RUNOFF

Incorrect surface water management and drainage design can be a significant contributing factor to potential MSE Wall and RSS failure. Saturation of a reinforced soil mass will build up hydrostatic forces and increase lateral pressures, reducing the factor of safety in a reinforced soil structure design. This is particularly relevant where surface drainage flows toward the wall structure. Storm events have been known to cause damage to such structures, as heavy rainfall,
when not properly managed, can cause erosion at the crest, undermining facing units. Collecting and removing water before it enters the reinforced zone of influence will significantly reduce the likelihood of water related failure. This is described in FHWA NHI-10-024 MSE Walls and RSS Vol 1, section 4.4.11.b. For top of wall drainage, the report recommends that a grassed swale, or 4 inches of either concrete ditch or asphalt lining can be used behind the facing to collect and remove water.

Internationally, the most common application for GCCM’s is for channel lining works. An 8mm thick GCCM could be used to replace the otherwise typically required 100mm of concrete or asphalt and reduce the volume of material used in swale by over 90%.

The GCCM can be installed immediately after MSE Wall/RSS construction as its flexural properties, as discussed in section 2.1, enables the GCCM to practically accommodate any potential settlements from the reinforced soil structure. This provides a significant benefit over poured concrete, which can crack under settlement and enable water ingress into the reinforced soil mass.

The low permeability of the base GCCM polymeric layer will prevent water infiltration into the reinforced soil mass, as discussed in section 2.3. GCCM manufacturers recommend following basic installation principles of standard geosynthetic erosion mats, so the edges of the GCCM should be buried in a back filled anchor trench at slope crests in order to avoid undermining from water ingress. An example of a GCCM top of slope drainage swale with a buried edge is shown in Figure. 5.

Larger GCCM drainage channels can also be used to collect surface water runoff before it reaches the reinforced soil structure, thereby preventing saturation of the reinforced mass and minimizing the risk of increasing hydrostatic pressures. This can be a preferred solution if the catchment area upslope is large and would result in significant water runoff heading towards the reinforced soil structure during storm events. These channels collect and direct the water away from the reinforced soil structure, and are designed as the appropriate drainage systems to safely control and manage runoff. An example of a GCCM drainage channel to the back of an MSE wall reinforced soil mass is shown in Figure 6.

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![Figure 5. GCCM swale near top of slope, Spain. Courtesy of Concrete Canvas Ltd.](image1)

![Figure 6. GCCM channel behind reinforced soil mass, UK. Courtesy of Concrete Canvas Ltd.](image2)
TOE DRAINAGE

Toe of MSE Wall/ RSS drainage design is critical in preventing erosion at the base and edges of the structure. Designers need to ensure that any flowing water is safely directed away from the wall and cannot erode foundation soils which could cause undermining of the reinforced soil structure leading to likely failure. Insufficient toe drainage design can result in saturation of foundation soils, which can compromise a reinforced soil structure by causing soil softening and deterioration of the engineering properties of the foundation. Where internal drainage outlets discharge through a reinforced soil structure, FHWA NHI-10-024 MSE Walls and RSS Vol I section 5.3.4 advises that outlets should drain onto a concrete apron which is usually precast, to prevent damage or clogging by future construction/maintenance activities.

GCCM’s can provide alternative, equally effective toe drainage solutions to these issues, similar to crest drainage applications. The abrasion resistance of the GCCM, as discussed in section 2.2, prevents scour and erosion of drainage channels that are subject to sediment flow and ensures that watercourses in front of reinforced soil structures are not undermined (Figure 7). GCCMs can also be mechanically fixed to MSE wall facing units and grouted to concrete panels, so any back of wall internal drainage can discharge through the wall and onto the GCCM, preventing scour and undermining at the toe of the structure. The weed suppression benefits of GCCMs, as described in section 2.4, prevent possible drainage capacity reduction through vegetation growth and silting (Figure 8).

FACING TO MSE WALLS AND RSS

FHWA NHI-10-024 MSE Walls and RSS Vol I and Vol II specifies a number of possible facing solutions for MSE Walls including precast concrete modular blocks and panels, wire/steel mesh and geosynthetic wrap around. For RSS’s, facings can vary from temporary erosion blankets for shallow slope, up to 45 degree face angle, with no wrap geosynthetic construction requirement, to steeper slopes with face angles greater than 45 degrees, that require wrapped geosynthetic reinforcement over temporary or permanent erosion control blankets and geotextiles, or covered by armored facings (e.g. gunite, asphalt, wire mesh).
Geosynthetic wrap faced structures are commonly specified for MSE Wall and RSS construction due to the reduced construction costs over concrete and wire/steel mesh facing systems. In geosynthetic wrap faced reinforced soil structures, although most geosynthetic reinforcement, such as high density polyethylene (HDPE) geogrids, that form the structural component of the wrap face are UV resistant due to the addition of carbon black in their manufacturing process, it is the secondary geosynthetic components behind the geogrid wrap at the face, that are used to contain the soil until vegetation is established, that will unlikely withstand permanent UV exposure.

Vegetation typically provides sufficient protection to geosynthetic elements from UV resistance. However, establishing vegetation cover on steep slopes is not always possible and depends on a number of factors including but not limited to: structure orientation to sunlight, quality of topsoil behind the wrap face and irrigation. Seasonal weather changes can prevent year-round vegetation growth. Other factors that could affect geosynthetic durability include damage from wildlife or vandalism.

When vegetation does not establish or if the structure is damaged, permanent solutions need to be considered in order to prevent further degradation of the geosynthetic structure face and its eventual propagation into the integrity of the rest of the reinforced soil structure, if left unrepaired. These could be in the form of concrete panels applied similar to two-stage facing solutions, or by applying sprayed concrete. Concrete panel solutions are expensive and require careful design to suitably mechanically connect to the wrap faced structure. Sprayed concrete applications require protection of existing infrastructure to prevent rebound during installation. Sprayed concrete is also prone to cracking during settlement of the reinforced soil structure.

GCCM’s can be used as a permanent facing option to protect unvegetated or damaged wrap faced reinforced soil structures, replacing the conventional concrete solutions. The GCCM can be draped over the geosynthetic wrap face and anchored along the perimeter edges to prevent wind and water ingress. The roll applied GCCM is lighter and easier to handle than precast elements and its flexural strength allows it to accommodate any potential settlement of the reinforced soil mass. Its flexible nature prior to hydration also allows for the installation of drainage weep holes during installation to allow for the effective drainage of any groundwater to freely discharge out of the MSE/RSS structure. GCCM’s have been used to protect geosynthetic wrap slopes and walls worldwide as summarized by the case studies below:

Southeast area, SC, USA. A steep geotextile reinforced slope on a landfill site was initially designed with a soil and vegetation cover. However, due to rapid degradation of the geotextile wrap face, an immediate permanent facing solution was required. 750 square meters of GCCM material was applied in three days, including creating toe drainage to divert water runoff and prevent saturation of foundation soils (see Figures 9–11). The primary benefits in using the GCCMs included the speed and ease of installation over conventional solutions which would have taken several weeks to mobilize and install.

Reinforced soil wall facing, Oceania. A temporary geosynthetic reinforced soil bund wall (inner face vertical, outer face sloped) required a facing solution to transform it to a permanent structure. The reinforced soil slopes were constructed with uniaxial, high density polyethylene (HDPE) reinforcing geogrids. The foundation and bottom courses of geogrid reinforcement were faced with concrete segmental blocks. Above this the primary geogrid reinforcement was wrapped around to form the facing, with the free end of the upper geogrid wrap connected to the
next reinforcement layer using a Bodkin joint. A geotextile liner was installed to the inside face to prevent loss of fill trough the facing and was designed to contain the soil temporarily for the short life of the structure.

Figure 9. Proposed cross section of GCCM protection to RSS. Courtesy of Milliken & Co.

Figure 10. GCCM installation over wrap faced RSS. Courtesy of Milliken & Co.

Figure 11. Completed GCCM protection with toe drain. Courtesy of Milliken & Co.

Figure 12. Wrap faced bund requiring permanent protection. Courtesy of Concrete Canvas Ltd.

Figure 13. Placing GCCM to protect bund structure. Courtesy of Concrete Canvas Ltd.

Figure 14. Installed GCCM to protect wrap faced bund. Courtesy of Concrete Canvas Ltd.
The clients’ requirements changed and they needed to keep the structure in place permanently. They and had hoped that vegetation would establish over time, but after 8 years in service this could not be maintained all season and the facing geosynthetics were exposed to UV degradation. Birds were also damaging the facing geosynthetics by burrowing in the structure. Shotcrete was used as a temporary filler due to settlement caused by the damage but was never considered viable as a permanent facing due to cracking from settlements and cyclic temperature and moisture changes. 3,200 square meters of GCCM material was applied to protect the entire bund, secured to the vertical bund face using polymer earth percussion anchors and mechanically secured to a segmental block MSE Wall at the toe (see Figures 12-14). The GCCM has prevented further UV degradation of the geosynthetic facing material and stopped animals nesting, ensuring the longevity of the bund structure.

CONCLUSION

The physical and practical properties of GCCMs enable them to be incorporated in MSE Wall and RSS design to replace conventional concrete techniques. When designing new structures, GCCMs can be specified into crest and toe drainage designs to provide low permeability, low maintenance drainage channels directing water away from reinforced soil structures and foundation soils, preventing potential structure failure. For existing wrap faced structures that have not been or cannot be vegetated or are subject to physical damage, GCCMs can be used as a protective facing to ensure the longevity of the geosynthetic wrap faced structure. GCCMs have a distinct advantage over poured or sprayed concrete in these applications as they can accommodate acceptable post construction settlements, providing the performance of conventional concrete solutions, but with the flexibility of geosynthetics.

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