FIRST DRAFT 5-20-08

A New Design and Construction Guideline for Geosynthetically Confined Soil (GCS™)

Part 1

Background and Introduction

Recommended procedures for designing Mechanically Stabilized Earth (MSE) structures are provided in documents maintained by government agencies and national trade associations (American Association of State Highway and Transportation Officials, United States Forest Service, National Concrete Masonry Association, Federal Highway Administration, and more). The design approach adopted by these agencies attributes the stabilizing effects of the soil reinforcement as a type of unprestressed "tieback" where the soil reinforcement's tensile resistance opposes the horizontal earth pressure. The magnitude of the force generated by the horizontal earth pressure assigned to each layer of soil reinforcement is in proportion to the individual reinforcement's elevation in the retaining wall and its vertical spacing between neighboring layers. No credit is given to spacing/confining effects of the inclusions.

MSE design philosophy is a translation from models for tieback and externally supported retaining systems. MSE concepts and precepts are patently in error. MSE failure rates of 2 to 10% are reported, and it follows that many more MSE walls exist at factors of safety well below design expectations. With closer spacing of the inclusions in granular backfill, performance exceeds design expectations by factors of 10 to 20. This phenomenon was again demonstrated in NCHRP Report 556.

Members of the Soil Nail Launcher, Inc. team have been involved in reinforced/confined soil research for more than 40 years. We have supported an international search for an analytical model that reflects measured behavior in MSE. This has been something akin to the quest for the Holy Grail, and including some of the Pythonian (as in Monty) deviations from the original story. It always comes back to corrupting models designed for element contribution into models that describe and predict composite behavior.

We have concluded that a significantly more accurate model for design of earth/geosynthetic composites is not in our near futures. It is a paradigm issue. While we know that inclusions impart an additional stabilizing influence on the soil mass (in addition to providing a horizontal tensile force opposing the earth pressure), inclusions also affect the state of stress within the soil mass, effectively providing an “improved” soil shear strength. At issue is that measured performance of these composites – *measured performance* – has been at full scale and more of a full scale triaxial model. Yet our modeling capabilities limit us to element contribution. As such, models can only be empirical, adjusted to observed behavior, and therefore not extendable to untested combinations of spacing, soil type and other variables.

Even minor tension in *closely spaced* confining elements imparts a significant confining stress on the soil mass, providing a significant departure from the assumed tieback contribution in MSE theory. Hence, the phrase “Geosynthetically Confined Soil” or GCS™ is used to differentiate these wall systems from other MSE wall types. Some quarters of the Federal Highway Administration refer to this more generically as Geosynthetically Reinforced Soil or GRS. We think the term “reinforcement” reinforces the “tieback” paradigm of MSE.

SNL is a design/build company. First costs for design and construction are practically the same for GRS/GCS™ and traditional MSE. SNL warrants their work, thus they would have to factor in the cost of current and incipient failures if they built prevailing MSE systems. Since SNL, Inc. GCS™ and generic FHWA GRS versions are markedly more reliable, they are by definition less expensive – and infinitely more desirable…. who would invest their engineering reputations or their company’s fate in systems known to fail when a factor of safety of 20 costs the same? Why is this point so difficult to make within AASHTO and FHWA?

SNL, Inc. and their engineers have used an empirical approach (observation of observed behavior) in design and construction of GCS™ for decades. Our team has been responsible for spending tens of millions of tax-payer dollars in MSE/GRS/GCS™ research and we have hundreds of millions of dollars worth of structures and related features built with or supported by our GCS™ constructions.

With this as a background, we would like to introduce……….

THE NO-MATH DESIGN AND CONSTRUCTION GUIDELINE FOR GEOSYNTHETICALLY CONFINED SOIL™ RETAINING WALLS, BRIDGE AND BOX ABUTMENTS, PIERS, geoBarriers™

One design for Multiple Applications

In an engineering era where design of civil works is described with mathematical equations based on theory, premise, proofs and empiricism, it is certainly novel to see a protocol for design and construction of any major feature to be done without equations. At issue is that performance of the ultra-simple composite of granular soil and layers of inclusions cannot yet be modeled beyond empiricisms based on specific measured performance. So a seemingly rigorous mathematical computation is moot. (see notes 1 and 2 at the end)

Serendipitously, speaking in strict engineering terms, one of the most tested and most used of this genre of composites of earth and steel or plastic inclusions has been our Geosynthetically Confined Soil (GCS™) or the generic FHWA version, Geosynthetically Reinforced Soil (GRS). This overly simple combination of Concrete Masonry Units (CMUs – cinder blocks), granular fill and sheets of geofabric has demonstrated consistently excellent performance in thousands of research and field constructions.

The design is as easy as 1,2,3. A row of blocks, a lift of compacted, granular backfill, and a sheet of geosynthetic fabric. We can go up and up to maybe 300 vertical feet and even a negative batter if requested.

It is the case of a dollar waiting on a penny. When and if our engineering theorists can devise a mathematical protocol that accurately describes behavior of this composite, it will only verify what we already know and practice. Meanwhile, the transportation infrastructure in the U. S. is losing the benefits of their investment in research - but not at SNL. Like it says in AASHTO, if you know better, you are obligated to do better.

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We have been in full implementation for years with this approach. You are invited to join as you wish.

Design Tenants – Simple as 1,2,3

1. We use an internationally available concrete block known as a Concrete Masonry Unit or CMU. They are also commonly called "cinder blocks". Remembering how Carl Sagan described the vast numbers of stars…."billions and billions"…. there are about that many cinder blocks in service around the world today. While larger blocks have been developed as "wall blocks", there is no need for these, and even worse, something is flawed in that shape, size, components, or construction. There is a failure rate with MSE wall blocks that is not observed with CMUs. (Have you ever seen a Cinder Block fail?)

   CMUs are described in ASTM…. We often ask that the manufacturer add more cement in blocks destined for tall walls. This increases compressive strength from about 2500 psi to 4000 psi. No good reason. Our associates in Mexico use 1500 psi blocks in walls 55 feet high. They exhibit a little cracking here and there, but no structural deficiency.

2. Geosynthetics are used for the inclusion. We use a common woven polypropylene that has a wide strip tensile strength (ASTM…) of about 180 pounds per inch. This is a lot. We use cotton bedsheets with 12 pounds per inch in full scale demonstrations. We have observed consistently high quality in our geosynthetics industry, and typically use price and availability to guide our selection.

3. Backfill is a granular soil. For simplicity, we ask for road base with a Plastic Index of 6 or less. About any soil with a friction angle of more than 30 degrees can be made to work. Pea gravel, 57 stone and more are equally suitable, and desirable in rapid drawdown situations. Soils less than the ideal manufactured types require more engineering consideration and in participation of the actual construction.

Geometry of walls and abutments is determined by external calculations. And you thought there were no calculations involved. Well, not for internal stability, but your GCS™ structure will have to have a safe and happy environment. We perform global stability analyses as we deem appropriate and we look carefully at the foundation underneath. There are no minimum widths or depths or embedments. The GCS™ structure will not fail internally – but look for everything else.

Construction

Compaction, compaction, compaction. Take care of this aspect and the rest will appear easy. Know and understand your backfill and exercise quality control.

1. First is the first course of CMU's. Place them on a reasonable foundation and on a bed of sand or similar bedding material. This first course should be carefully leveled – otherwise, the builders will fight alignment all the way to the top. Filling the block cells or cavities is optional. They behave a little better if filled, but as skills improve, filling the cells becomes optional.

2. Place a full lift of backfill behind the first course of blocks. One trick is to foot tamp a half lift immediately behind the block by standing one foot on the block and pressing down on the backfill. This really locks the block in place. Then complete the lift and compaction. Use rubber mallets to bring errant blocks back into alignment.

3. Brush or broom the tops of the blocks and place a sheet of fabric to the front edge of the blocks. We use either machine or warp directions. Whichever is convenient.

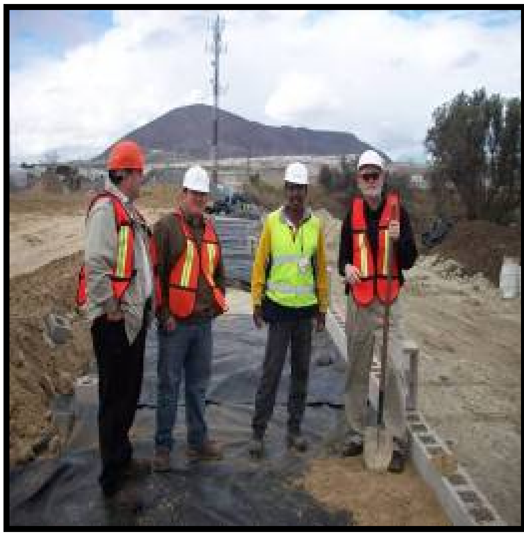
4. Place a row of blocks, being careful with alignment. Watch that these blocks want to gradually rotate forward with successive lifts.

Don’t delay dealing with this if it develops. Shim the front with sand or roofing shingles as needed.

5. The last element is completing the top lift. The top row of blocks can be plucked. Note that from the 3rd row down, removing a block is impossible. Long explanation – just take our word. So to keep the top blocks from being removed by vandals, here is one way to finish… don’t fill the cells in the top two rows. After the end of the top lift, we cut an X in the fabric in the sheet between the top two rows or burn them with a hand-held propane torch, and fill with wet or dry mix concrete. This creates a local “tieback” ……what an awful word in the GCS™ vocabulary….. but it keeps the CMUs in place.

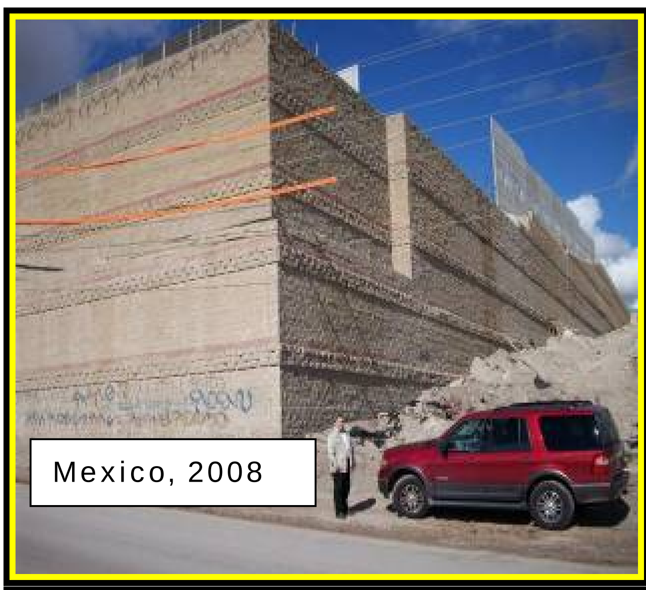
So, it is as simple as 1,2,3. CMUs, backfill, fabric.

Here are some photos from various projects to illustrate the steps.



These photos show a few examples of the 1,2,3 construction process.....
A row of concrete blocks, a lift of backfill and a sheet of geosynthetic.
Disappointingly Simple

Here are some examples of completed GCS™ Walls and Bridge Abutments



1. (Modeling can be created, but only around a specific set of field observations, thus it becomes moot. Moot in that we have the answer, we are only making up the question. However, if you insist, you can convolute MSE computations to match measured performance, say those measured in NCHRP Report 556. That would produce a numerical design protocol.)

2. (One last point – those of you who use MSE design formulae may not yet understand that the only safety factor that will not exist in your constructed wall will be the one you have obtained from those calculations. When there is a failure rate that is not indicated by your computations, then there is reason to suspect the computations. Allen of WashDot showed that failure on the contractor's part to tension the connection could lead to failure of your wall. These kinds of errors are certain to happen, which means that those designing MSE are subject to failures in their end products. What if your bridges failed at a 2-5% rate?)

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Part 2

Obtain a copy of NCHRP Report 556. This is a summary of decades of research in GRS/GCS™. Of particular importance are the bearing capacity tests. This 1, 2, 3 composite exhibits bedrock levels of bearing capacity, which is an indication of safety factor against internal failure.

Here is the link to buy this milestone document:

http://www.trb.org/news/blurb_detail.asp?ID=6151

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Part 3

Any new design and construction protocol needs supporting case histories and examples. Here are links to information relating to GCS™ design and construction and some case histories. This last part of this manual will be updated with new information, so check this page periodically.

Number 1 is Defiance County, Ohio. Warren Schlatter, P. E. and that group are the top implementers of NCHRP 556 to date: http://www.defiance-county.com/engineer/GRS.htm

Calvin Van Buskirk of British Columbia is a brilliant innovator in a variety of GCS™- type structures using close spaced woven polypropylenes:

http://www.for.gov.bc.ca/hfd/library/FIA/2006/LBIP_4509005a.pdf

http://www.forrex.org/publications/link/ISS45/vol9_no1_art18.pdf

http://findarticles.com/p/articles/mi_qa3764/is_200705/ai_n19432543

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